Application Areas of Digital Image Processing

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- Machine Vision
- Medical Imaging
- Remote Sensing
- Biometrics
- Document Image Processing
- Defence/Military Applications
- Photography
- Entertainment

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- Medicine
- Tomography
- Demography (study of human population)
- Crop Investigation
- Astrology
- Television / Relay Transmissions
- Photography
- Printing
- Robotics
- Remote Sensing
- Video Conferencing
- Telemetric
- GPS Navigation
- Retail Industry (security)
- Biometrics
- Industrial

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Machine Vision

- Application of computer vision to industry and manufacturing.
- It contains computer science, optics, mechanical engineering and industrial automation.
- Applications are like inspection of manufactured goods such as chips, automobiles, food, pharmaceuticals etc.
- It uses digital camera, smart cameras, image processing s/w to perform inspections.
- They perform tasks such as counting objects, reading serial number, searching for defects.

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Examine individual pixels of images, process them and develop conclusion with the help of knowledge base and pattern recognition engines.

Components of Machine Vision System:-

- Digital Camera
- Lighting Source
- Digitizers
- Processor
- Computer S/w to process image
- Sensors for Image Acquisition
- I/O hardware or communication links.
- Actuators to sort or reject defective parts.

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Application of Machine Vision

- Large scale industrial manufacturing
- Safety systems in industrial environment.
- Inspection of pre manufactured objects.
- Visual stock control and management systems (counting and bar-coding).
- Control of AGV (Automated Guided Vehicles).
- Automated monitoring of sites for security and safety.
- Monitoring of agricultural production.
- Quality control, retail automation and consumer equipment control.

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Medical Imaging

- Create images of human body is known as medical imaging.
- 2 Types:-
- **Clinical** :- reveal, diagnose or examine disease (CAT, MRI , endoscope, sonography)
- **Medical Science** :- study of anatomy and function of human body (forensic , microscopy searches (bioinformatics))
- Medical imaging incorporates radiology, radiological sciences, endoscopy, medical photography, microscopy, fluoroscopy, nuclear medicine, PET, ultrasound, projection radiography etc.

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Remote Sensing

- It is a science of collecting information about objects, area or a phenomena from a distance without being in physical contact with them.
- Classified into two categories:-

Active Remote Sensing:- system uses its own source of electromagnetic energy.

e.g..- Radio waves and Microwaves

Passive Remote Sensing:- Uses Sun as a source of electromagnetic energy.

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- According to the properties of object, the electromagnetic radiation is reflected, scattered or transmitted through the object.
- The reflected energy is measured back from the sensors, which are employed either in an aircraft or a satellite.
- Remote Sensing is divided into 2 categories depending on the platform:-

Airborne:- Aircrafts carry remote sensing equipment.

e.g.. DAKOTA, AVRO, BEACH CRAFT, SUPERKING AIR 200

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Space borne:- Satellite is the platform which carries sensors and other remote sensing equipments.

- They are put into earth's orbit with the help of launch vehicles. They are divided into 2 categories:-

- **Polar orbiting satellites**:- works at low altitude. Revolves around the earth in sun synchronous orbit.
- **Geostationary satellites**:- operate at high altitude. Stationary with reference to earth. Velocity = velocity of earth . At 36,000kms from earth.

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Applications of Remote Sensing

- Agriculture
- Forestry
- Land use and soils
- Geology
- Urban Land Use
- Water Resources
- Coastal Environment
- Disaster Management
- Rainfall estimation
- Mineral Explorations
- Ground water studies

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Biometrics

- Way of identifying human beings based on certain physiological and behavioral characteristics such as fingerprint, face, DNA, iris, voice, signature analysis and signature verification.

- This area is useful for law enforcement agencies to analyze and recognize fingerprint , face, DNA and iris.

- Automatic analysis in biometrics reduces time and helps us to accomplish task in quicker and efficient manner.

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Document Image Processing

- It aims to create a paperless office by capturing the documents in the form of an image.

- Image archival and retrieval systems effectively archive and help in retrieving the documents.

- Applications such as content based retrieval system, image search engines, script recognition systems etc.

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Defence/Military Applications

- Helps to acquire useful image at night and under atmospheric conditions such as fog and smoke.

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Photography

- For creating special effects such as blending, animation etc.

- Publishers can enhance and layout digital images for publication.

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Entertainment

- Applications such as video conferencing, video phones, video editing, animation, image morphing etc are quite useful for personal as well as commercial purposes.

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File Formats

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- Digital imaging system can store and transmit images. Data is of 2 types:-
- Human Interpretable such as text and numbers
- Diffused which only machine can interpret
- If image files are opened in normal editor, the information cannot be interpreted meaningfully.
- To get meaningful information, knowledge of the file format is required.
- **<u>File format</u> defines exactly how the image data is stored along with the image metadata in a file.**
- **Metadata refers to essential non-image information such as nature of image, dimensions and persons who created the image**

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- Need for File Format

It may be necessary to transmit an image across the network to a remote imaging system, where the image may be accessed in a different environment of operating system, processors and programming environments.

The difference in operating systems may cause interpretation mistakes.

To avoid such mistakes file formats are necessary.

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- 2 types of file formats
- ➢ Bitmapped /Raster (2D array of pixel intensities)
- ➢ Vector (Image is stored as collection of vectors i.e. list of points, lines etc.)
- **<u>Bitmapped / Raster File Formats</u>**:-
- **GIF :-** (Graphics Interchange Format)

  Lossless compression, high quality, 8-bit color support (256 colors), smaller in size, supports animation, synthetic images.
- **JPEG :-** (Joint Photographic Experts Group)

  provides both lossy and lossless compression common format for storing and transmitting photographic images on the web

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- **PNG :-** (Portable Network Graphics) lossless compression, not restricted to 256 colors, designed for transferring images on the internet

DICOM :- (Digital Imaging and Communication) very popular file format in medical imaging, contains metadata such as patient details, equipment and acquisition details.

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- **<u>Vector File Formats</u>** :-

SVG :- (Scalable Vector Graphics) scalable to the size of the viewing window and adjust resolution according to the window. Include smaller file size, resolution independence etc.

SWF :- For vector animation using Flash. It is possible to incorporate bitmaps into these files.

QuickTime :- Digital Video format

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CHAPTER 1

INTRODUCTION TO IMAGE PROCESSING

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What is Digital Image Processing?

- Image can be defined as a two dimensional function **f(x,y)** where **x** and **y** are spatial (plane) co-ordinates and the amplitude (gray levels) of **f** at any pair of co-ordinates (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 image a **digital image**.
- Field of digital image processing refers to processing digital images by means of a digital computer.

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- Digital image is composed of a finite number of elements, each has a particular location values, which are called **pixels**.

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- There are three types of computerized processes on images:-

1. **Low level processes**:- primitive operations like image pre-processing, reduce noise, contrast enhancement and image sharpening.

   "Both input and output are images "

   eg. Photoshop

2. **Mid level processing** :- segmentation (i.e. partitioning an image into regions or objects) , classification of individual objects

   (recognition).

   Input are generally images but output are attributes extracted from those images.

   eg. Edges, contours

3. **High level processing** :- making sense of recognized objects

   image analysis (AI).

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- Humans can only see in the visual band of electromagnetic spectrum.
- But imaging machines cover almost entire EM spectrum, ranging from gamma rays to radiowaves.
- They can operate on images generated by sources which include ultrasound, electron microscopy and computer generated images.
- To understand the extent of image processing application, we categorize images according to their source.
- Principal energy source is **electromagnetic energy spectrum**.
- Other sources are acoustics, ultrasonic, and electronic.
- Synthetic images can be generated by computer.

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Electromagnetic Spectrum

- It can be conceptualized as propagating sinusodial waves of varying wavelengths.

OR

Can be thought of as stream of massless particles each travelling in a wavelike patterns and moving at speed of light.

Each massless particle contains certain amount of energy called as Photon.

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ELECTROMAGNETIC SPECTRUM

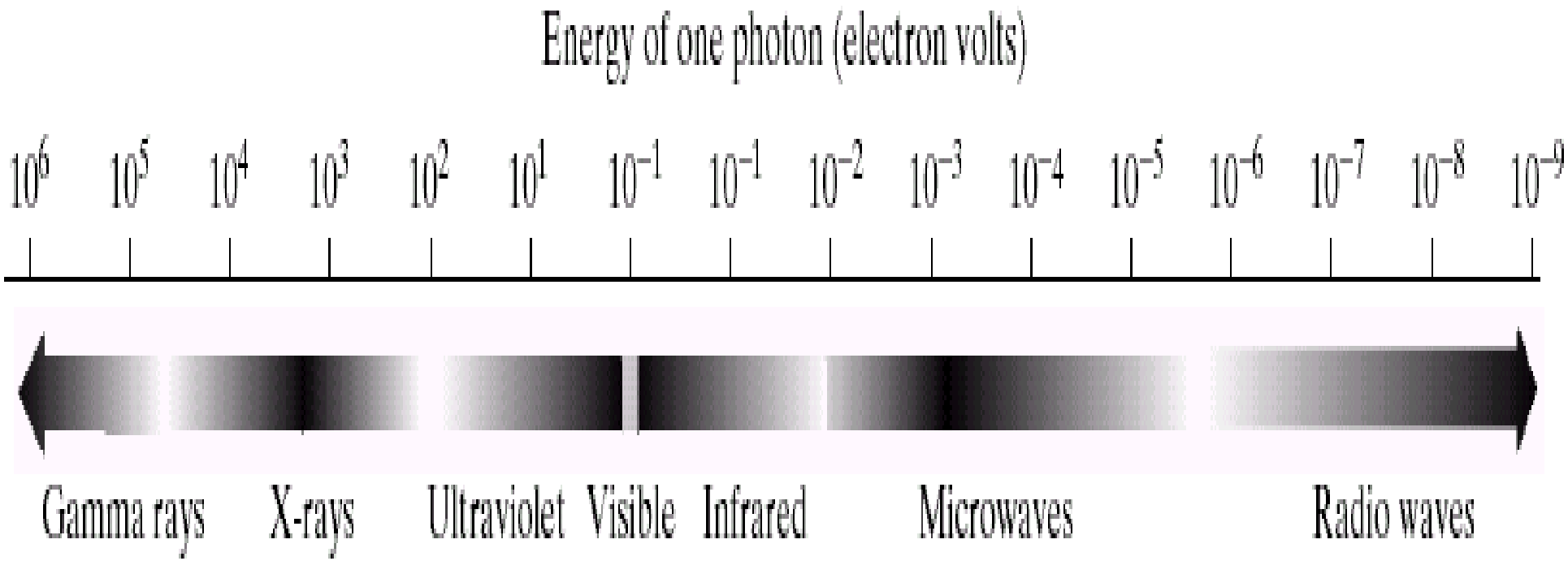

FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

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Examples of Fields that use Digital Image Processing

1. <u>GAMMA-RAY Imaging</u>

- Nuclear Medicine

  eg. Bone scan, PET
- Astronomical Observation

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a b
c d

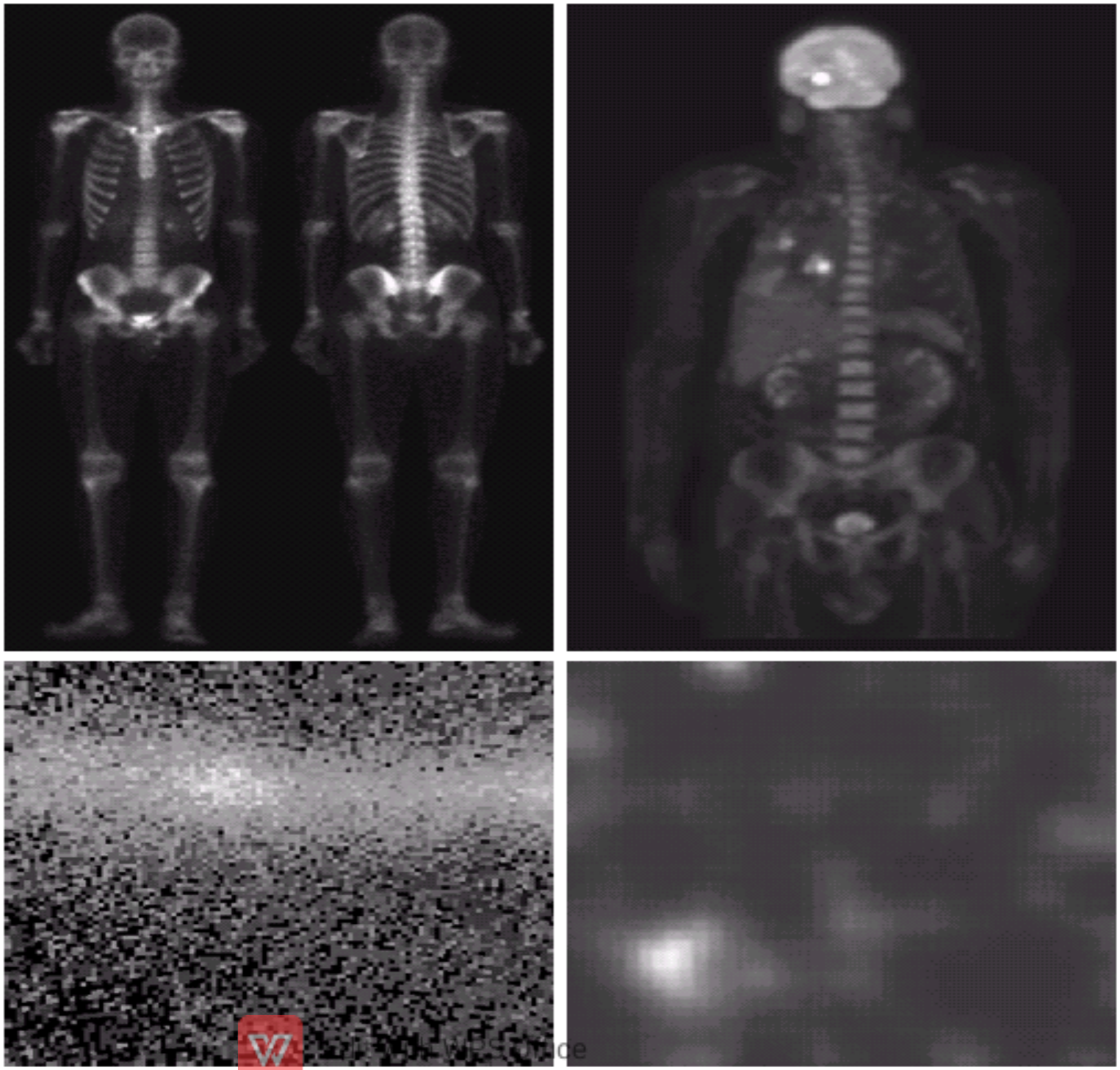

FIGURE 1.6 Examples of gamma-ray imaging. (a) Bone scan. (b) PET image. (c) Cygnus Loop. (d) Gamma radiation (bright spot) from a reactor valve. (Images courtesy of (a) G.E. Medical Systems, (b) Dr. Michael E. Casey, CTI PET Systems, (c) NASA, (d) Professors Zhong He and David K. Wehe, University of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

2. X-RAY Imaging

- Medical Diagnostics
  eg. Chest X-Ray, Angiography, CAT
- Astronomy
- Industry
  eg. Problems in Electronic circuit board

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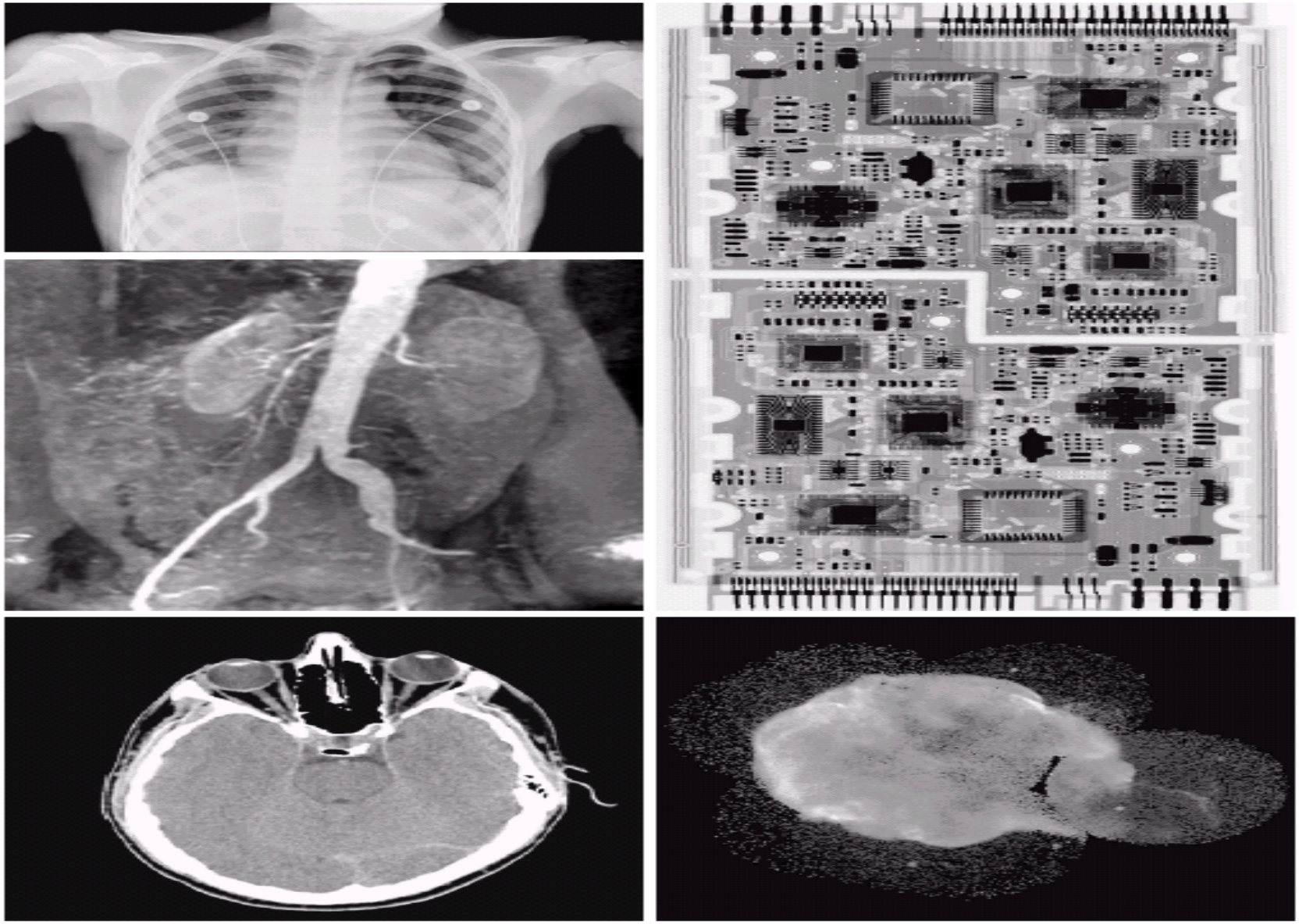

a b c d e

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

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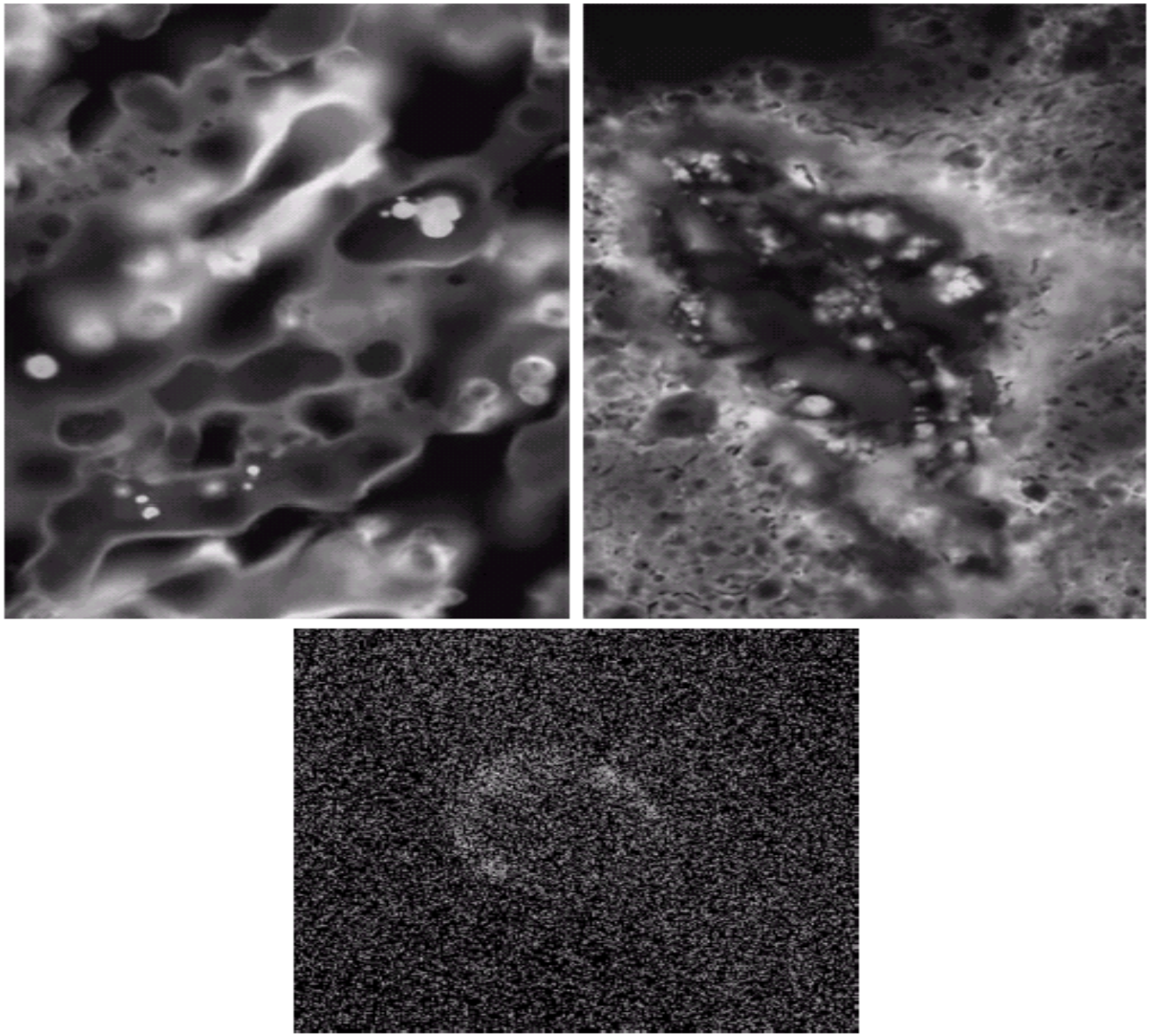
3. Imaging in UV Band

- Lithography
- Industrial Inspection
- Microscopy
- Lasers
- Biological Imaging
- Astronomical Observations

Edit with WPS Office

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.)



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4. Visible Band

Normal human day to day activities and Imaging

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5. Infrared Bands

- Light microscopy
  eg. Pharma
- Astronomy
- Remote Sensing
- Industry

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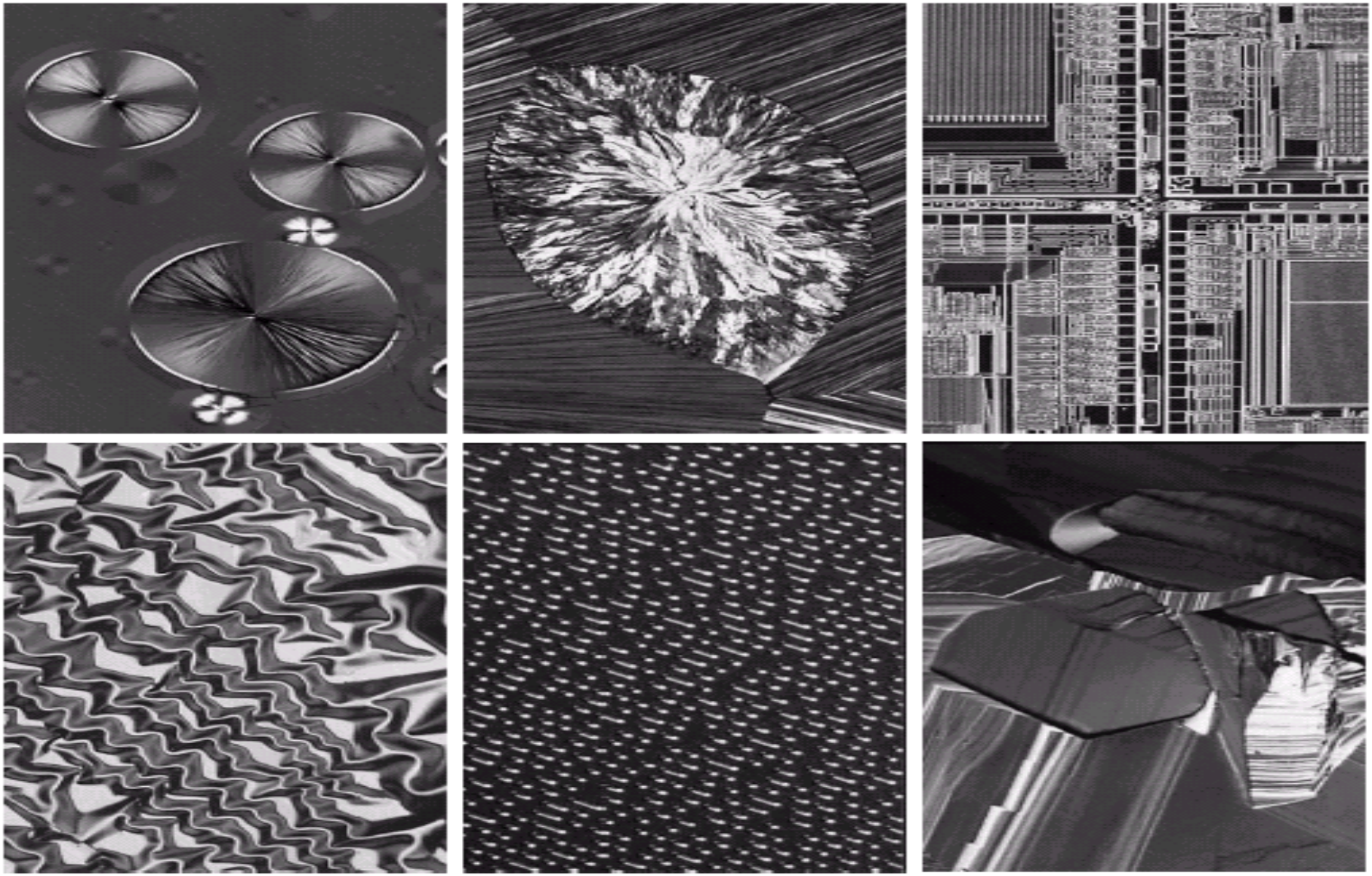

a b c
d e f

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.)

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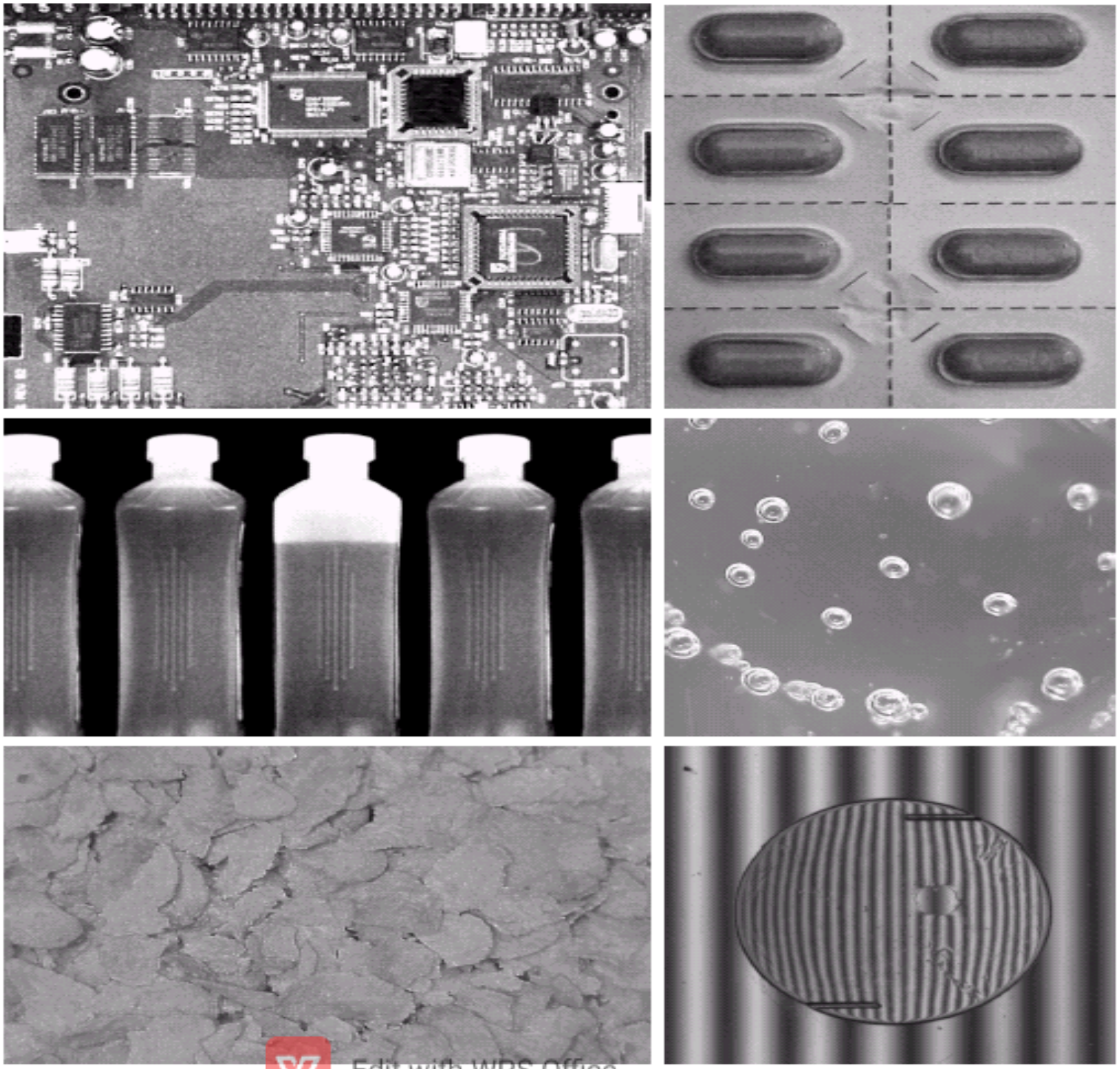

a b
c d
e f

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.)

Edit with WPS Office

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.)

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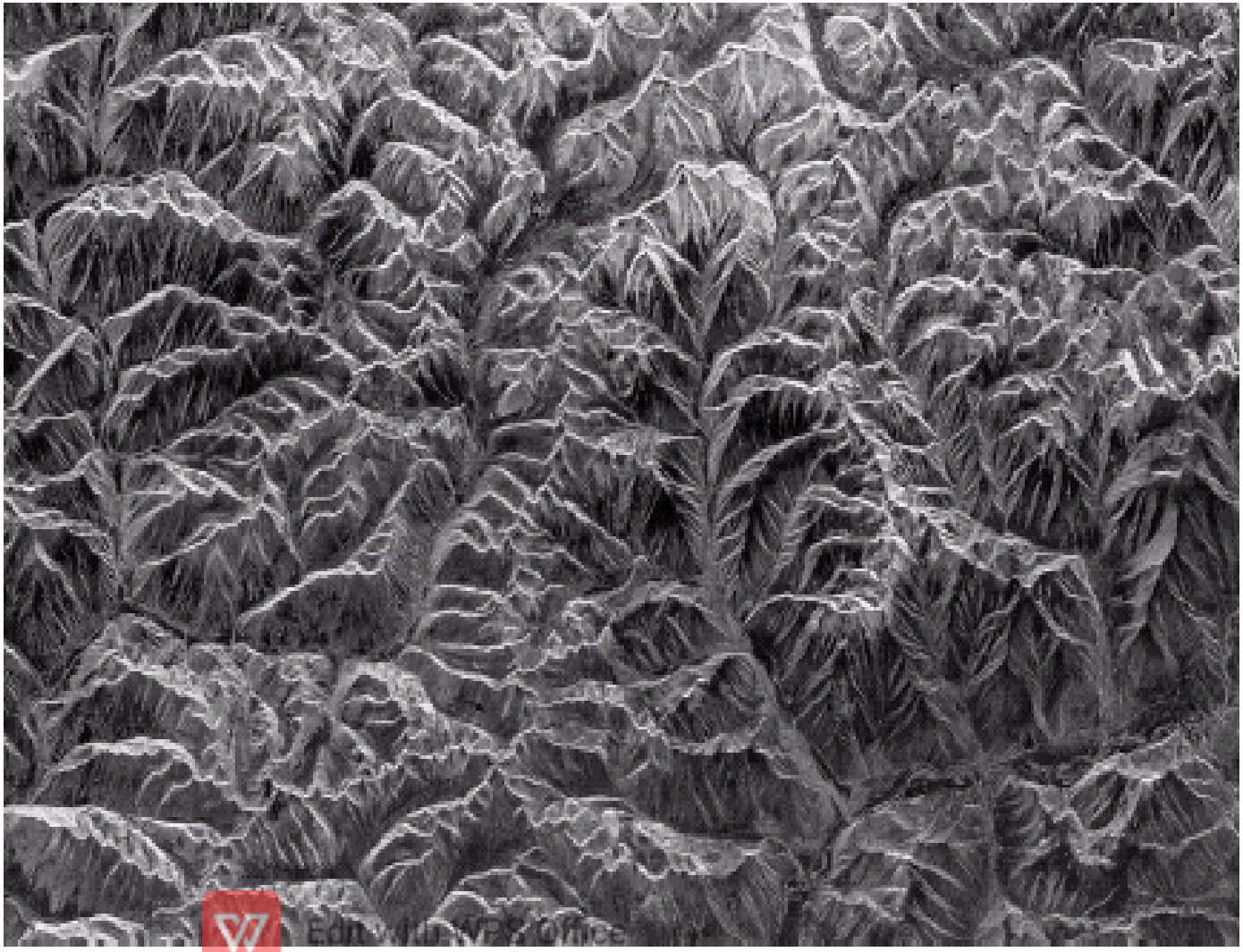
6. Imaging in Microwave Band

- RADAR
- Microwave Oven

FIGURE 1.16
Spaceborne radar image of mountains in southeast Tibet. (Courtesy of NASA.)



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RADAR

- Has the ability to collect data over any region at any time regardless of weather or ambient lighting conditions.
- They can penetrate clouds and under certain conditions can also see through vegetation, ice and extremely dry sand.
- Sometimes, it is the only way to explore inaccessible regions of the Earth's surface.
- It works like a flash camera having its own illumination to illuminate an area on the ground and take a snapshot image.
- Instead of camera lens it uses an antenna and a digital computer to record its images.
- One can only see the microwave energy that was reflected back towards the radar antenna.

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6. Imaging in RadioBand

- Medicine

  eg. MRI(Magnetic Resonance Imaging)
- Astronomy

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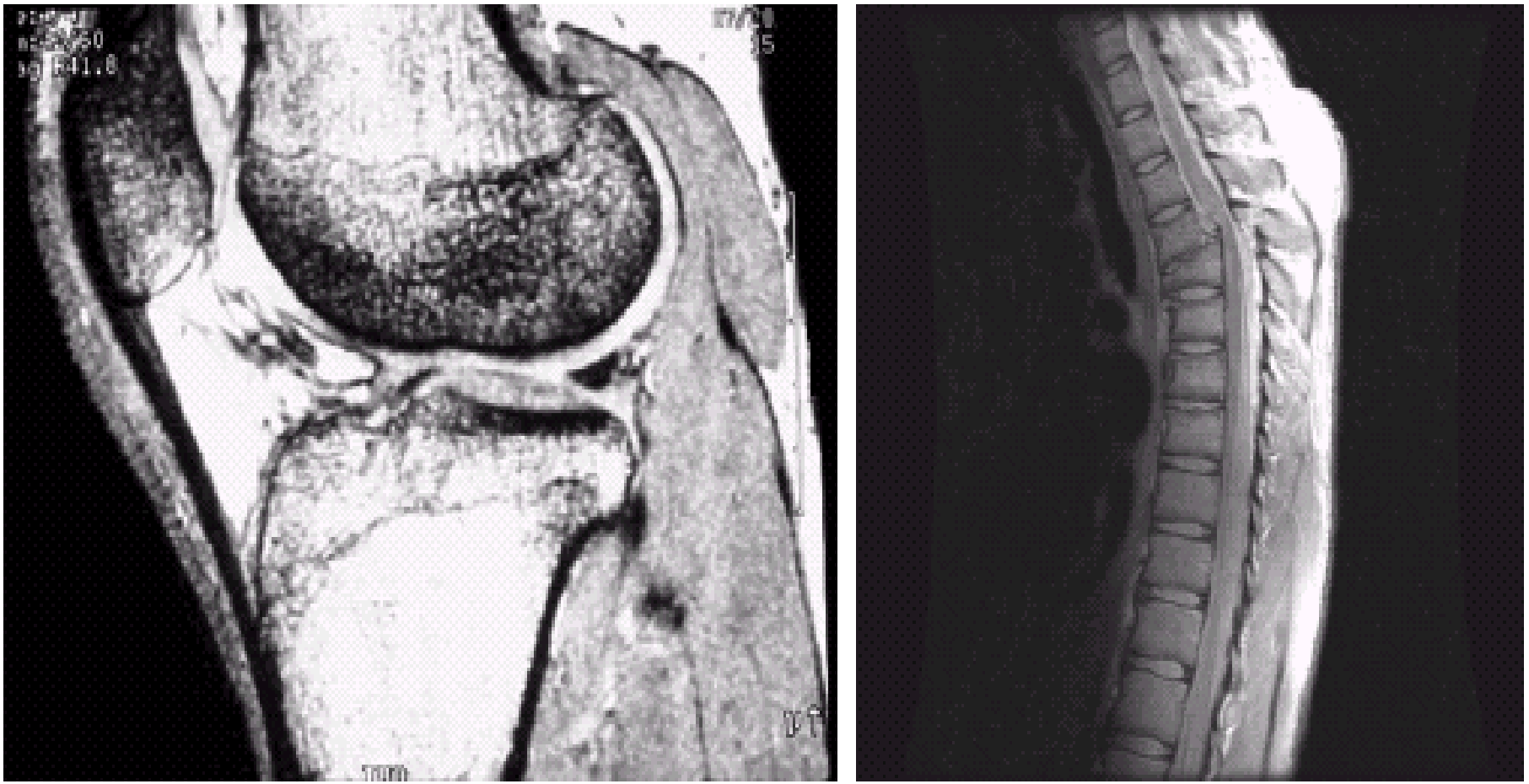

a b

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.)

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Other uses of Radio Band

- OTG
- Television
- AM and FM
- Bluetooth

OTG uses radiowaves so penetrating power less
Microwave oven uses microwaves so penetrating power more.

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Other Imaging Modalities

Acoustic Imaging

"Using sound"

Examples include

- Geological Exploration

  eg. Mineral oil exploration

- Industry
- Medicine

  eg. Sonography

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FUNDAMENTAL STEPS IN DIGITAL IMAGE PROCESSING

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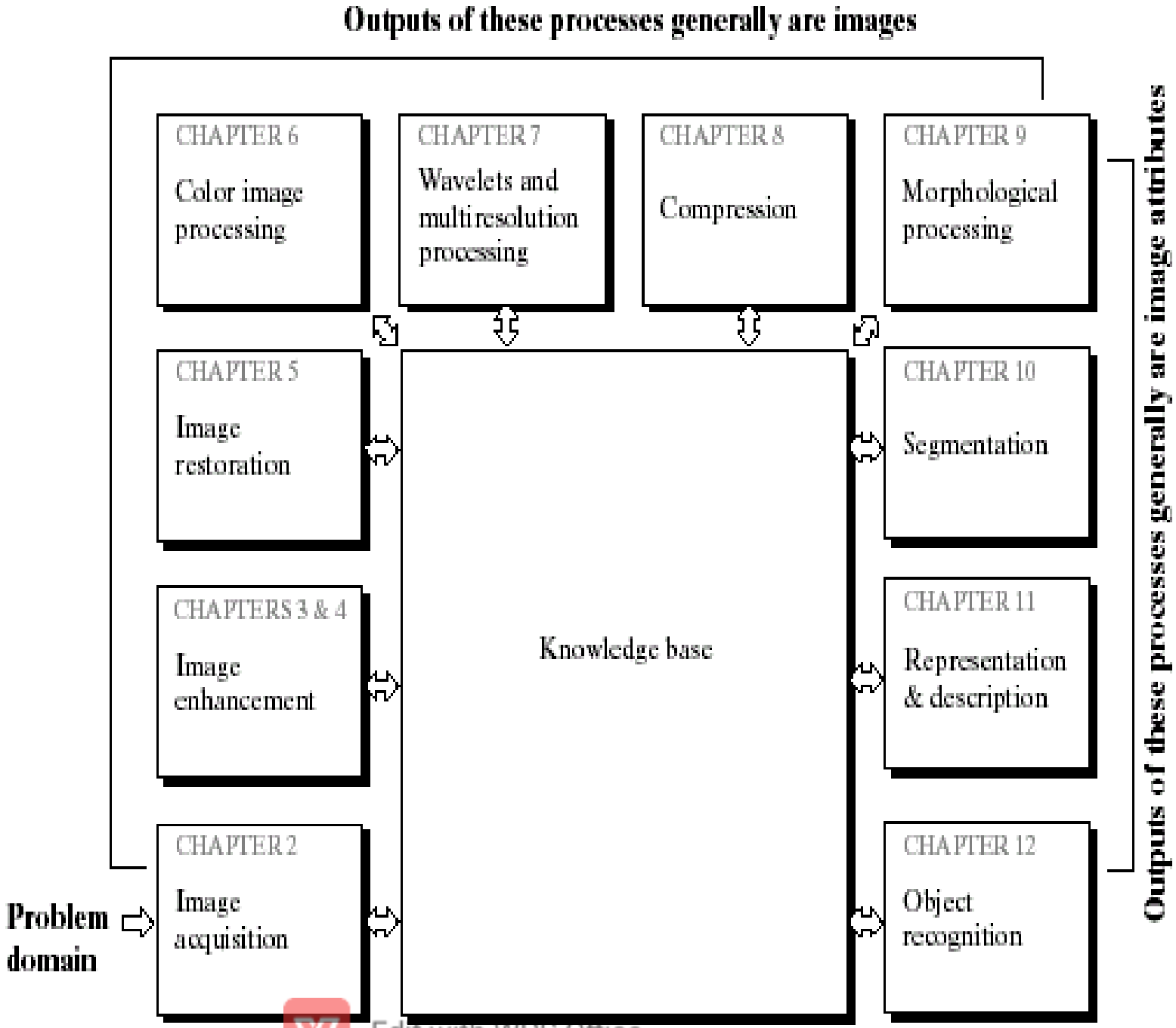
FIGURE 1.23 Fundamental steps in digital image processing.



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COMPONENTS OF GENERAL PURPOSE IMAGE PROCESSING SYSTEM

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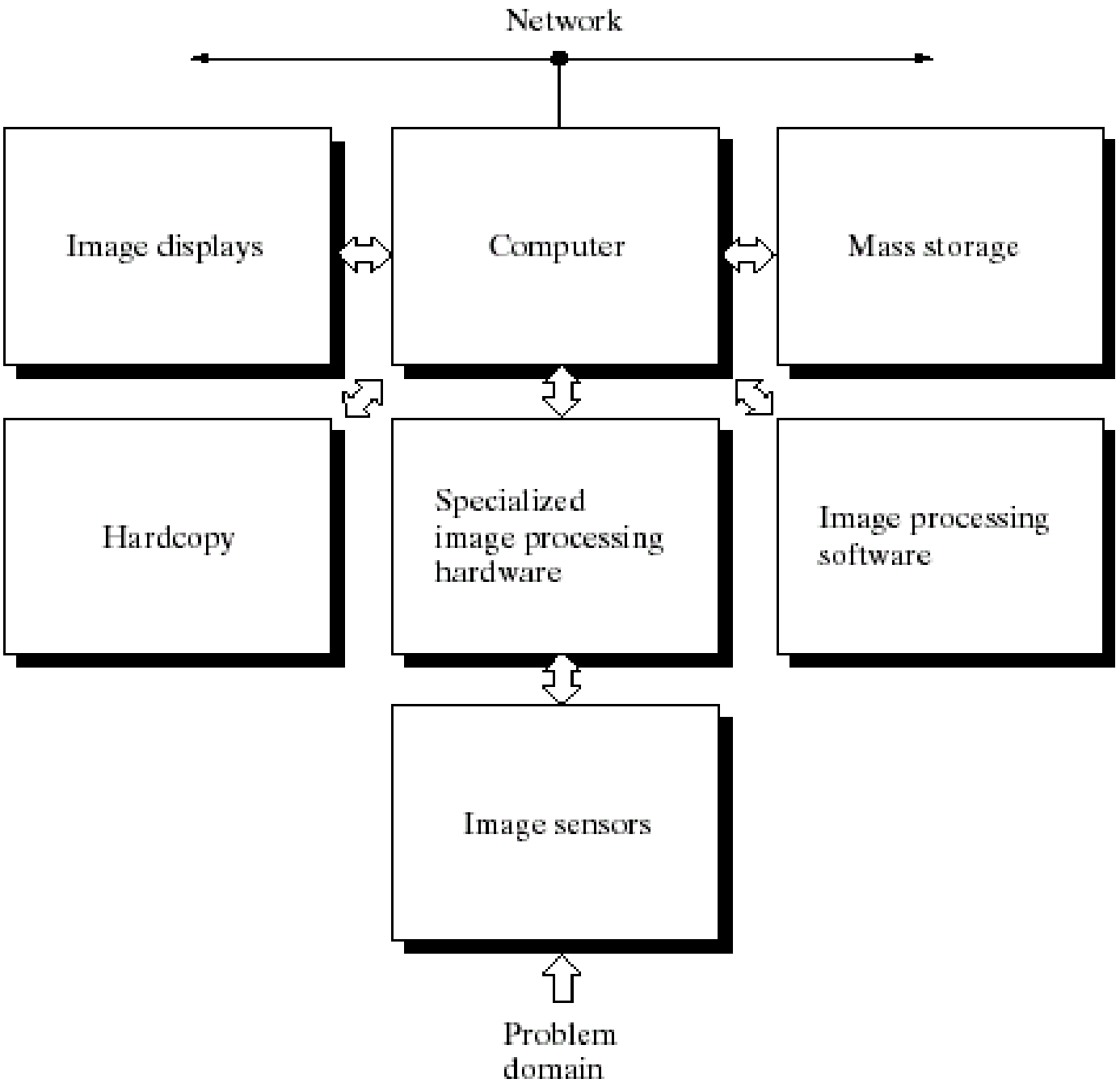

FIGURE 1.24 Components of a general-purpose image processing system.

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CHAPTER 2

DIGITAL IMAGE FUNDAMENTALS

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Structure of Human Eye

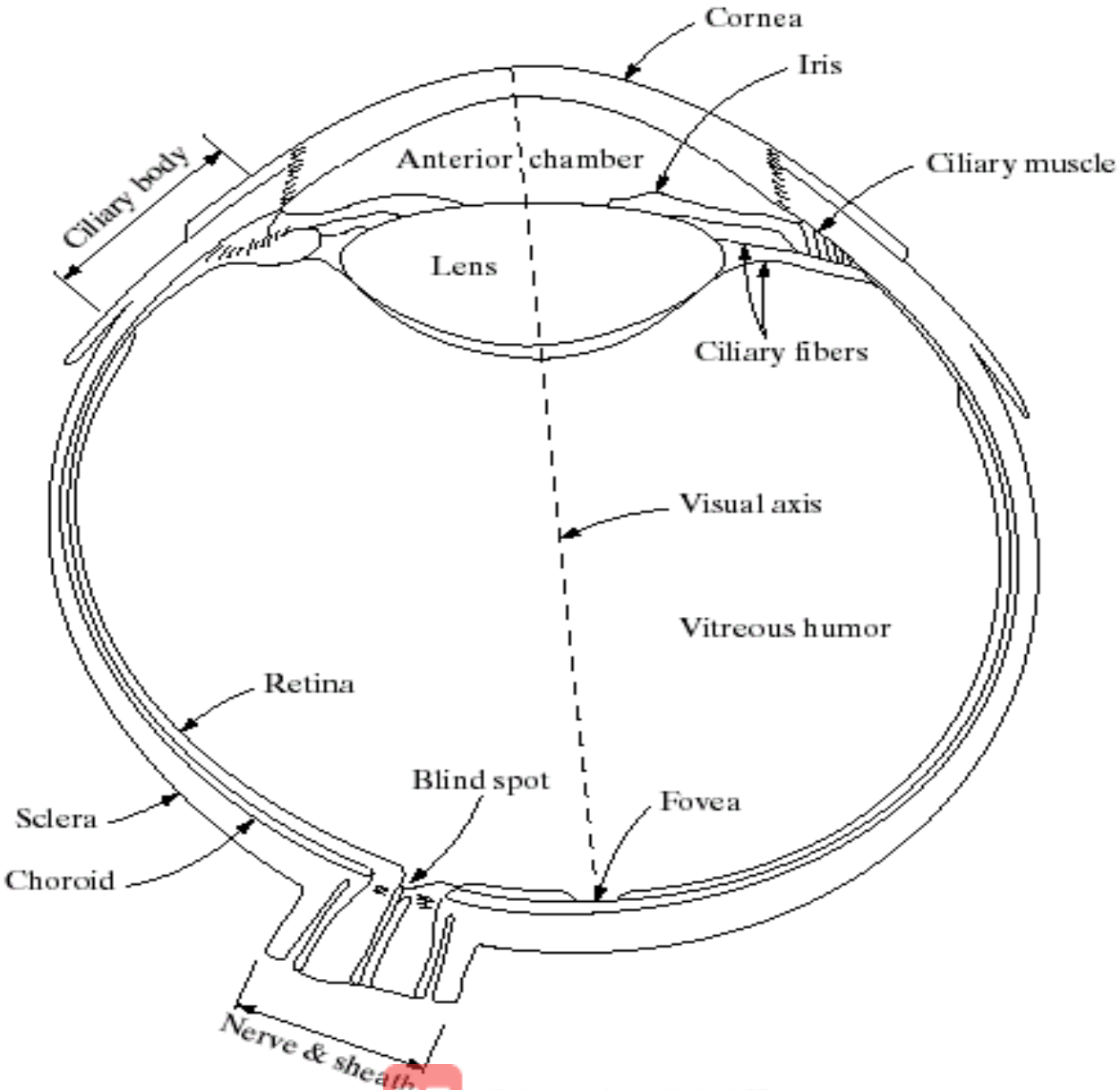

FIGURE 2.1 Simplified diagram of a cross section of the human eye.

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- **Lens**- 60-70% water, 6% fats and more proteins than any other tissues.
- Slightly yellowish which increases with age which leads to cataracts.
- Lens absorbs 8% of visible light spectrum.
- Infrared and UV are absorbed by the proteins and in excessive quantity can damage the eye.
- Innermost membrane is **retina**.
- Pattern vision is obtained by the distribution of discrete light receptors over the surface of the retina.
- Two classes of receptors:-
- **Cones**:- 6 to 7 million
- Located in central portion and are highly sensitive to color.
- Fine details can be resolved.
- Cone vision is called as **photopic** or **bright light vision**.

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- **Rods:-** 75 to 150 million distributed over the retinal surface.
- The larger area of distribution and the fact that several rods are connected to a single nerve end reduce the amount of detail seen by these receptors.

- General overall picture.
- Not involved in color vision and are sensitive to low levels of illumination
- Eg. Objects that appear brighter in daylight, when seen by moonlight appear as colorless because the rods are stimulated. This phenomenon is known as **scotopic** or **dim light vision**.

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- Major difference between **lens of eye** and **ordinary optical lens** is that former is flexible.
- To focus on distant objects, the controlling muscles cause the lens to be relatively flattened. Similarly, these muscles allow the lens to become thicker in order to focus on objects near the eye.
- The distance between centre of the lens and the retina (focal length) varies from approx. 17mm to 14mm.
- When the eye focuses on an object farther away than 3m, the lens exhibits its lowest refractive power.

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Light and Electromagnetic Spectrum

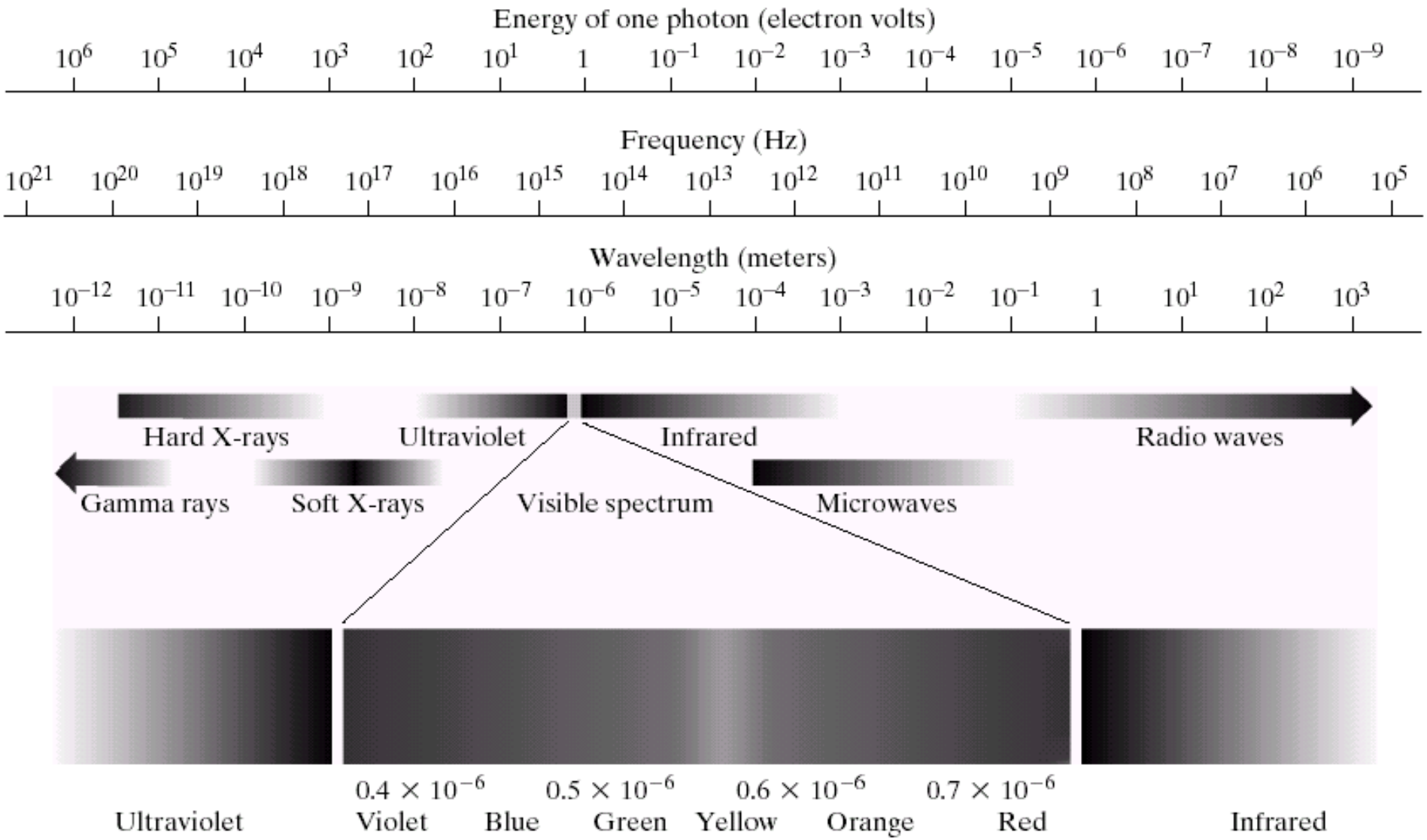

FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

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- Range of colors we perceive in visible light represents a very small portion of EM spectrum.
- EM spectrum can be expressed in terms of wavelengths, frequency or energy.

Wavelength (λ)

Frequency (v)

Therefore, **$\lambda = c/v$**

Where, c is the speed of light (2.998×10^{8} m/s)

Energy of various components of EM spectrum is given by the expression

$E = h\,v$, where h is Planck's constant

- Unit of wavelength are metres with microns (μm i.e 10^{-6}m) and nanometres (10^{-9}m) being used frequently.

- Frequency is measured in Hertz (Hz).
- Commonly used unit of energy is electronVolt.

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- Energy is proportional to frequency.

- Higher frequency (shorter wavelength) electromagnetic phenomena carry more energy per photon.

Radiowaves have photons with low energy, microwaves have more energy than radiowaves then infrared, visible, UV, X-rays and gamma rays, most energetic of all. So, gamma rays are dangerous to living organism.

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- Light is a particular type of EM radiation that can be seen and sensed by human eye.

- Visible band of EM spectrum ranges from 0.43μm (violet) to 0.79μm (red).

- EM is divided into six broad regions: violet, blue, green, yellow, orange, red. No color ends abruptly but blends smoothly into next.

- The colors that humans perceive is determined by nature of light reflected from the object.

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- A body that reflects light which is balanced in all visible wavelengths appears white to the observer. Otherwise, the body that reflects in limited range exhibits some shades of color.

- Eg. Green objects reflect light with wavelengths in the range 500nm to 570nm.

- Light that is void of colors is called **achromatic** or **monochromatic** light.

- Only **attribute** of such light is **intensity or amount**.

- Gray level is used to describe monochromatic intensity because it ranges from black to gray and finally to white.

- **Chromatic** light spans the EM spectrum from approx. 0.43μm to 0.79μm.

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- Three basic quantities are used to describe the quality of chromatic light source.

1. **Radiance**:- Total amount of energy that flows from light source and is usually measured in Watts.

2. **Luminance**:- Gives a measure of amount of energy an observer perceives from a light source.

   measured in lumens (lm).

Eg. Light emitted from a source from far infrared region could have significant energy (radiance) but an observer would hardly perceive it , its luminance would be zero.

3. **Brightness**:- It is a subjective descriptor of light perception that is impossible to measure.

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- At the short wavelength end of EM spectrum, we have gamma rays and hard X-rays (industrial appl).
- Chest X-rays are in the high end of soft X-rays and dental X-rays are in lower energy of that band.
- Soft X-rays blends into UV region which in turn blends into visible spectrum.
- Then comes Infrared band which radiates heat.
- Part of IR band close to visible spectrum is called near-infrared region.
- Opposite end is called far infrared region.
- It blends with microwave band. It is the source of energy for microwave ovens.
- Finally, radiowave band encompases television as well as AM and FM radio.

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Image Sensing and Acquisition

- The types of images in which we are interested are generated by combination of an illumination source and the reflection or absorption of energy from that source by the elements of the scene being imaged.

- Illumination may originate from a source of EM energy such as RADAR, infrared, X-ray, ultrasound or computer generated illumination pattern.

- Scene elements could be molecules, buried rocks or human brain or sun.
- In case of rocks light is reflected from surface while X-rays pass through human body.

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General working of Sensors

- They are used to transform illumination energy into digital images.
- Incoming energy is transformed into voltage by combination of input electrical power and sensor material that is responsive to a particular type of energy being detected.
- The output voltage waveform is the response of the sensors and a digital quantity is obtained from each sensor by digitizing its response.

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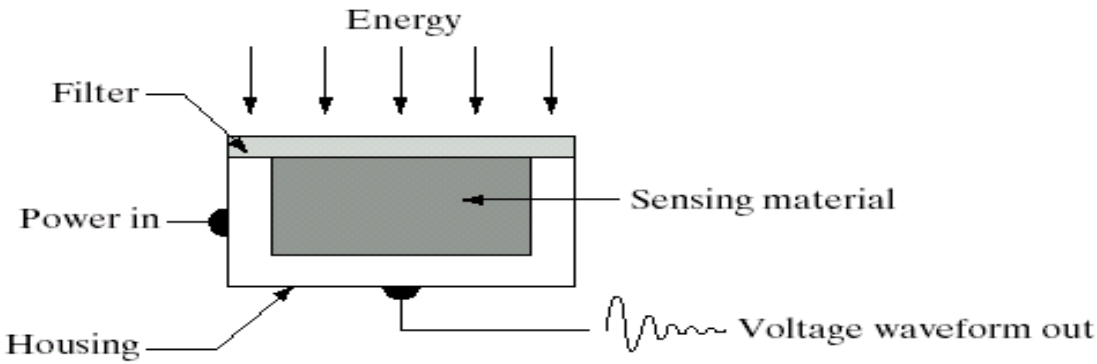
Sensors

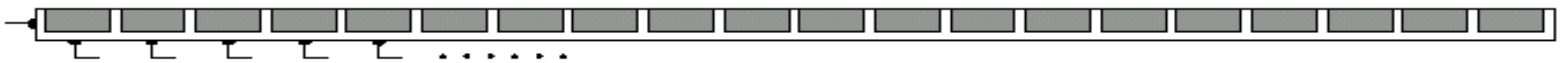
a
b
c

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

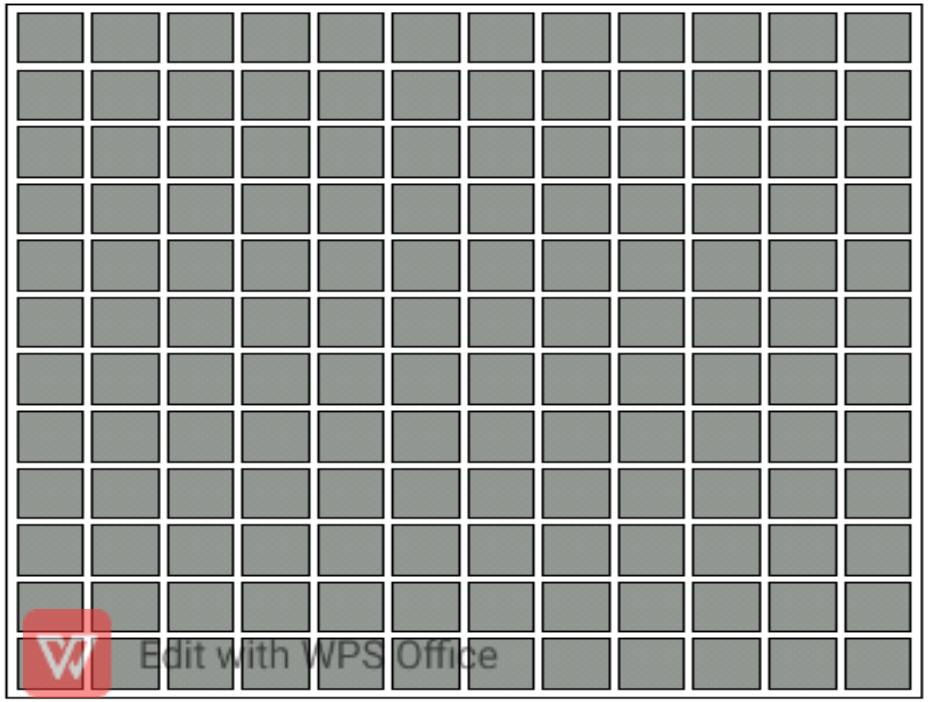


Single Sensor

Sensor strip



Sensor Array



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Working of Single Sensor

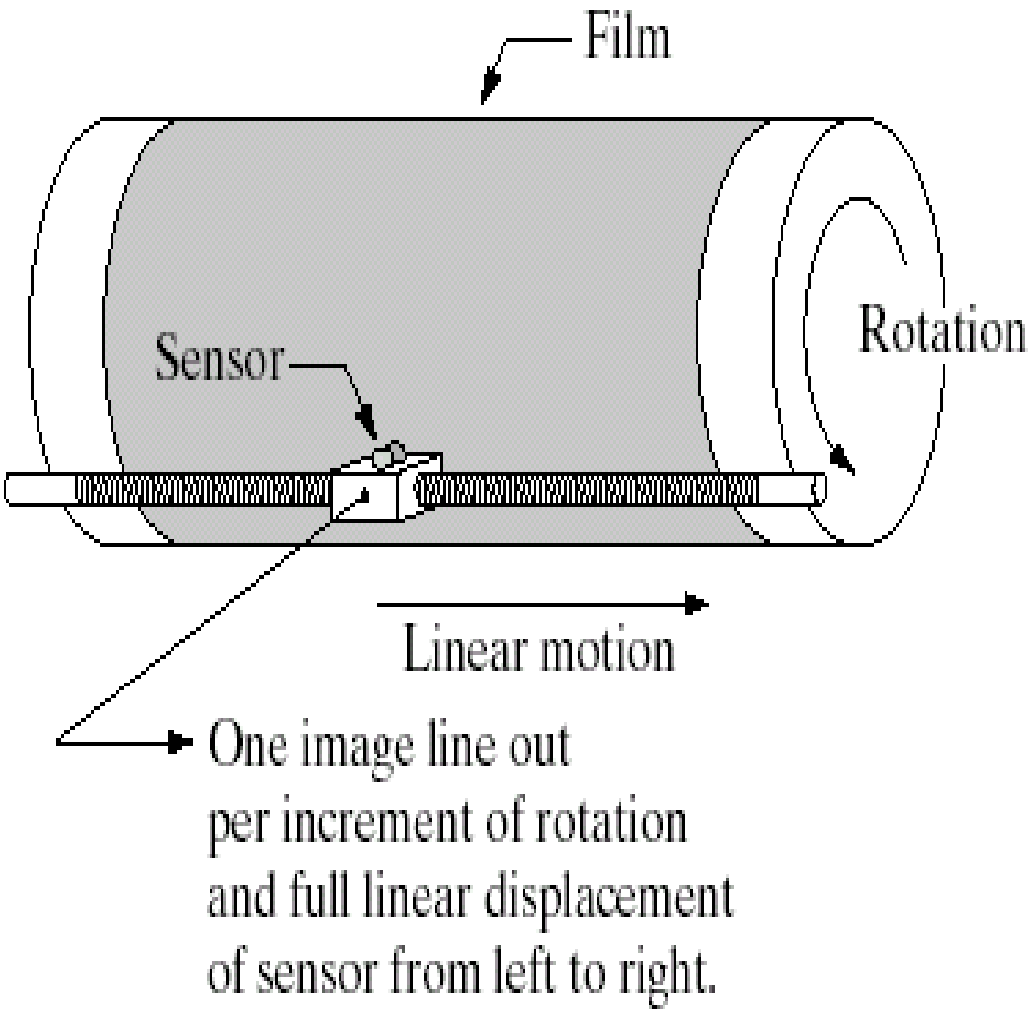

FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

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Image Acquisition using single sensor

- Most familiar sensor of this type is photodiode which is constructed of silicon materials and output voltage is proportional to light.

- The use of filter in front of sensor improves selectivity.
- E.g. Green pass filter in front of light sensor favours light in green band.

- In order to generate a 2D image using single sensor, there has to be relative displacements in both X and Y directions between the sensor and area to be imaged.

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- Film is mounted on drum whose mechanical rotation provides displacement in one direction and the sensor is mounted on screw which provides motion in perpendicular direction

- This method is inexpensive but slow to obtain high resolution images.
- This type of sensors are known as **microdensitometer**.

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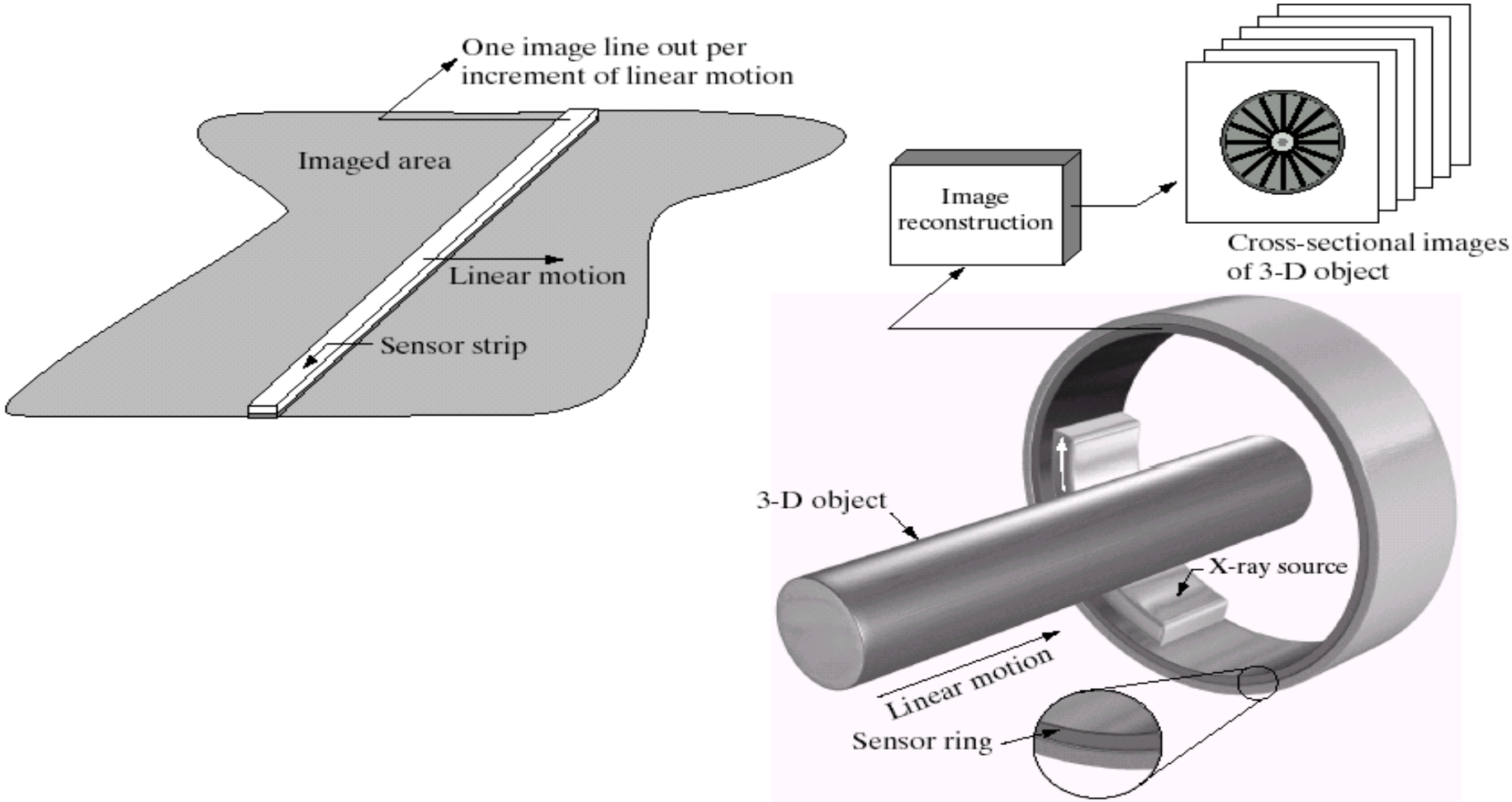
Working of Sensor Strip



a b

FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

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Image Acquisition using Sensor Strip

- Consists of inline arrangement of sensors.
- Strip provides sensors in one direction, motion perpendicular to the strip provides imaging in other direction.
- Sensing devices with 4000 or more inline sensors are possible. This principle is used in flatbed scanners.
- Inline sensors are used in airborne applications where imaging system is mounted on a plane and to provide second direction the plane flies at a constant height.
- Sensor strips arranged in a ring configuration are used in medical and industrial application to obtain slice images of 3D objects.

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Image acquisition using Sensor Arrays

- In this arrangement the sensors are arranged in 2D way.
- This is also found in digital cameras. A typical sensor for this camera is CCD (Charged Couple Devices).
- They are generally arranged as 4000 x 4000 elements or more. The response of each sensor is proportional to the light which falls on the surface of sensor.
- The advantage of sensor array is complete image can be obtained by focusing the energy on surface of sensor and no motion is required.

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Digital Image Acquisition

- The energy from the illumination source falls on the object.
- It is reflected from the scene element or can also be transmitted through.
- The reflected energy is focussed on to an image plane.
- If the illumination source is light, the focusing system is lens. The sensor arrays produces the output proportional to light falling on each sensor.
- The output are digitized and converted into digital image.

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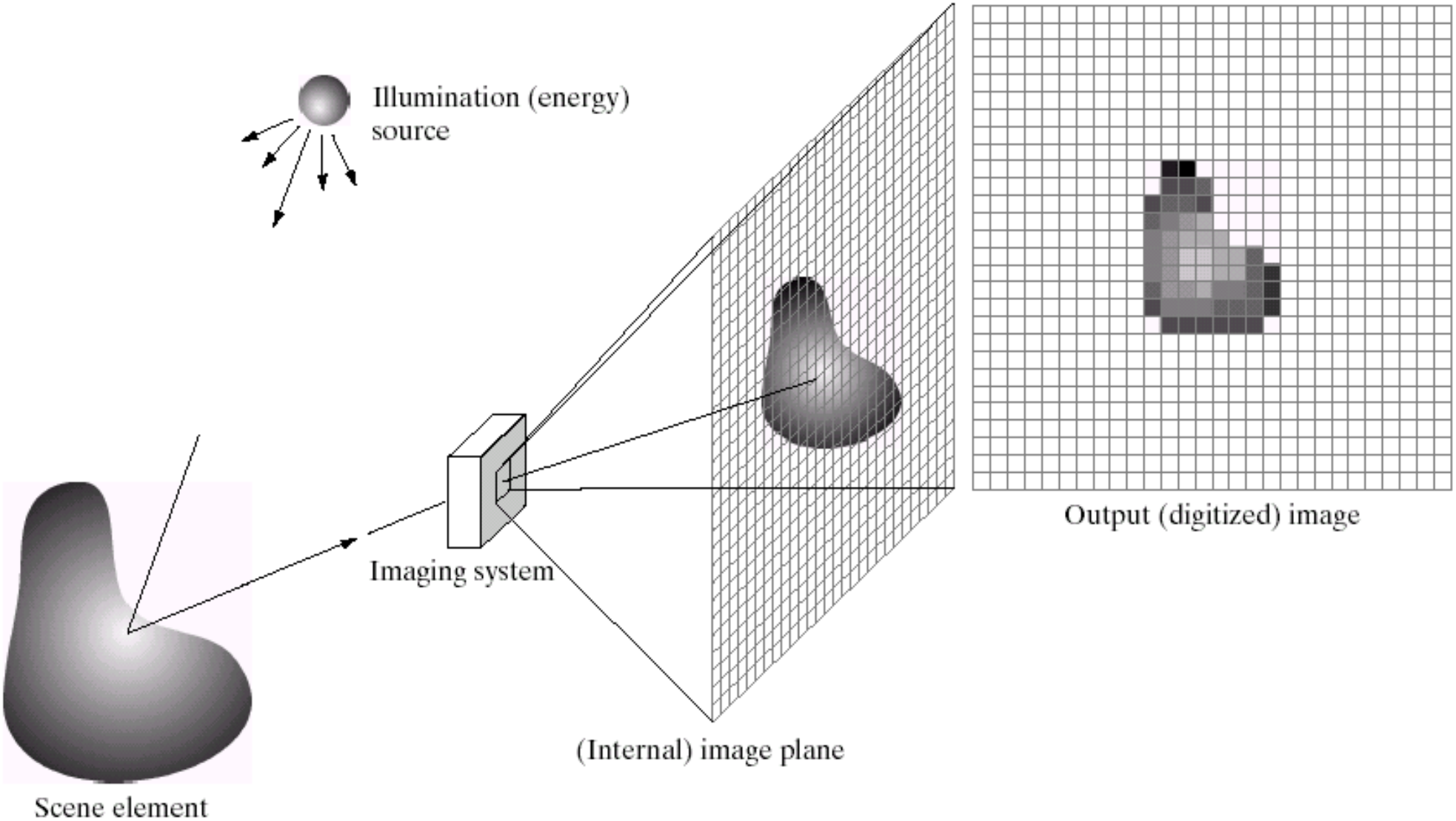

a
b c d e

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

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Simple Image Formation Model

- Image is denoted by 2D function in the form **f(x,y).** The value or amplitude of **f** at spatial co-ordinates (x,y) is a positive scalar quantity.
- When an image is generated from a physical process its values are proportional to energy radiated by a physical source (e.g.. EM spectrum).

- Assuming a monochrome image, as a consequence f(x,y) must be non-zero and finite

i.e. $0 < f(x,y) < \infty$

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The function **f (x,y)** may be characterized by 2 components:

1. Amount of source illumination **incident** on the scene being viewed.
2. Amount of illumination **reflected** by the objects in the scene.
3. These are called as illumination and reflectance components and are denoted by **i(x,y)** and **r(x,y)**
4. respectively :
5. The 2 functions combine as a product to form f (x, y).
6. $$f(x,y) = i(x,y)\, r(x,y) \qquad \ldots\ldots\ldots\ldots(1)$$

where, $0 < i(x,y) < \infty$ .....(2)

and $0 < r(x,y) < 1$ .....(3)

Means reflectance is bounded by 0 (total absorption) and 1 (total reflectance)

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- Nature of i(x,y) is determined by the illumination source and r(x,y) is determined by the characteristics of the imaged objects.
- These expressions are also applicable to images formed via transmission of illumination through a medium such as chest X-ray. In this case it should be transmissivity instead of reflectivity function with same limits.
- The intensity of a monochrome image at any co-ordinate (x0,y0) the gray level (l) of the image at that point.

$$l = f(x0,y0)$$

From 1 to 3 it is evident that l lies in the range

$$Lmin <= l <= Lmax$$

In theory, Lmin is positive and Lmax has to be finite.

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- In practice, Lmin = imin rmin

  and, Lmax =imax rmax

The interval [Lmin, Lmax] is called the grayscale. We need to shift this interval [0,L-1] where I=0 is black and I=L-1 is white on grayscale. All intermediate values are shades of gray varying from black to white.

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Sampling and Quantization

- From previous sections we have known that there are various ways to acquire images, but our objective is to generate digital image from sensed data.
- The output of most sensors is continuous voltage waveform.
- To create a digital image we need to convert the continuous sensed data into digital form. This involves two processes :

Sampling and Quantization

- Digitizing co-ordinate values is called **Sampling**.
- Digitizing amplitude values is called **Quantization**

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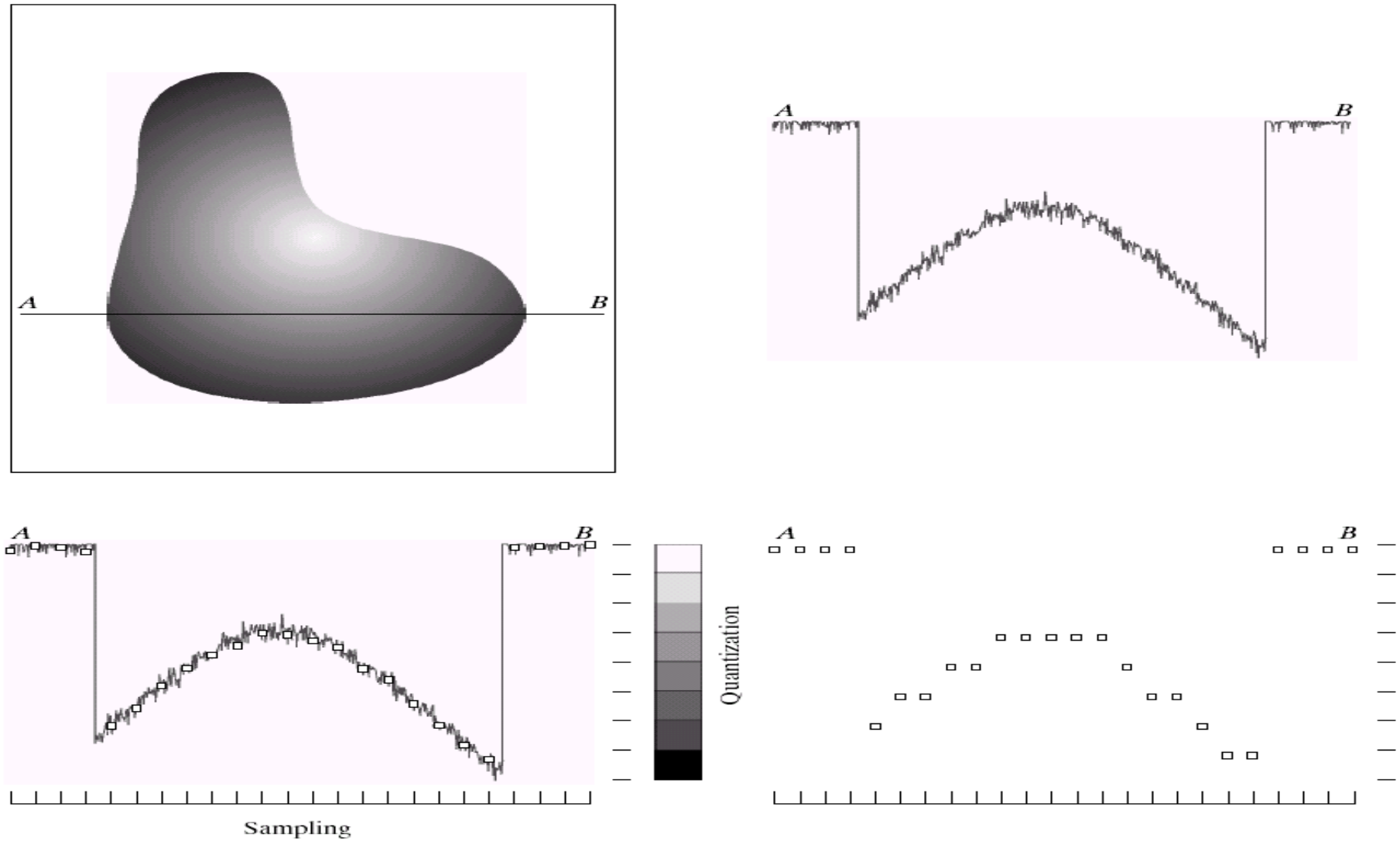
Sampling and Quantization



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.

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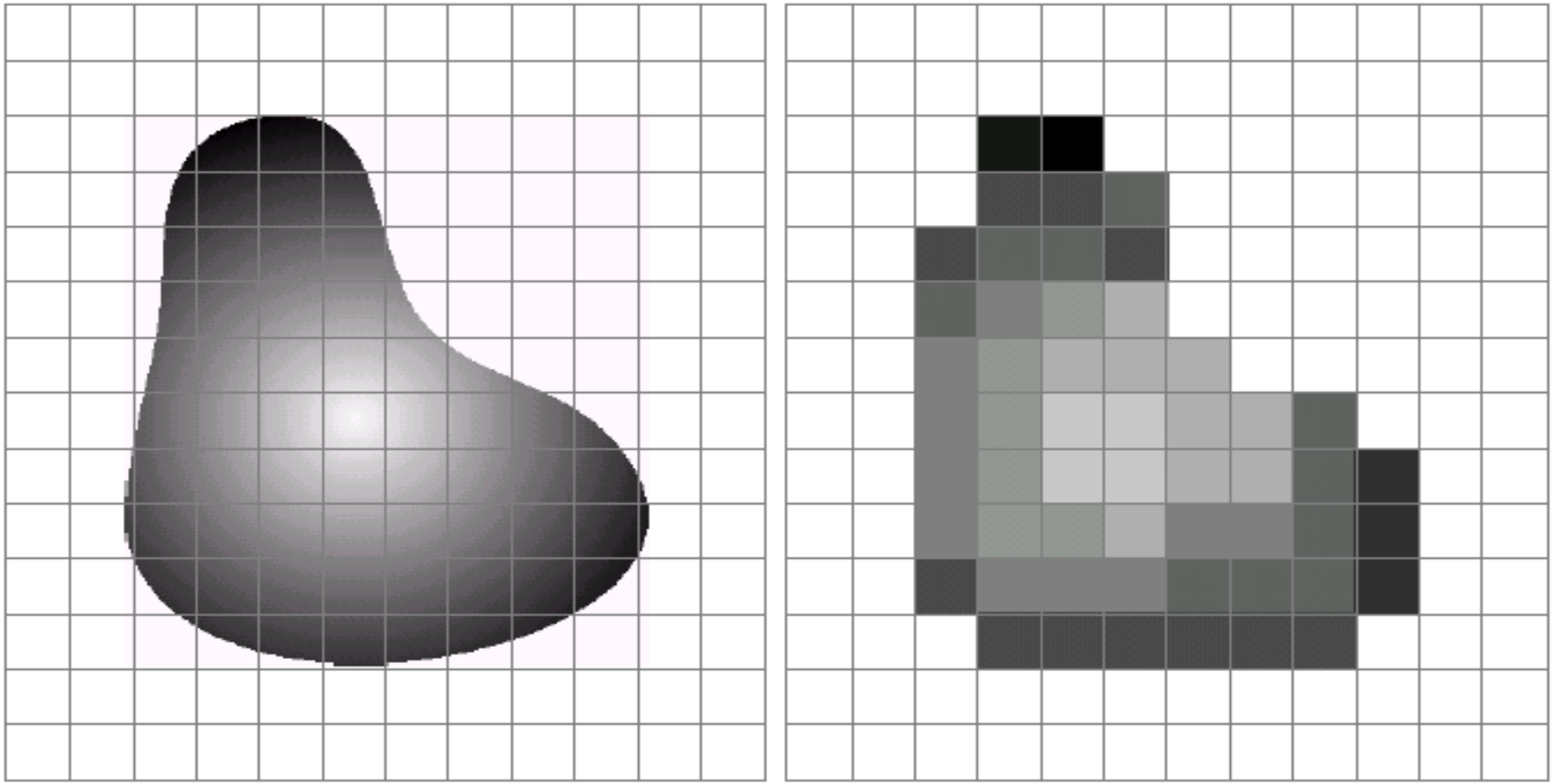
Result of Sampling and Quantization



a b

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

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Representation of Digital Images

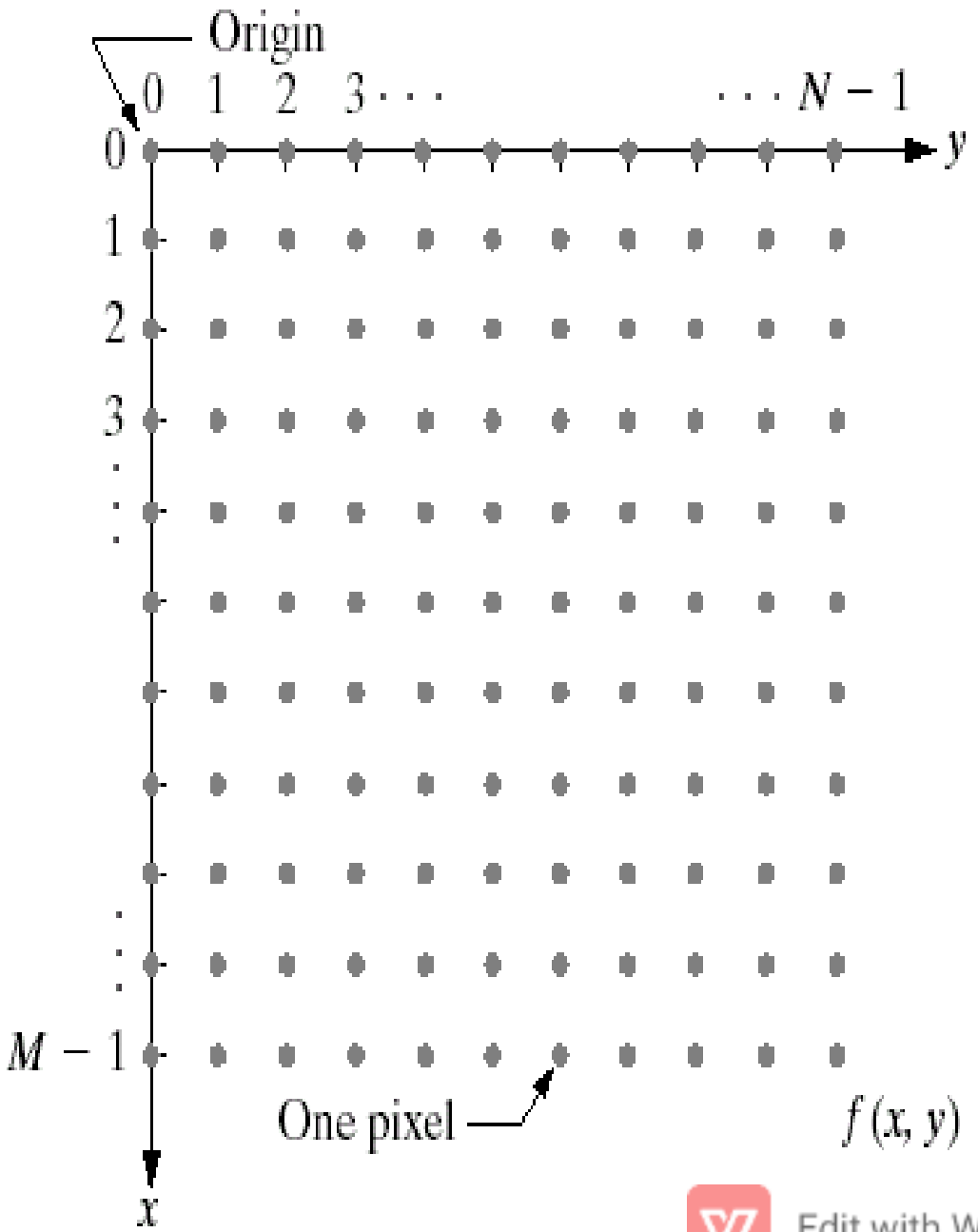

FIGURE 2.18 Coordinate convention used in this book to represent digital images.

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- Result of sampling and quantization is a matrix of real numbers.
- Suppose sampling is M rows and N columns in x and y directions
- Therefore, digital image is f (x,y)

  where, 0<=x<=M and 0<=y<=N

x and y are now discrete quantities.

Suppose we take integer values for discrete quantities then,

(x,y) = (0,0).....origin

(x,y) =(1,0) .....

Complete M x N digital image in following compact matrix form can be written as:

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- Right side of the equation is by definition a digital image.
- Each element of this matrix array is called image element, picture element or pixel.
- The limit on M and N is finite and positive. L represents number of discrete gray levels used for pixels.
- Due to the processing, storage and hardware considerations L is a power of 2.

$$L = 2^k$$

The image is known as k-bit image.

Eg. 2 bit image, 3 bit, 8 ,32 and so on

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- If L is the quantization level, the gray levels lie in the range 0 to L-1, [0, L-1]. This is known as **dynamic range** of an image.
- If the number of gray levels are high, dynamic range is also high.
- If the dynamic range is high, contrast is more.
- If the dynamic range is low, image has dull or washed outlook.
- Number of bits required to store an image:
- For b bits : $b = M \times N \times k$
- For a square image : $b = N^2k$ $(M = N)$
- If there are 2^k gray levels, it is known as k-bit image.
- Eg. If there are 256 gray levels, 8-bit image.

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Spatial and Gray Level Resolution

- Sampling is the principal factor for determining spatial resolution of an image.
- Spatial resolution is the smallest discernible detail in an image.
- Gray level resolution is the smallest discernible change in gray level.
- In the following figure image is of size 1024 x 1024 pixels whose gray levels are represented by 8 bits.
- The other images are the results of sub-sampling the 1024 x 1024 image. The sub-sampling is accomplished by deleting appropriate number of rows and columns from original image.

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- E.g. 512 x 512 image was obtained by deleting every other row and column from 1024 x 1024 image.
- The 256 x 256 image is obtained by deleting every other row and column from 512 x 512 image.

- The number of gray levels are kept 256.
- The size difference makes it difficult to see effects resulting from reduction in the number of samples.

- The simplest way to see the effects is to bring all sub sampled images upto size 1024 x 1024 by row and column replication.

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Varying Number of samples.

Constant Gray level

FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

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With reference to the figure…

- Comparing fig. **a** and **b** it is difficult to tell these two images apart. The level of detail lost is too fine to be seen.

- Fig. **c** shows a very slight fine checkerboard pattern in borders. More of this effect are much more visible in 128 x 128, 64 x 64 and 32 x 32 images.

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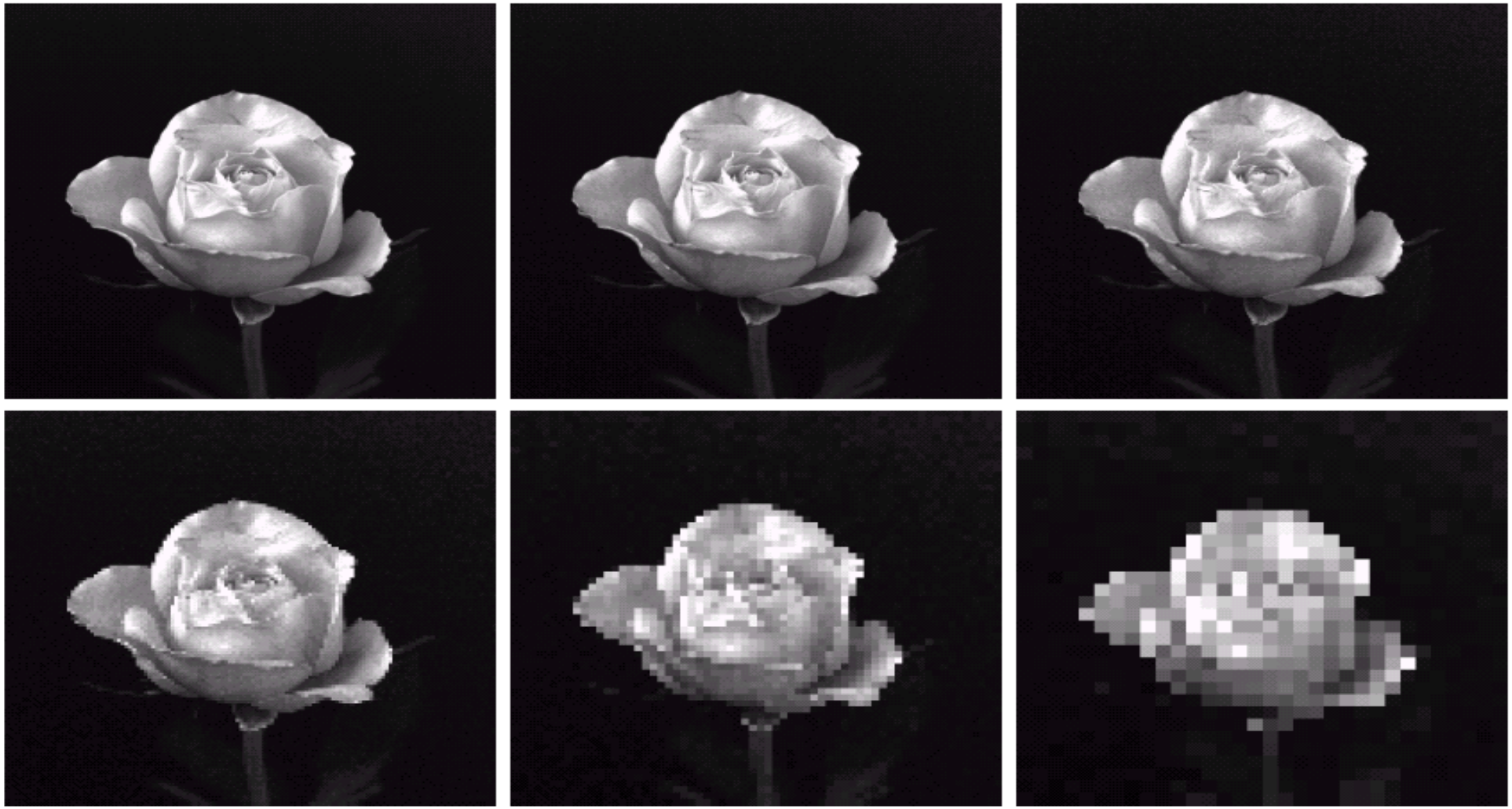
Resampling



a b c
d e f

FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

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Gray Level Resolution

- We keep the number of samples constant and reduce the number of gray levels from 256 to 2.
- Fig. **a** is 452 x 374 CAT image displayed with k=8 (256 gray levels)
- Figures **b** through **h** are obtained by reducing the number of bits from k=7 to k=1 while keeping the spatial resolution constant at 452 x 374 pixels.

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With reference to the figure…

- The 256 , 128, 64 level images are visually identical for all practical purposes.

- 32 level image (**d**) has very fine ridge like structure caused due to an insufficient number of gray levels in smooth areas of digital images called false contouring.

- It is quite visible in images displayed using 16 or less gray levels (**e** to **h**).

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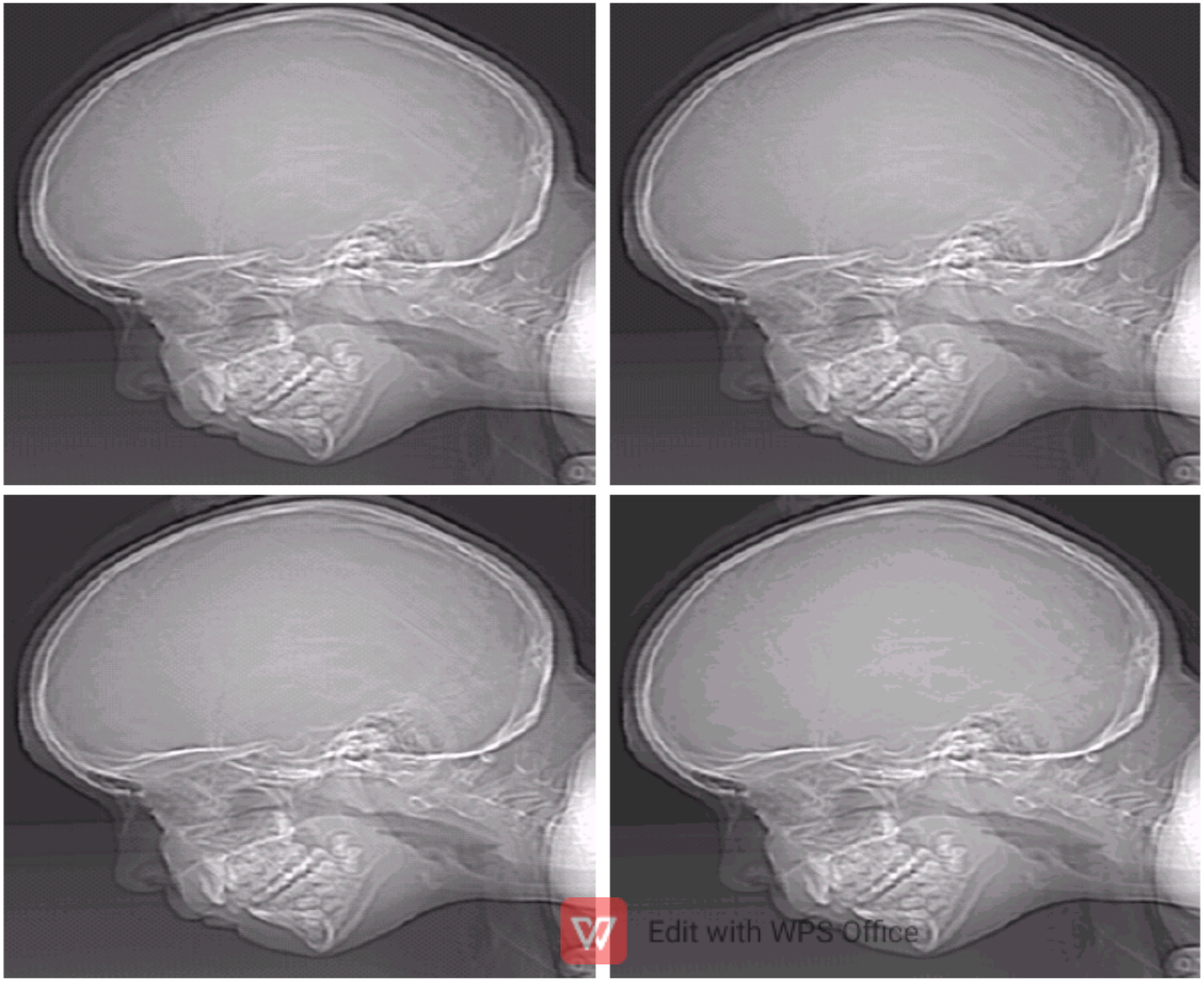
Varying Number of Gray Levels



a b
c d

FIGURE 2.21 (a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.

Constant Spatial Resolution

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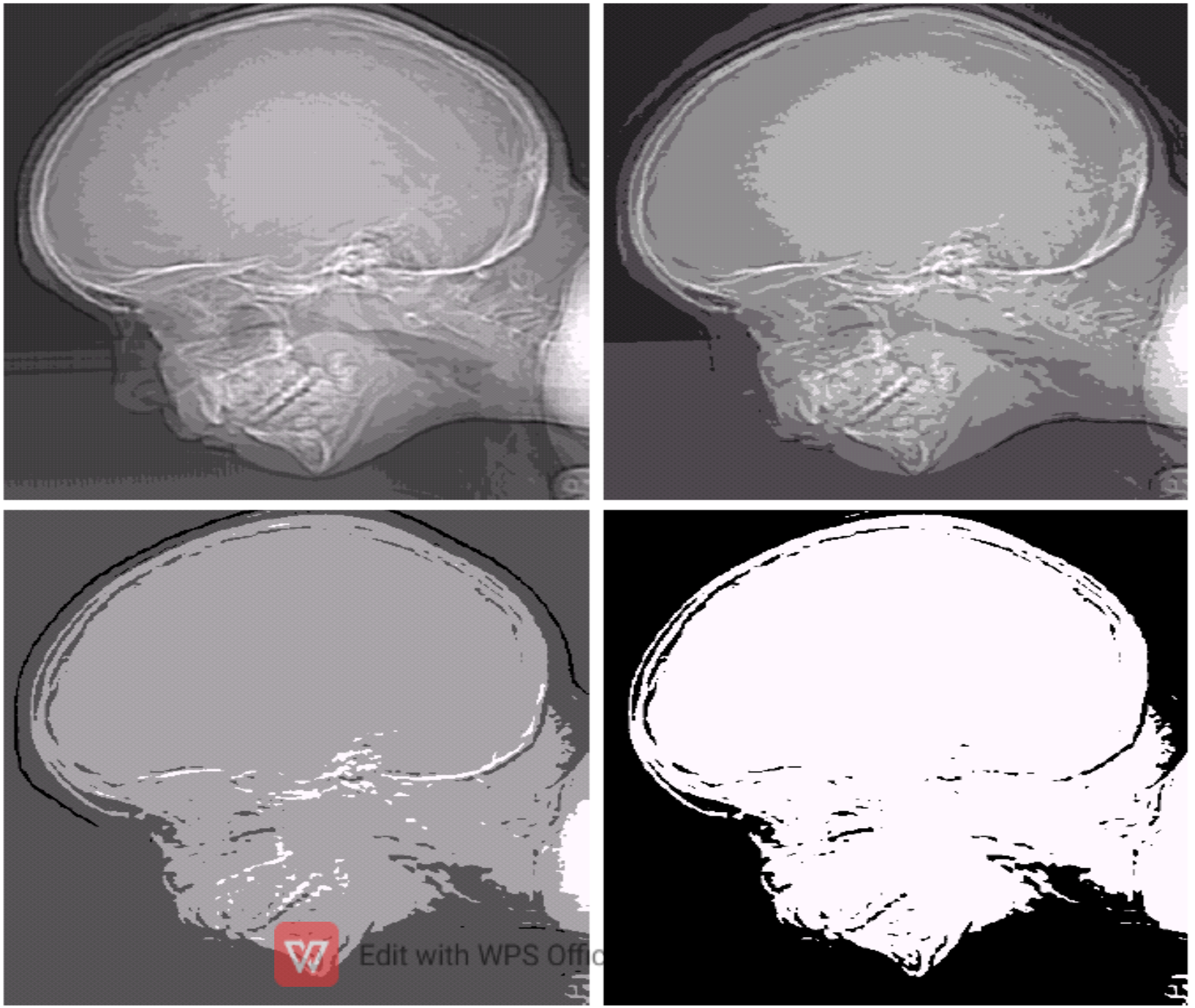
(Contd…)



e f
g h

FIGURE 2.21 *(Continued)* (e)–(h) Image displayed in 16, 8, 4, and 2 gray levels. (Original courtesy of Dr. David R. Pickens, Department of Radiology & Radiological Sciences, Vanderbilt University Medical Center.)

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- The following example illustrates the effects produced on image quality by varying N and k independently.
- The three types of images containing less, more and large detail was generated by varying N and k and the observers were asked to rank them according to the subjective quality.
- Results were summarized in the N-k plane. The graph was known as iso-preference curve. The points on the iso-preference curve corresponds to the subjective quality of image.
- The graph tends to shift upward and right which means increasing N and k increases the quality.
- But is the result same for all images?

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Low-level detail Medium-level detail Large amount detail

a b c

FIGURE 2.22 (a) Image with a low level of detail. (b) Image with a medium level of detail. (c) Image with a relatively large amount of detail. (Image (b) courtesy of the Massachusetts Institute of Technology.)

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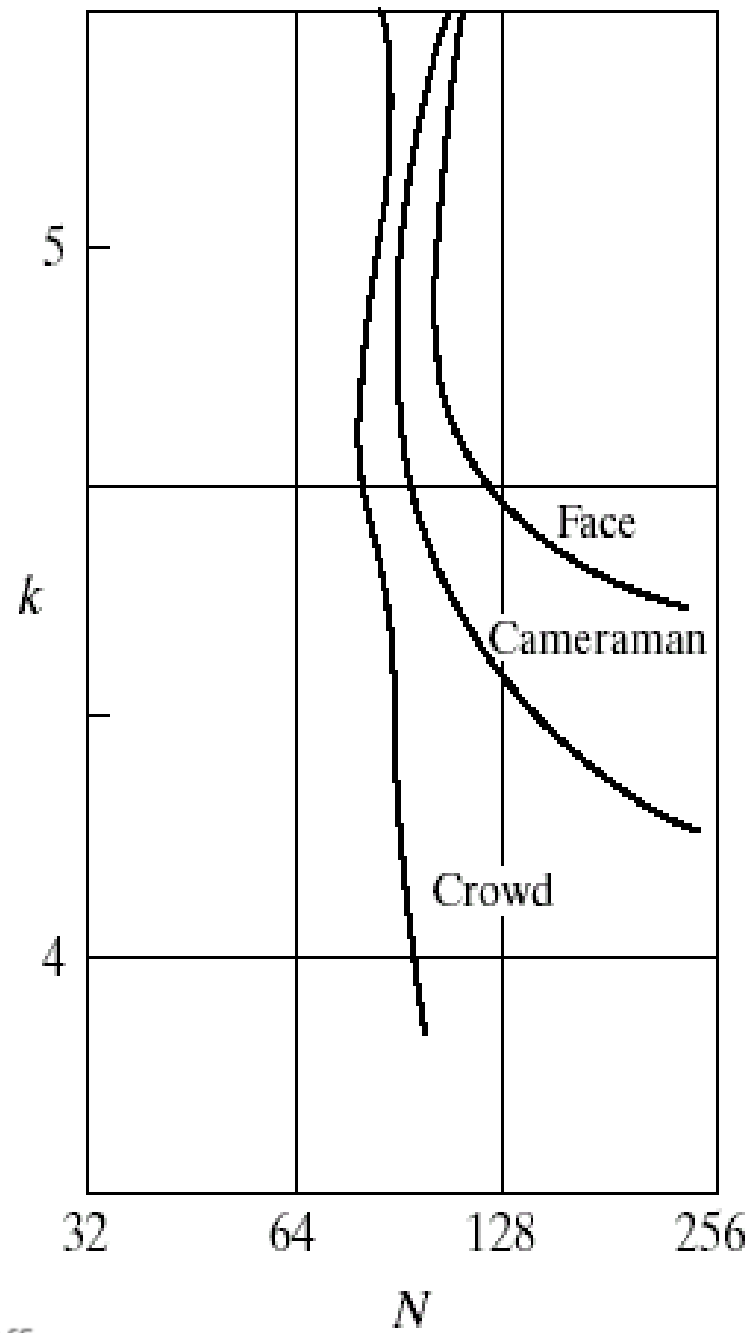
FIGURE 2.23 Representative isopreference curves for the three types of images in Fig. 2.22.

Iso-preference curve



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Zooming and Shrinking Digital Images

- It is related to Sampling and Quantization because zooming may be viewed as oversampling while shrinking may be viewed as under sampling.
- The key difference between Sampling and Quantization and Zooming and Shrinking is that the later is applied on digital image.
- Zooming requires 2 steps:

➤ the creation of new pixel locations , and

➤ the assignment of gray levels to those locations.

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- Methods for zooming:

➤ Nearest neighbor Interpolation

➤ Pixel Replication (special case)

➤ Bilinear Interpolation

Image shrinking is done in similar manner as zooming.

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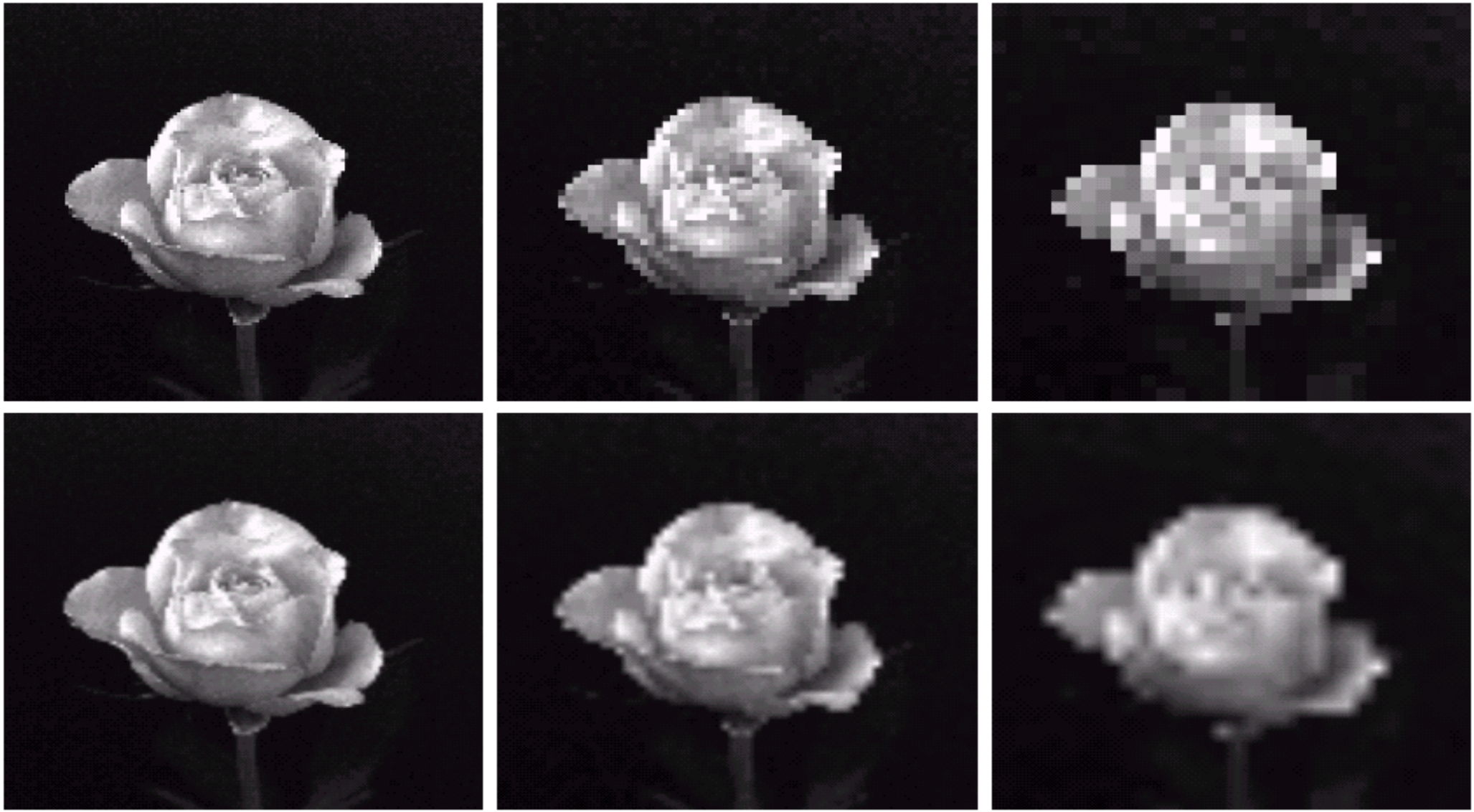
Zooming



a b c
d e f

FIGURE 2.25 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.

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Basic Relationship between pixels

- Image is denoted by f (x ,y). To refer to a particular pixel we will use p and q.
- **Neighbors of a pixel**
- A pixel p at co-ordinates (x,y) has 4 horizontal and vertical neighbors whose co-ordinates are given by

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

This set of pixels is called 4-neighborhood of p denoted by N_4 (p).

Each pixel is at 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.

The **4 diagonal** neighbors of p are **(x+1,y+1),(x+1,y-1), (x-1, y+1), (x-1,y-1)** and are denoted by N_D (p).

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- These points along with 4-neighbors are called 8-neighbors of p denoted by N_8 (p).
- Some of the points in N_D (p) and N_8 (p) fall outside the image if (x,y) is on the border of image.
- **4-Neighbor N_4(p)** **Diagonal Neighbor N_D(p)**

(x,y+1)

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

(x,y-1)

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

p (x,y)

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

N8(p)

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

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

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

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Adjacency, Connectivity, Regions and Boundaries

- To establish that two pixels are **connected**, it must be determined if they are neighbors and if their gray levels satisfy a specified criterion of similarity.

- In binary image with values 0 and 1, two pixels may be 4-neighbors ,but they are said to be connected only if they have same value.

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Adjacency

- Let V be the set of gray level values. In a binary image, V={1}, if we are referring to adjacency of pixels with value 1.
- In grayscale image, suppose possible range of gray values is 0 to 255, set V could be any subset of these 256 values.
- We consider 3 types of adjacency:

1. **4-adjacency**:-Two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$.
2. **8-adjacency**:-Two pixels p and q with values from V are 8-adjacent if q is in the set $N_8(p)$.

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3. **<u>m-adjacency (mixed)</u>**:- 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 $N_4(p) \cap N_4(q)$ has no pixels whose values are from V.

A digital path from pixel p with co-ordinates (x,y) to pixel q with co-ordinates (s,t) is a sequence of distinct pixels with co-ordinates (x0,y0) , (x1,y1),…,(xn,yn) where

(x0 ,y0) = (x,y) and (xn,yn) =(s,t) and pixels (xi,yi) and

(xi-1, yi-1) are adjacent for 1<=i<=n. n is the length of path . If (x0,y0) = (xn,yn) the path is closed path.

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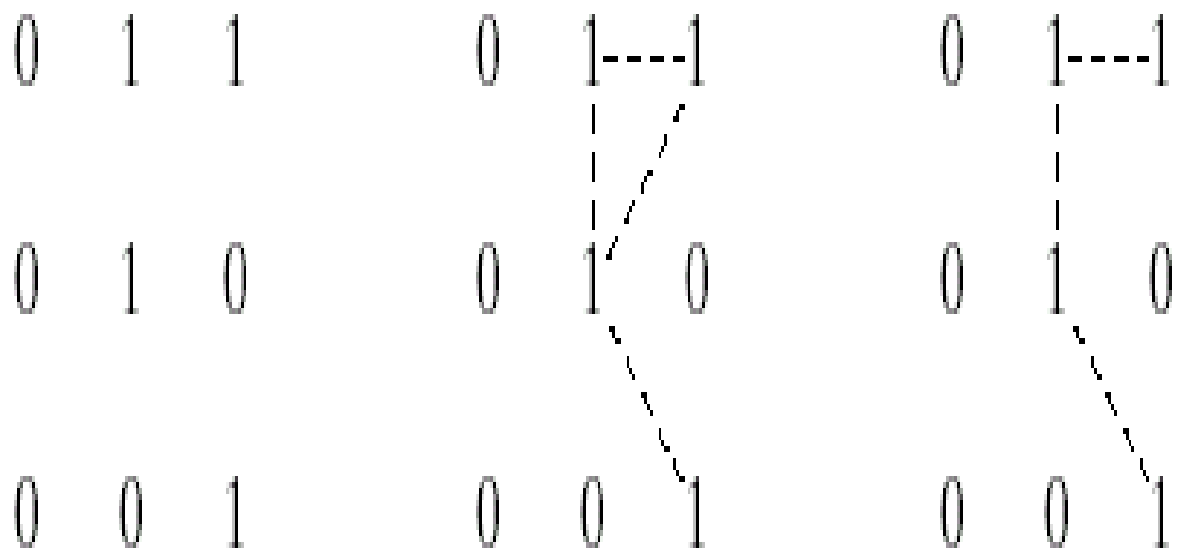
Adjacency



a b c

FIGURE 2.26 (a) Arrangement of pixels; (b) pixels that are 8-adjacent (shown dashed) to the center pixel; (c) *m*-adjacency.

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Connectivity

- Let S represent a subset of pixels in an image. 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.
- If it only has one connected component, then set S is called a connected set.

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Region

- Let R be a subset of pixels in an image. We call R a region of the image if R is a connected set.

Boundary

The boundary of a 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.

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Distance Measures

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

  a). D (p,q)>=0 (D (p,q) =0 iff p=q)

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

  c). D (p,z) <= D (p,q) + D (q, z)

Euclidean distance between p and q is defined as

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

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The D_4 distance (city block distance) between p and q is defined as

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

- The D_8 distance (chessboard distance) between p and q is defined as

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

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Image Operations on Pixel Basis

- We have represented image in the form of matrices.
- We can refer to an operation like “dividing one image by another” –means division is carried out between corresponding pixels in the two images.
- E.g. f and g are images, first element of the image formed by “dividing” f by g is simply the first pixel in f divided by first pixel in g, assuming none of the pixels in g have value 0.

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Linear and non-linear operations

- Let H be an operator whose input and output are images.
- H is said to be a linear operator if for any two images f and g and any two scalar a and b

  $$H(af + bg) = a\,H(f) + b\,H(g)$$

  The result of applying a linear operator to the sum of two images (multiplied by constants) is identical to applying the operator to the images individually, multiplying the results by appropriate constants and then adding those results.

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- E.g. an operator whose function is to compute the sum of k images is a linear operator.
- An operator that computes the absolute value of the difference of two images is not a linear operator.

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CHAPTER 3

Image Enhancement in Spatial Domain

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- **<u>Spatial Domain-</u>** Aggregate of pixels composing an image.
- Procedures that operate directly on these pixels.
- Spatial Domain processes will be denoted by the expression

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

- f (x,y) -Input image
- g (x,y)- Processed Image
- T- operator on f defined over some neighborhood of (x,y).
- Example:- Sum of k images for noise reduction or AND operation of two images etc.

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- Principal approach in defining a neighborhood about a point (x,y) is to use a square or rectangular sub image area centered at x,y.
- Centre of sub image is moved from pixel to pixel starting top left corner,
- The operator T is applied at each location (x,y) to yield the output g at that location.
- The process utilizes only the pixels in the area of the image spanned by the neighborhood.
- g depends only on the value of f at (x,y) and T becomes a gray-level transformation function of the form
- $s=T(r)$
- Where,
- r- gray level of f(x,y)
- s- gray level of g (x,y) at point (x,y).

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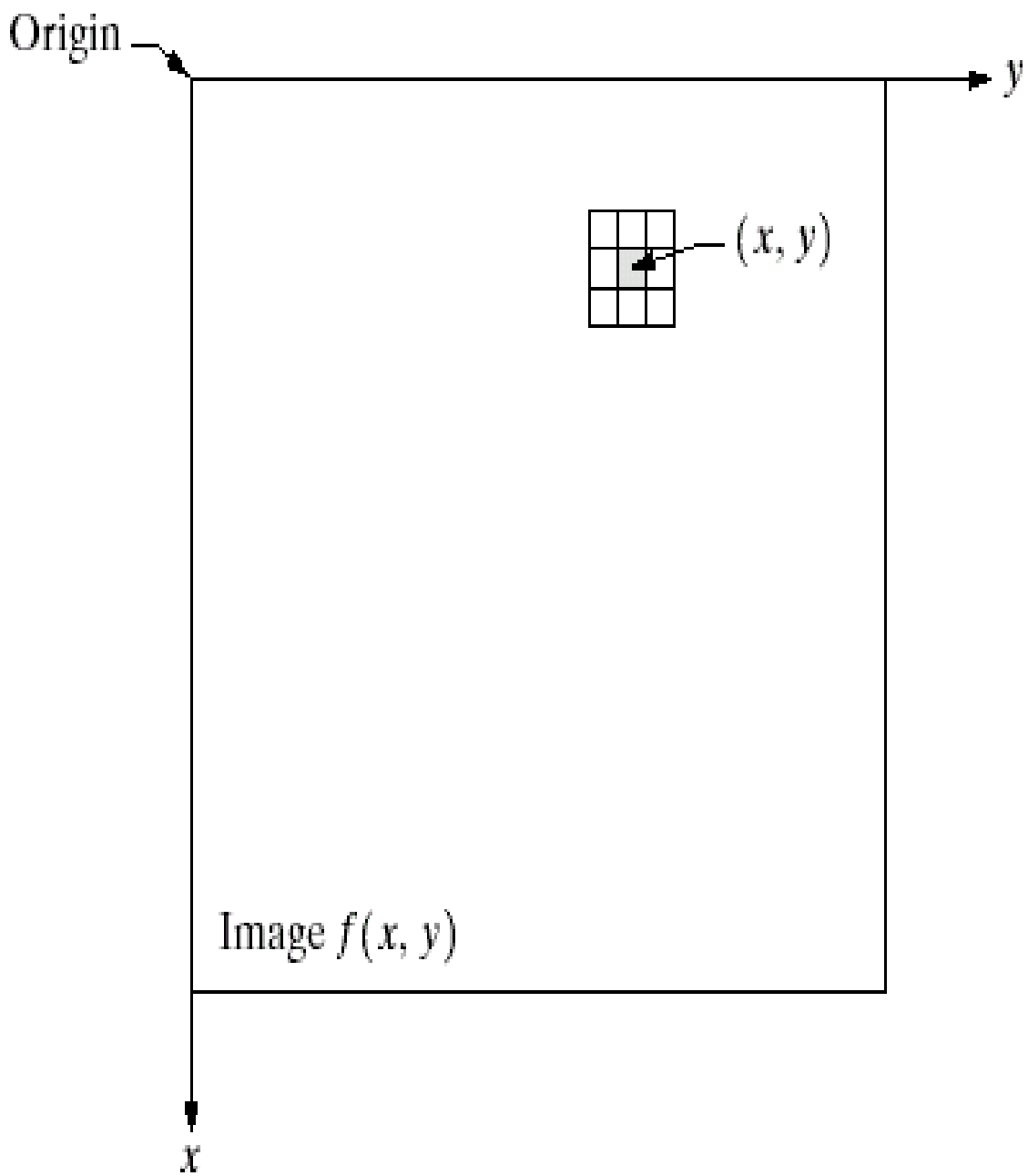
FIGURE 3.1 A 3×3 neighborhood about a point (x, y) in an image.



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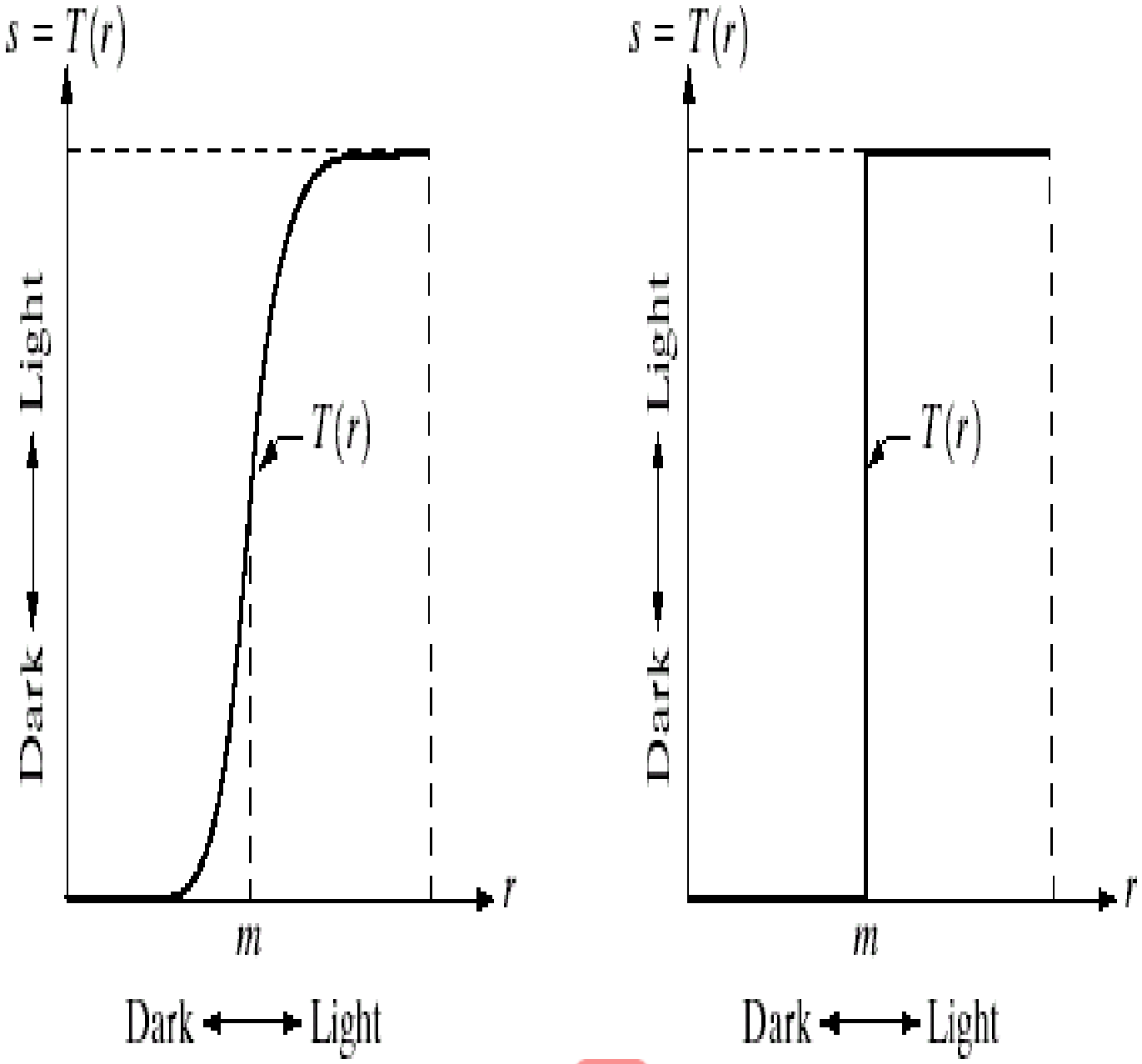

a b

FIGURE 3.2 Gray-level transformation functions for contrast enhancement.

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- If T(r) has the form (a) , the effect of this transformation would be to produce an image of higher contrast than the original by darkening the levels below m and brightening above m.

- In (b), T(r) produces a two level image. A mapping of this form is called **thresholding function**.
- Because enhancement at any point in an image depends only on the gray level at that point, techniques in this category are referred to as **point processing**.

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- The values of pixels before and after processing are denoted by r and s respectively in the form

  $$s=T(r)$$

  Where T is the transformation which maps a pixel value r into pixel values s. Values of transformation function are stored in 1-D array and mapping from r to s are implemented via table lookups.

  For an 8-bit environment, lookup table contains 256 entries.

  The following are the three basic functions used frequently for image enhancement.

- Image Negatives
- Log Transformation
- Power Law Transformations

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Image Negatives

- Negative of an image with gray levels in the range [0,L-1] is obtained by using the negative transformation given by

$$s = L-1-r$$

Reversing the intensity levels of an image produces the equivalent of a photographic negative.

It is particularly suited for enhancing white or gray level detail embedded in dark regions of an image, specially when the black areas are dominant.

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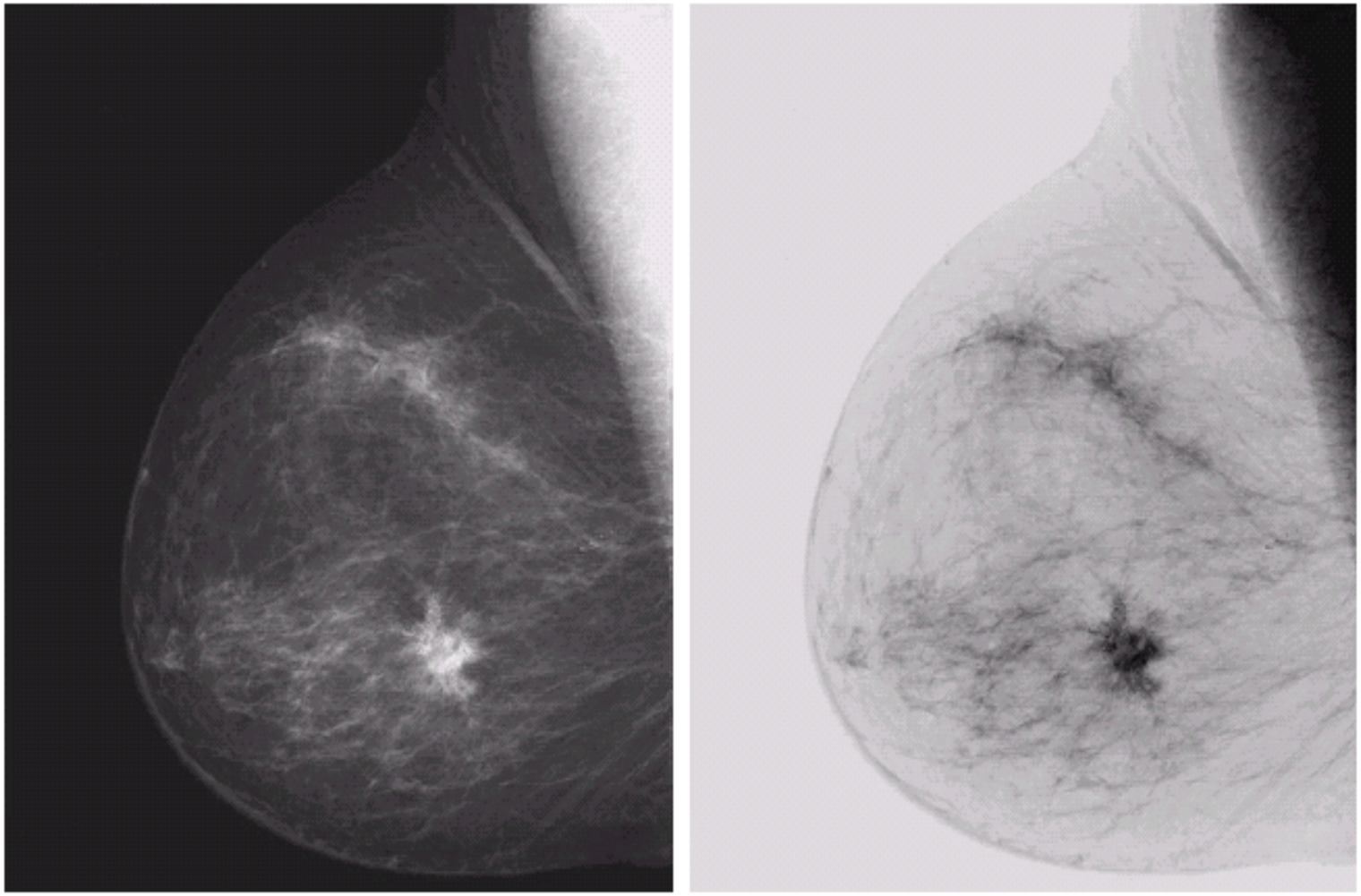
Image Negatives



a b

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

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Log Transformation

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

Where,

c= constant and,

r >=0 (assumed)

Shape of log curve shows that this transformation maps a narrow range of low gray level values in input image into wider range of output levels. This type of transformation is used to expand the dark pixels in the image while compress the high level pixels. The inverse log function performs just the opposite function.

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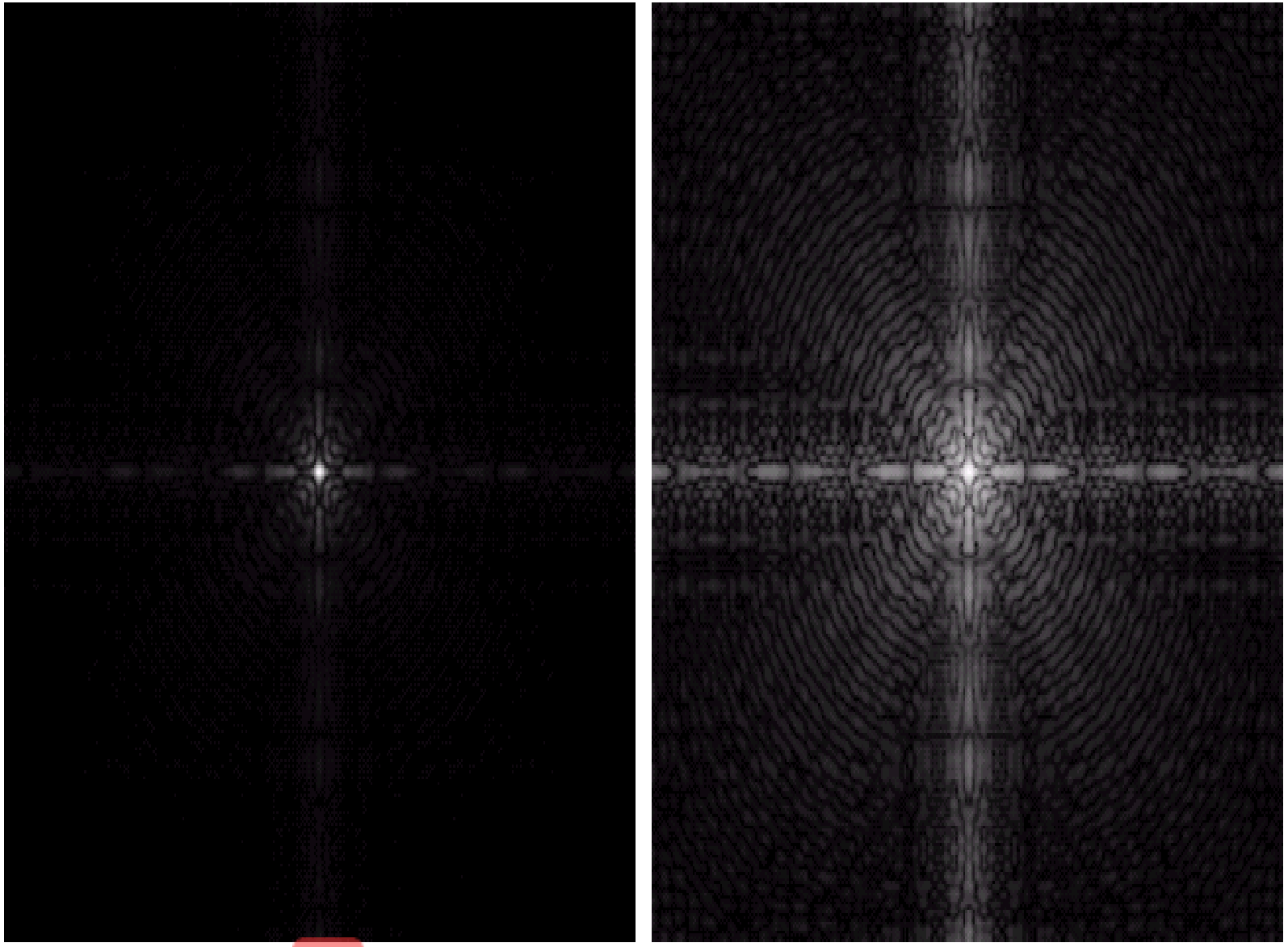
Log Transformation

a b

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



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Power Law Transformation

$$s = c\, r^{\gamma}$$

Where,

γ is fixed.

c and γ are positive constants.

As the value of γ changes, the manner in which the output intensities are obtained also changes.

In first figure, as gamma decreases, detail becomes visible, we reduce till it gives washed look.

In second figure, it has already washed look , so we need to compress gray level.

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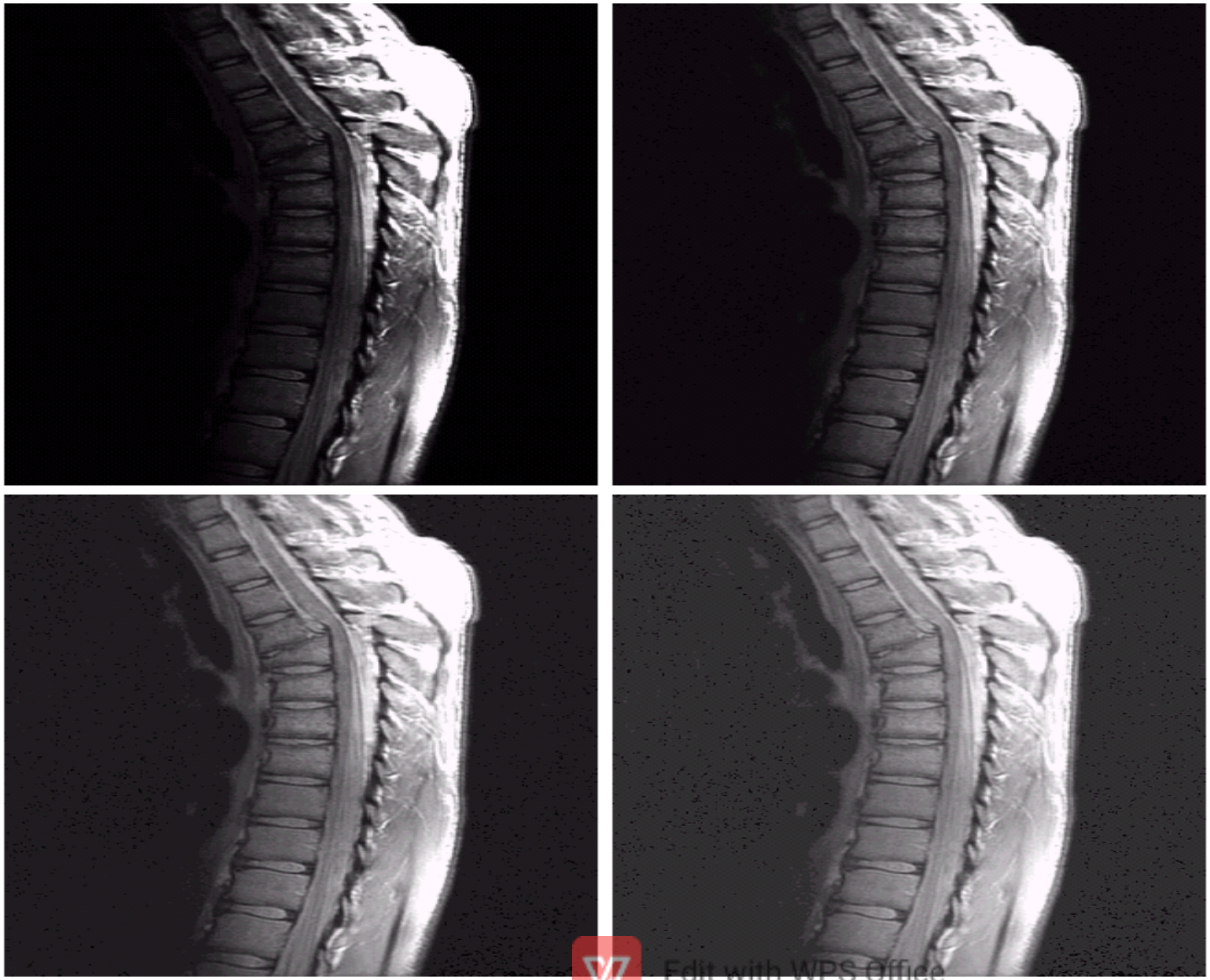
Value of gamma 0.6,0.4,0.3 respectively



a b
c d

FIGURE 3.8 (a) Magnetic resonance (MR) image of a fractured human spine. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 0.6, 0.4$, and 0.3, respectively. (Original image for this example courtesy of Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

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Value of gamma 3.0,4.0,5.0 respectively

a b
c d

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

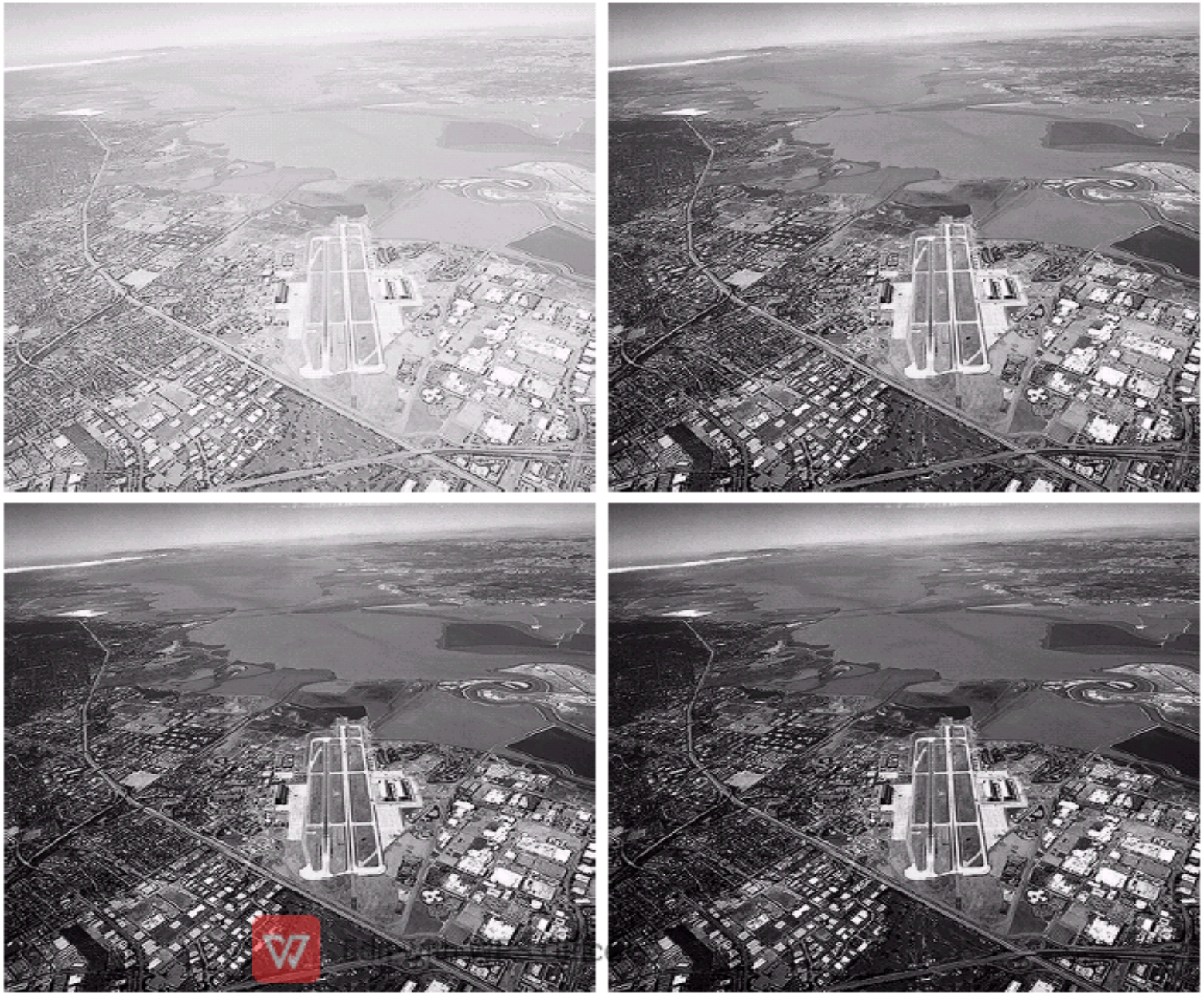
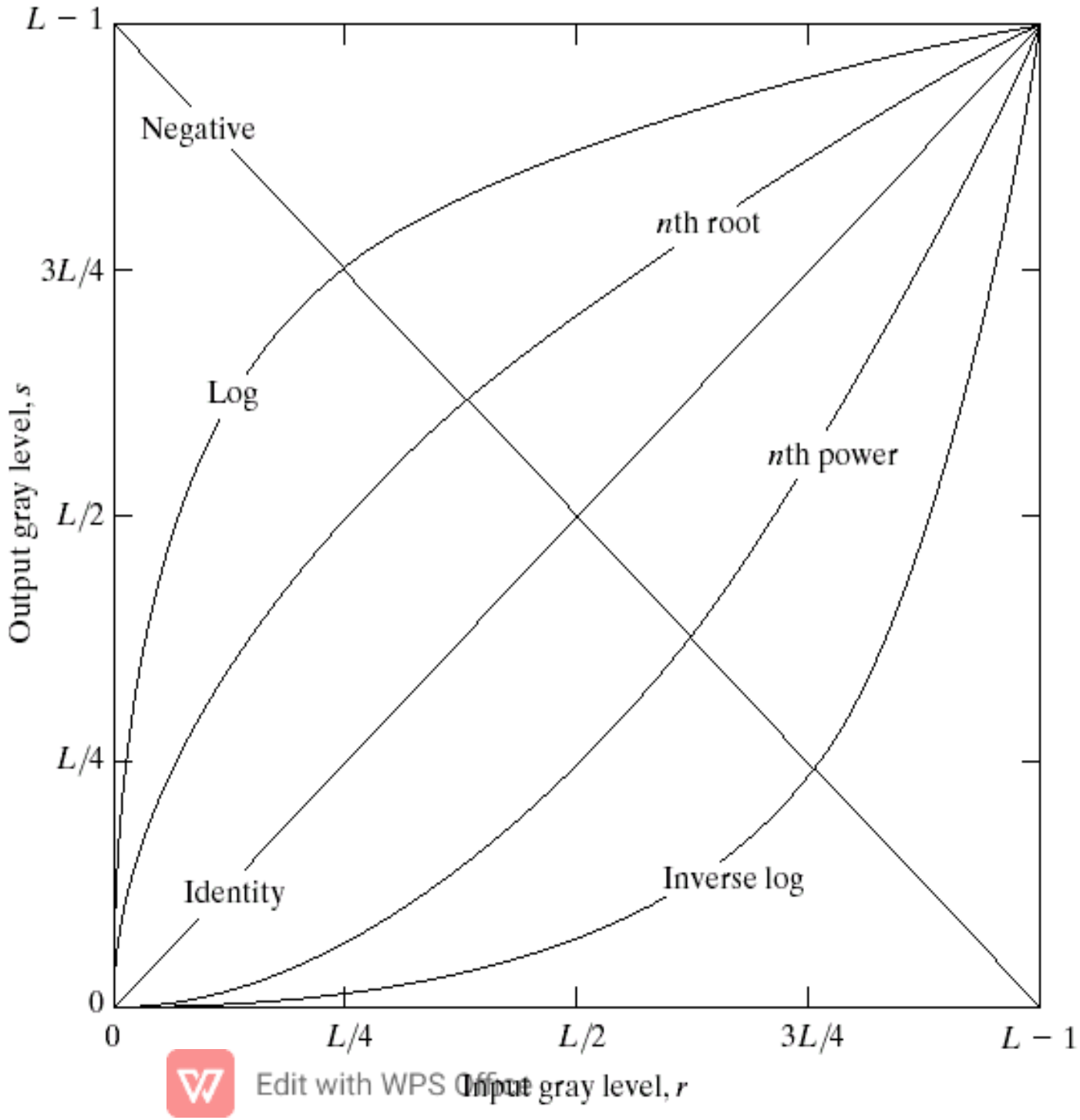


FIGURE 3.3 Some basic gray-level transformation functions used for image enhancement.



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Piecewise Linear Transformation Functions

- It is a complementary approach to the methods discussed before.
- The principal advantage of this function over the types of function is that the form of piecewise function can be arbitrarily complex.
- A practical implementation of some important transformations can be formulated only as piecewise functions.
- Principal disadvantage is that their specification requires considerably more user input.

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Contrast Stretching

It is one of the simplest piecewise linear function.

Low contrast images can result from:-

- Poor illumination
- Lack of dynamic range in image imaging sensor
- Wrong setting of lens aperture during image acquisition.

Idea behind contrast stretching is to increase the dynamic
range of the gray levels in the image being processed.

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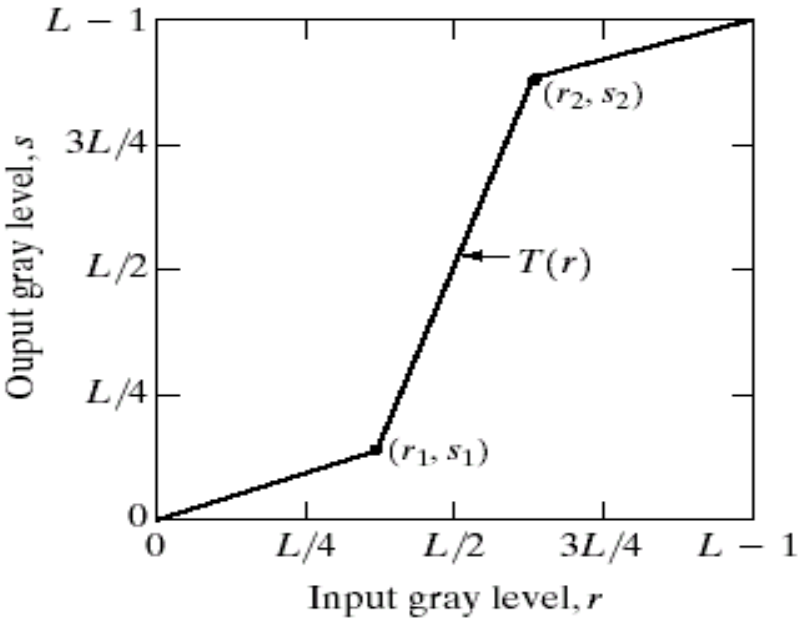
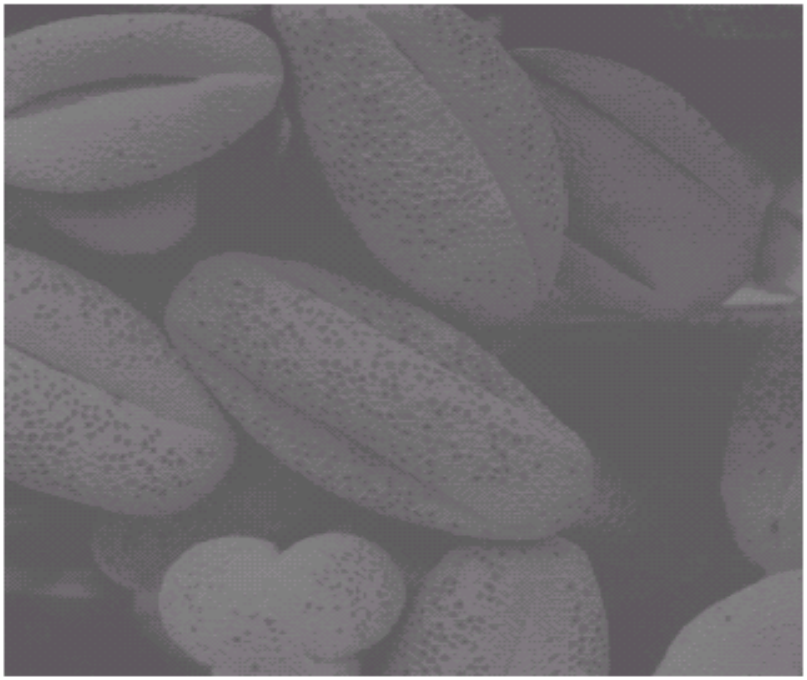
Contrast Stretching





a b
c d

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

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From the graph 3.10 (a):-

Location of points (r1,s1) and (r2,s2) control the shape of transformation function.

If **r1=s1** and **r2=s2**, the transformation is linear function that produces no changes in gray levels.

If **r1=r2** and s1=0 and s2=L-1, the transformation becomes a thresholding function that creates a binary image.

Intermediate values of (r1,s1) and (r2,s2) produce various degrees of spread in gray levels of output image, thus affecting the contrast.

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In general,

r1 <= r2, **s1<=s2** is assumed so that the function is **single valued and monotonically increasing**. It preserves the order of gray levels.

Fig (b) shows 8-bit image with low contrast.

Fig (c) shows the result of contrast stretching obtained by setting (r1,s1)=(rmin, 0) and (r2,s2)=(rmax, L-1) where rmin and rmax denote the minimum and maximum gray levels in the image.

Fig (d) shows the result of using thresholding function.

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Gray level Slicing

- Highlighting a specific range of gray levels in an image is often desired.
- Applications include enhancing features such as masses of water in satellite images and enhancing flaws in X-ray images.
- There are many ways of doing level slicing, but most of them are variations of 2 basic themes:-
- One approach is to display a high value for all gray levels in the range of interest and a low value for all other gray levels. Fig (a)
- This transformation produces a binary image.
- The second approach (b) brightens the desired range of gray levels but preserves the background and gray level in the image.

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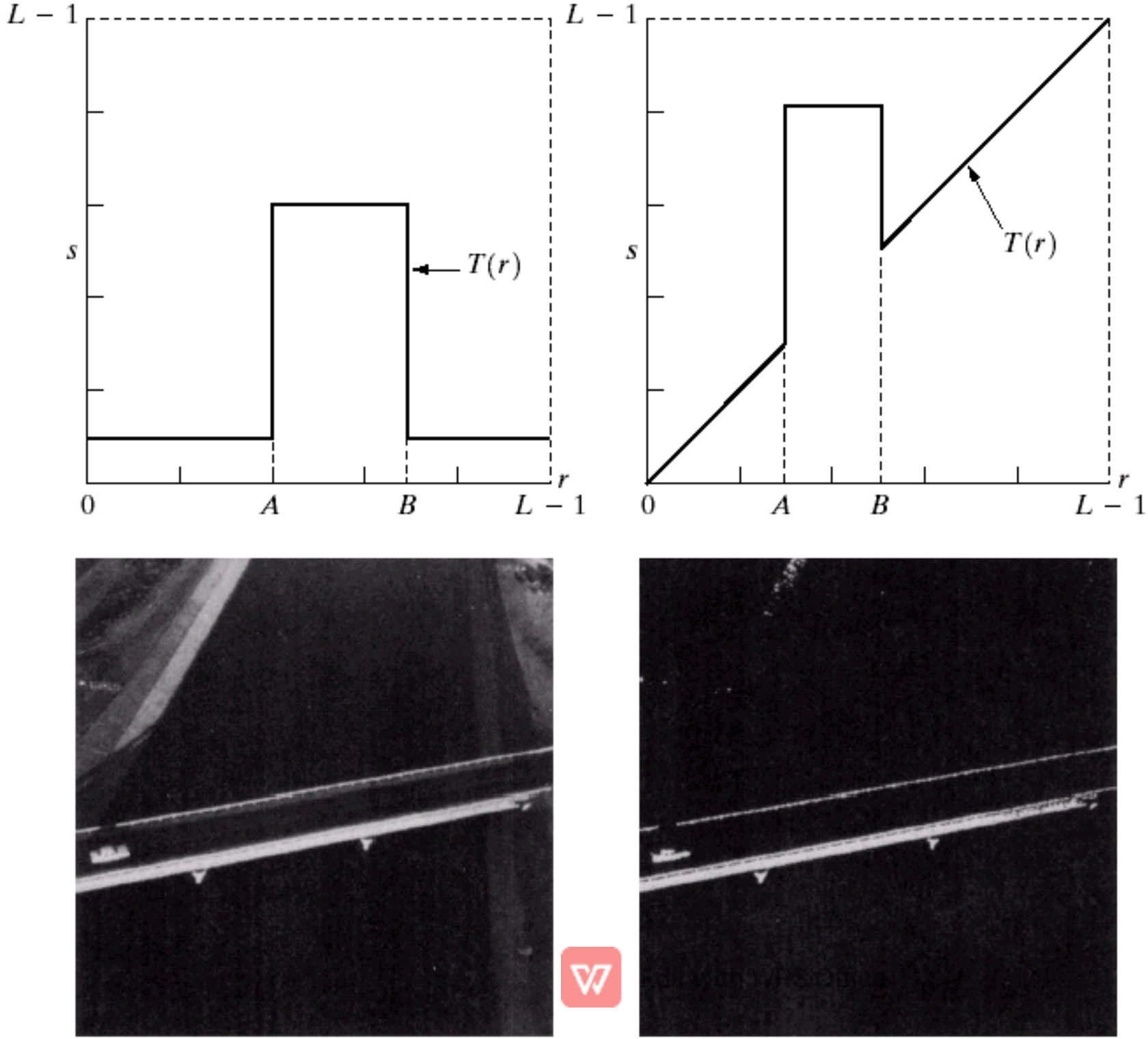

a b
c d

FIGURE 3.11 (a) This transformation highlights range $[A, B]$ of gray levels and reduces all others to a constant level. (b) This transformation highlights range $[A, B]$ but preserves all other levels. (c) An image. (d) Result of using the transformation in (a).

Bit-Plane Slicing

- Instead of highlighting gray level ranges, highlighting the contribution made to total image appearance by specific bits might be desired.
- Suppose each pixel in an image is represented by 8-bits.
- Imagine that the image is composed of eight 1-bit planes, ranging from bit plane 0 for the least significant bit to bit plane 7 for most significant bit.
- In terms of 8-bit bytes, plane 0 contains all the lowest order bits in the bytes comprising the pixels in the image and plane 7 contains all the high order bits.
- High order bits contain majority of visual significant data. Other bit planes contribute to more subtle (slight) details in an image.
- Separating an image into bit planes is useful for analyzing the relative importance played by each bit of the image.

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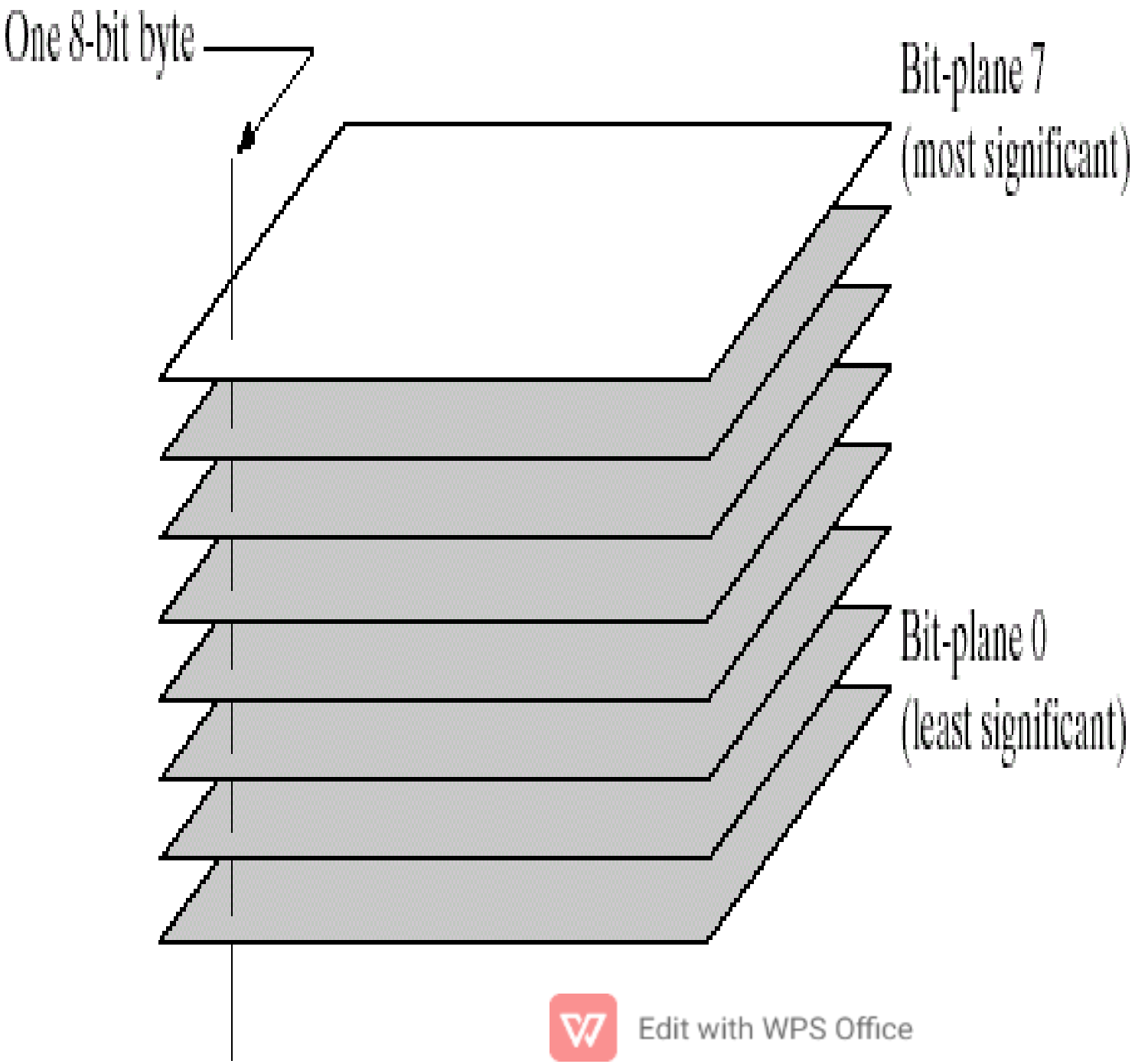

FIGURE 3.12 Bit-plane representation of an 8-bit image.

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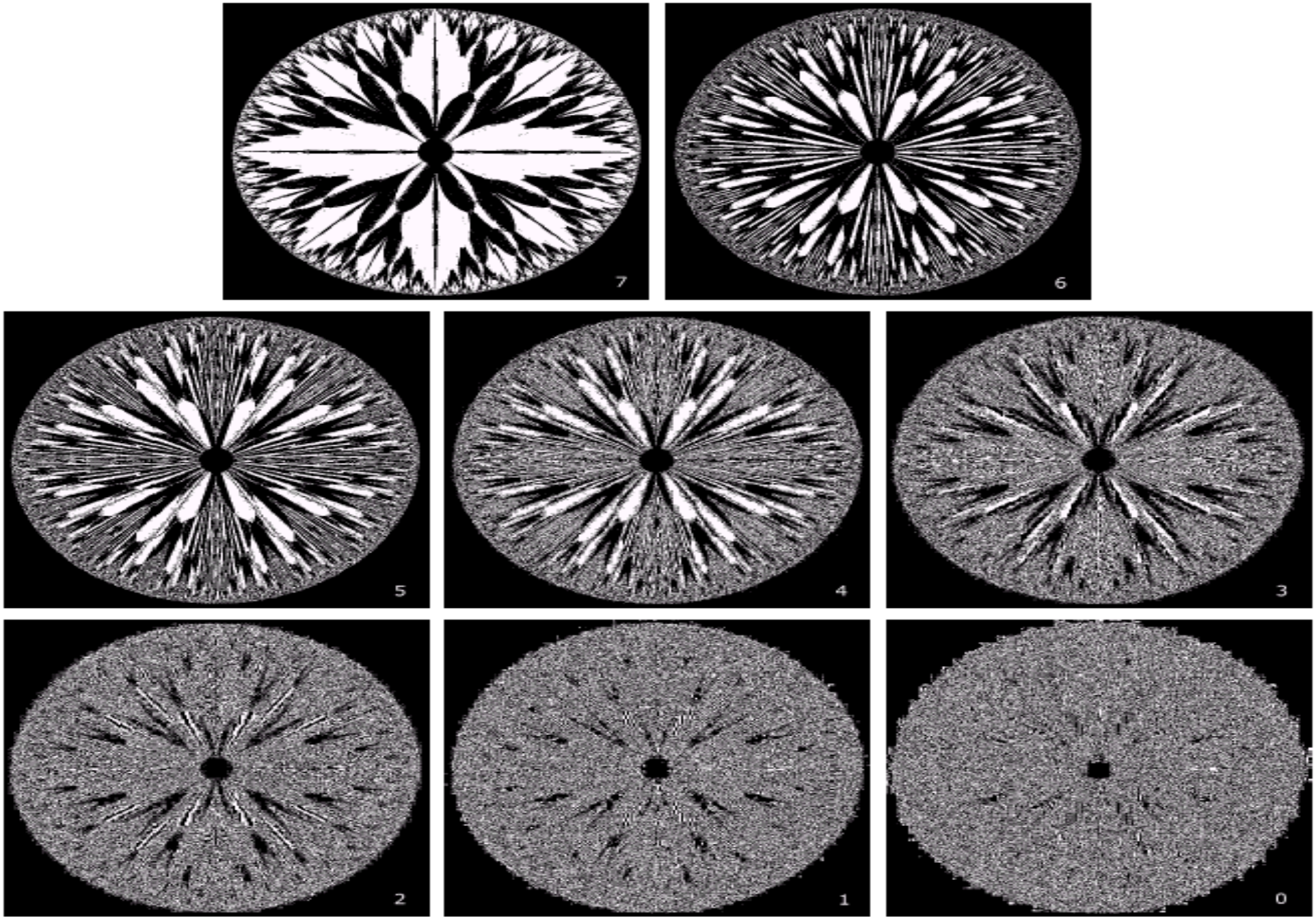

FIGURE 3.14 The eight bit planes of the image in Fig. 3.13. The number at the bottom, right of each image identifies the bit plane.

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HISTOGRAM PROCESSING

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- The histogram of a digital image with gray levels in the range [0, L-1] is a discrete function

$$h(r_k) = n_k,$$

where r_k is the kth gray level and n_k is the number of pixels in the image having gray level r_k.

- It is a common practice to normalize a histogram by dividing each of its values by the total number of pixels in the image denoted by n.
- Thus, normalized histogram is given by

$$p(r_k) = n_k / n,$$

For k = 0,1,2,...,L-1

$p(r_k)$ gives an estimate of the probability of occurance of gray level r_k.

Sum of all components of a normalized histogram is 1.

Histograms are basis for numerous spatial domain processing techniques.

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- Histogram manipulation can be used effectively for image enhancement.
- Provides useful image statistics.
- Useful for image compression and segmentation.
- They are simple to calculate in software and also used for hardware implementations, thus making them a real time image processing.

With reference to the following figure:-

It shows an image in four basic gray levels : dark, light , low contrast and high contrast.

Right side shows the histograms corresponding to these images.

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- Horizontal axis corresponds to gray level values **rk**.
- Vertical axis corresponds to values of **h (rk)= nk** or

  p (rk) = nk/n, if the values are normalized.
- Histogram plots are of **h (rk)=nk** versus **rk** or

  p (rk) =nk/n versus **rk**.

➤ In dark image, components of the histogram are concentrated on low (dark) side of gray scale.

➤ Histogram of bright image are biased towards high side of the gray scale.

➤ Image with low contrast has a narrow histogram and towards the centre of the gray scale.

➤ The components of the histogram in high contrast image cover a broad range of gray scale and distribution of pixels is uniform.

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- It is reasonable to conclude that an image whose pixels tend to occupy the entire range of possible gray levels and tend to be distributed uniformly, will have an appearance of high contrast and will exhibit a large variety of gray colors.

- The net effect will be an image that shows a great deal of gray level detail and has high dynamic range.

- It is possible to develop a transformation function that can automatically achieve this effect based only of information available in the histogram of the input image.

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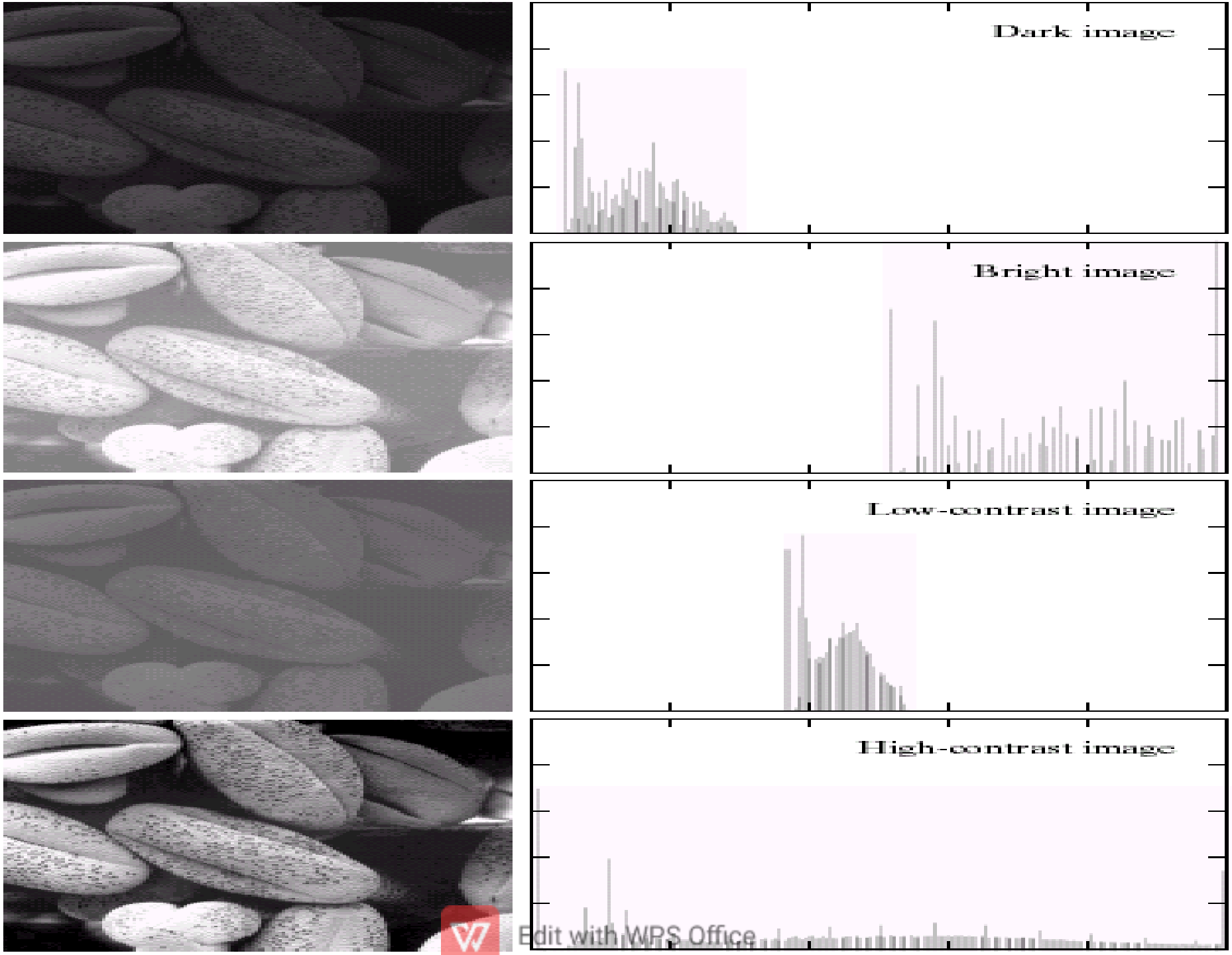

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Histogram Equalization

- Let variable r represent the gray levels of the image to be enhanced. Initially, we assume that r has been normalized to the interval [0,1], with r=0 representing black and r=1 for white.
- Consider a discrete formulation and allow pixels to be in interval [0,L-1].
- Let r satisfy the relation **s= T (r) 0<=r<=1**
- The transformation function T (r) should satisfy the following condition:-

1. It should be **single valued and monotonically increasing** in the interval 0<=r<=1.
2. If 0<=r<=1 then 0<= T (r) <=1

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- The reason for T (r) to be **single valued** is that inverse function exists, and **monotonicity** condition preserves the increasing order from black to white in the output image.

- A transformation function that is not monotonically increasing could result in at least a section of the intensity range being inverted, thus producing some inverted gray levels in output image.

- Second condition guarantees that the output gray levels will be in the same range as input levels.
- The inverse transformation is denoted by

$$r = T^{-1}(s) \quad 0<=s<=1$$

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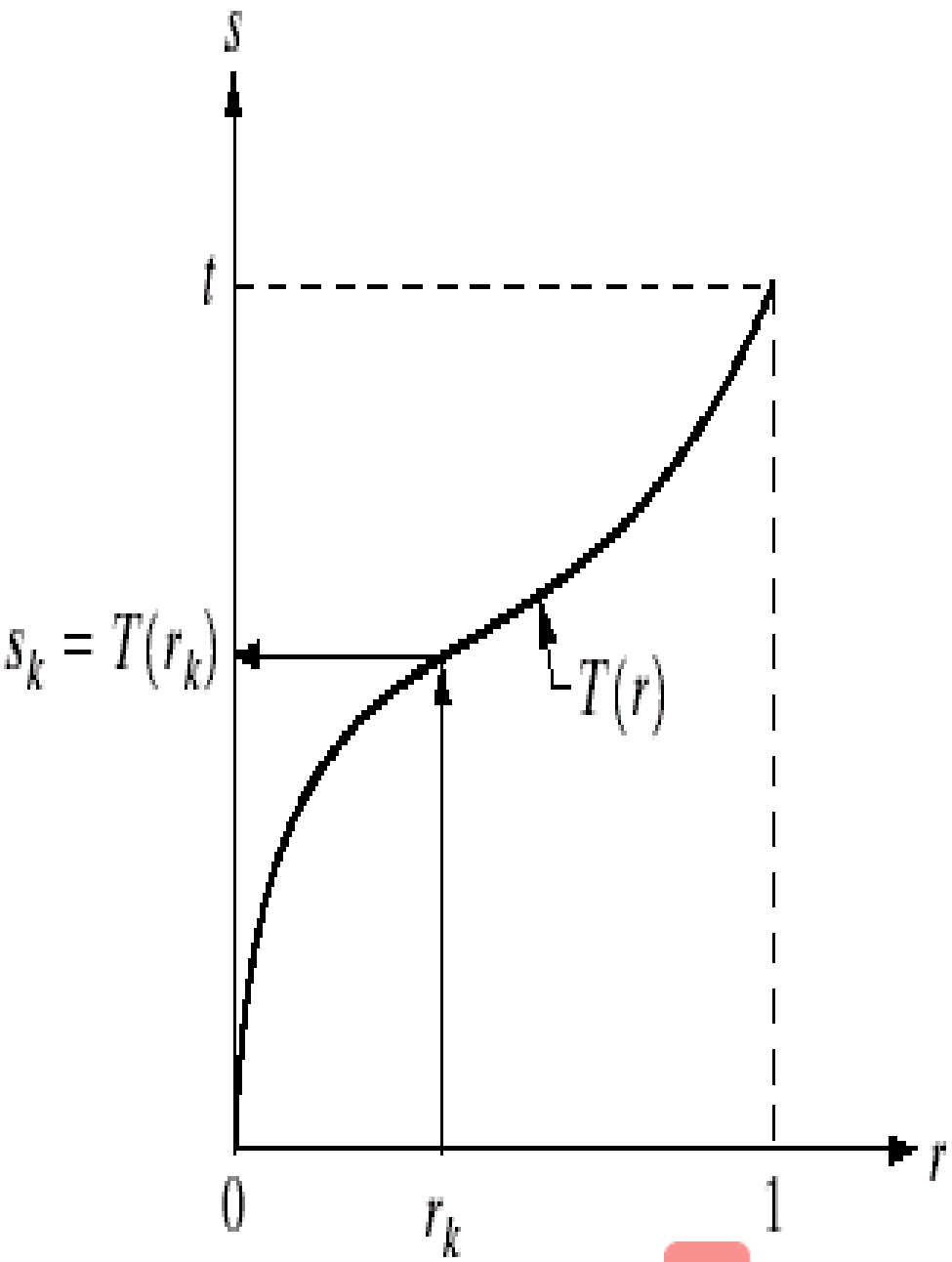

FIGURE 3.16 A gray-level transformation function that is both single valued and monotonically increasing.

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We need to prove that T (r) satisfies condition 1 and 2.

Let the gray levels in an image be random variables in the interval [0,1].

One of the most fundamental descriptors of random variable is probability density function (PDF).

Let p_r (r) and p_s (s) denote the PDF of random variables r and s respectively where the subscripts on p denote that p_r and p_s are different function.

A basic result from an elementary probability theory is that if p_r (r) and T (r) are known and T^{-1} (s) satisfies condition 1, then PDF p_s (s) of the transformed variable s can be obtained as

$$p_s(s) = p_r(r)\,|dr / ds|$$

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- PDF of transformed variables can be determined by gray level PDF of Input image and the transformation function.
- T (r) has the form

$$s = T(r) = \int_0^r p_r(w)\, dw$$

w is a dummy variable of integration.

Right side of the equation is recognized as CDF (Cumulative Distribution Function) of random variable r.

PDF are always positive and integral of a function is area under function, it follows that this transformation function is single valued and monotonically increasing and satisfies condition 1.

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- For second condition,

$$s = T(r) = \int_0^r p_r(w)\, dw \quad \ldots\ldots\ldots\ldots(1)$$

From the theory of probability

$$p_s(s) = p_r(r)\, |dr / ds| \quad \ldots\ldots\ldots\ldots(2)$$

Leibnitz rule- derivative of definite integral wrt upper limit is simply integrand evaluated at that limit.

Therefore, $ds/dr = d\,T(r) / dr$

$$= d\left[\int_0^r pr(w)\, dw\right] / dr \quad \ldots\ldots\ldots(3)$$

$$= p_r(r)$$

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- Putting in equation (2)

$$p_s(s) = p_r(r)\,|dr/ds|$$

$$= p_r(r)\,|1/p_r(r)|$$

$$= 1 \quad 0<=s<=1$$

Here, ps (s) is known as uniform probability density function.

Thus, it is proved that the form of T (r) given in equation (1) gives p_s (s) as uniform probability density function or

s is a random variable which obtained s from equation (1) gives a uniform probability density function. T (r) depends on p_r (r) but p_s (s) is always uniform.

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- For discrete values, probabilities and summations are used instead of PDFs and integrals. Probability of occurrence of gray level rk is

$$p_r(rk) = nk / n \quad k=0,\ldots,L-1$$

Discrete version of $T_r(r)$

$$sk = T(rk) = \sum_{j=0}^{k} p_r(rj)$$

$$= \sum_{j=0}^{k} nj / n \quad k=0,1,2,\ldots,L-1$$

Therefore, processed image is obtained by mapping each pixel with rk in input image into corresponding pixel with level sk in output image. This mapping is called **equalization or linearization.**

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Histogram Matching / Specification

- Histogram equalization automatically determines a transformation function that seeks to produce an output image that has uniform histogram.
- When an automatic enhancement is desired, it is a good approach, but it is useful sometimes to be able to specify the shape of the histogram that we wish the processed image to have.
- The method used to generate a processed image that has a specified histogram is called histogram matching or histogram specification.

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Development of the method

- Let r and z are continuous gray levels and random variables. $p_r(r)$ and $p_z(z)$ are PDF.
- r is the gray level of input image
- z is the gray level of output (processed) image.
- We can estimate $p_r(r)$ from the given input image, while $p_z(z)$ is the specified PDF that we wish the output image to have.
- Let s be a random variable with the property

$$s = T(r) = \int_0^r p_r(w)\, dw \quad \ldots\ldots\ldots(1)$$

w is dummy variable of integration.

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- Define a random variable z with the property

$$G(z) = \int_0^z p_z(t)\,dt = s \qquad \text{.....(2)}$$

t is a dummy variable of integration.

It follows from equation 1 and 2 that

G (z) = T (r) and therefore z must satisfy the condition

$$z = G^{-1}(s) = G^{-1}[T(r)] \qquad \text{.....(3)}$$

If p_r (r) is known T (r) can be known.

Therefore, p_z (z) is known.

G(z) can be found.

G^{-1} exists and satisfies condition 1 and 2.

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- Therefore, image with specified PDF can be obtained from input image by

1) Find T (r) from (1)
2) Find G (z) from (2)
3) Find G^{-1} (=z we wish output image to have)
4) Obtain the output image by applying (3) to all pixels.
5) The result of this procedure will be an image whose gray levels z, have the specified probability density function p_z (z).
6) Although this principle is straight forward, it is seldom possible to obtain analytical (continuous) expressions for T (r) and for G^{-1}.

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- This problem is simplified in case of discrete values.

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

$$= \sum_{j=0}^{k} n_j / n \qquad k=-,1,2,\ldots,L-1$$

n= Total number of pixels in image

nj= number of pixels with gray level rj

L = total number of gray levels

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Discrete formulation of G (z) given histogram from pz (zi) (i=0,1,…,L-1) is

$$V_k = G(z_k) = \sum_{i=0}^{k} p_z(z_i) = s_k \quad k=0,1,\ldots,L-1$$

$$z_k = G^{-1}(T(r_k)) \qquad k=0,1,\ldots,L-1$$

$$z_k = G^{-1}(s_k) \qquad k=0,1,\ldots,L-1$$

<u>**Implementation**</u>

- Represent gray levels rj, sj and zj where j=0 to L-1, in the form of a one dimensional array of dimension L x 1.
- All the mappings from r to s and s to z are in the form of table lookups between the pixel values and these arrays.

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- Each element of the table lookup contains two pieces of information.

a) The subscript k which denotes location of the element in array

b) The value of the array at the subscript

- Only integer pixel values are considered.

e.g. for 8-bit image L=256 Therefore, array range from 0 to 255.

1) Shows mapping r to s
2) Shows mapping z to v
3) Shows mapping z to s.

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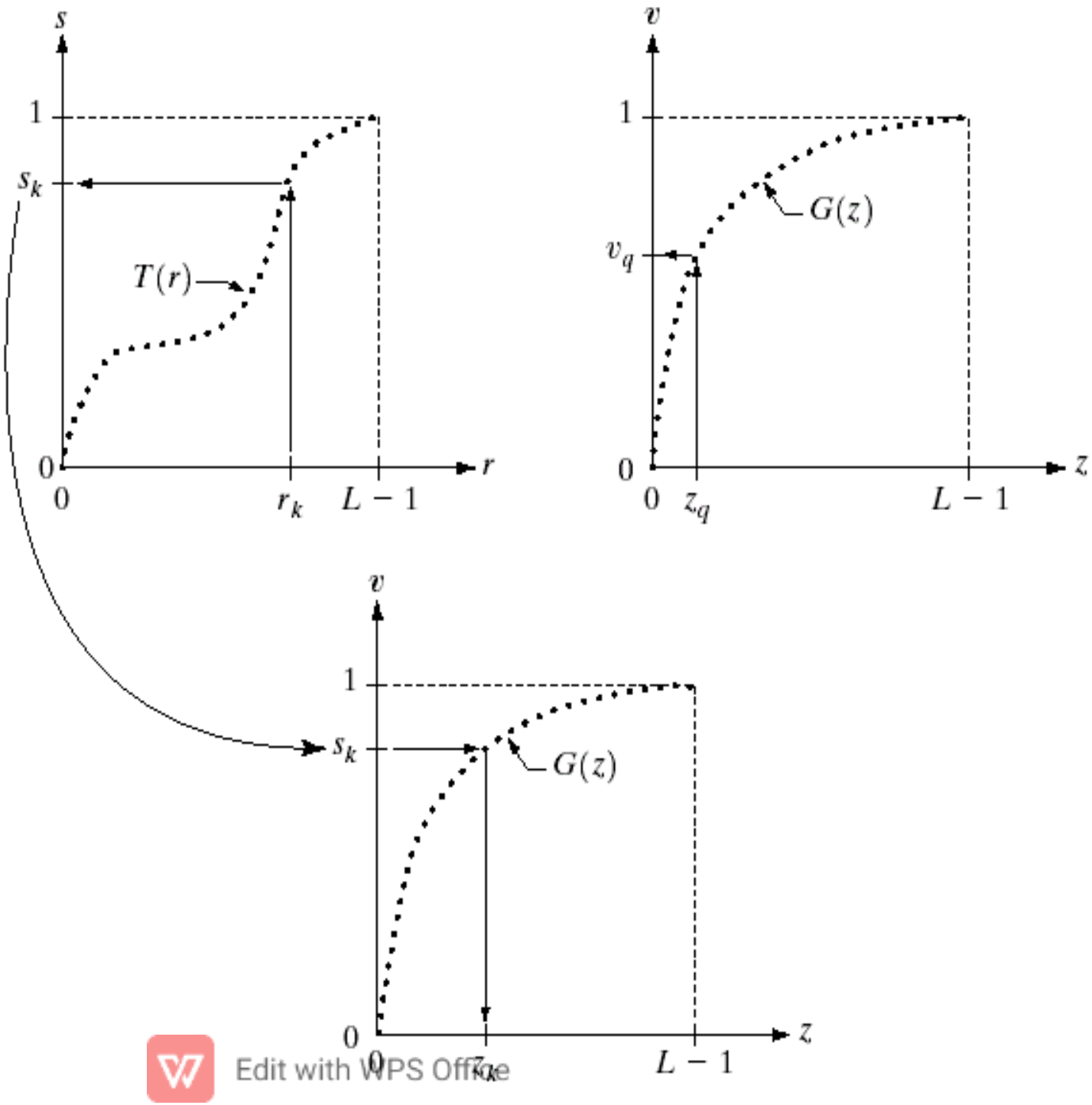
a b
c

FIGURE 3.19 (a) Graphical interpretation of mapping from r_k to s_k via $T(r)$. (b) Mapping of z_q to its corresponding value v_q via $G(z)$. (c) Inverse mapping from s_k to its corresponding value of z_k.



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- Si is computed as s = T (r)
- Vi is computed as V= G(z)
- But V=S (because T (r) = G (z))
- Therefore, same method is used for finding zk corresponding sk.
- Iterative method to find z to s.
- Vk= Sk
- G (zk) = Sk
- G (zk) – Sk = 0
- Therefore, for all values of k find zk which satisfies above equation.

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Summary

1) Since rk is given, histogram of Input image is obtained.
2) Using T (r), sk is calculated for every value of rk.
3) Obtain the transformation function g as
4)

$$G(z) = \int_{0}^{z} p_z(t)\, dt$$

4) Using the iterative scheme calculate zk for every value of sk.For that find the smallest integer in the interval [0, L-1] such that [G (zk)-sk] >=0.

Start with z=0 and increase in integer steps until the above equation is satisfied.

Repeating this process for all values of k would give the mappings of sk to zk.

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5) Therefore, for every pixel in the original image if the
6) value of that pixel is rk, map it to sk using T (r), then map sk to final zk using steps 2 and 4. The first mapping is called **histogram equalization** and the second is called **histogram specification**.

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LOCAL ENHANCEMENT

- Histogram processing methods falls under 2 categories: global and local

- **Global Enhancement**: When the pixels are modified by a transformation function based on gray level content of the entire image. Hence, enhancing complete image.

- **Local Enhancement**: When the details are to be enhanced over small areas in the image. The number of pixels in this areas do not have substantial influence on the global transformation.

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Techniques for Local Enhancement

- Device transformation function based on the gray level distribution in the neighborhood of every pixel.
- Histogram processing techniques can be easily adapted for local enhancement. Define a square or rectangle neighborhood and move the centre of this area from pixel to pixel.
- At each location, histogram of the pixels in the neighborhood is formed and then histogram equalization or specification can be used to enhance the intensity of that pixel.
- The centre of neighborhood is now moved to the next pixel and the same process is repeated.

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Enhancement using Arithmetic/ Logic Operations

- Arithmetic / Logic operations involving images are performed on a pixel by pixel basis between two or more images (excluding NOT – it is done on individual images).
- Logic operators also operate on pixel by pixel basis.
- AND, OR, NOT are functionally complete i.e. any other logic operator can be implemented by using only these 3 basic functions.
- When dealing with logic operators on grayscale images, pixel values are processed as strings of binary numbers.
- E.g. NOT on black 8-bit pixel produces white pixel (strings of 1s).

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- NOT operator performs the same function as negative transformation.
- AND and OR are used for **masking** i.e. for selecting sub-images in an image.
- In AND and OR image masks, light represents a binary 1 and dark represents a binary 0.
- Masking is sometimes referred to as region of Interest processing. (ROI).
- In terms of enhancement, masking is used to isolate an area for processing.
- This is done to highlight that area and differentiate it from rest of image.
- Out of 4 arithmetic operation, subtraction and addition are most useful.
- Division of two images is multiplication of one by reciprocal of another.
- Multiplication is used for enhancement.

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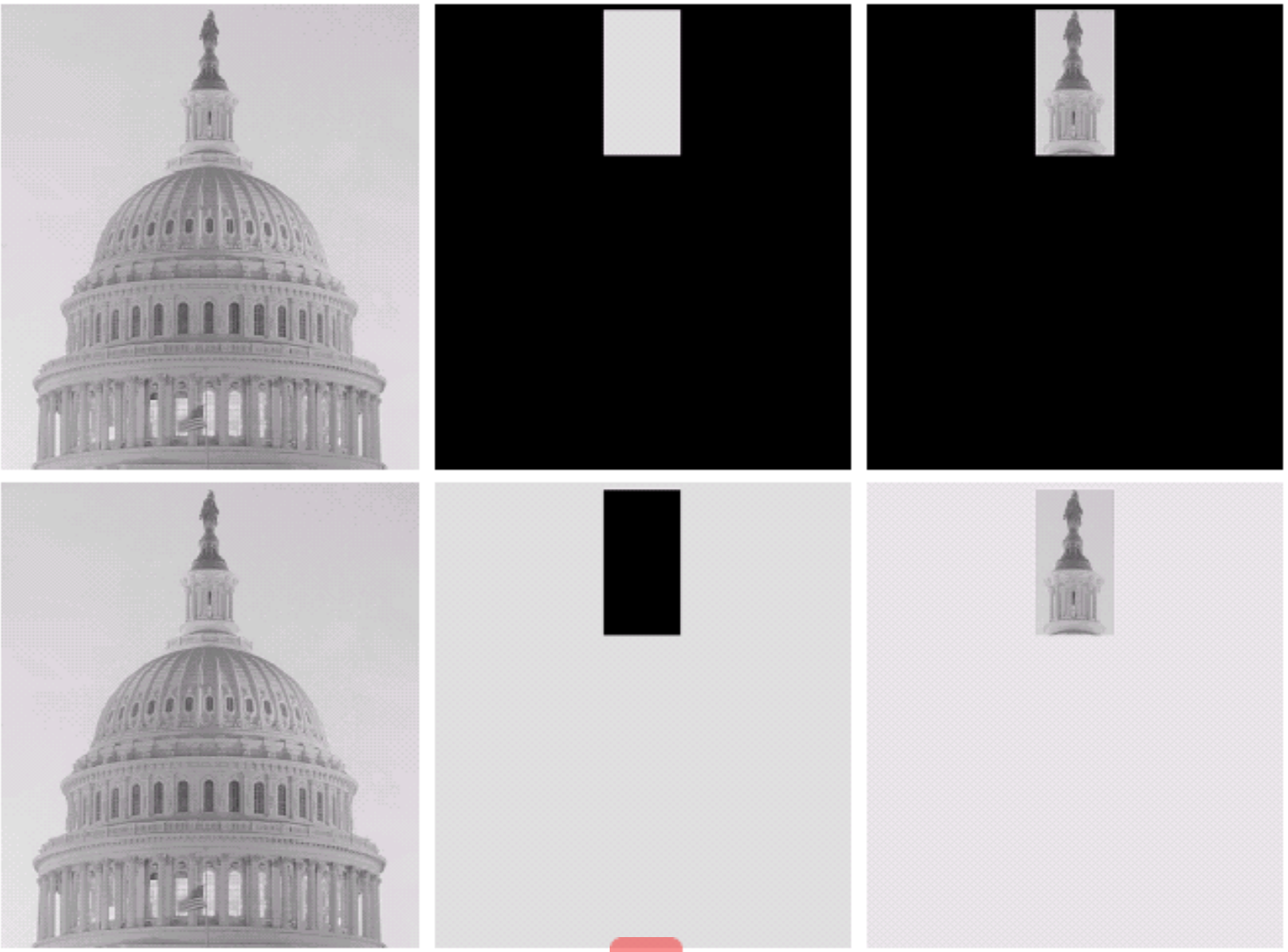
Result of AND Operation



a b c
d e f

FIGURE 3.27 (a) Original image. (b) AND image mask. (c) Result of the AND operation on images (a) and (b). (d) Original image. (e) OR image mask. (f) Result of operation OR on images (d) and (e).

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Image Subtraction

- The difference between 2 images f (x,y) and h (x,y) is

$$g(x,y) = f(x,y) - h(x,y)$$

is obtained by computing the difference between all pairs of corresponding pixels from f and h.

Key usefulness of image subtraction is the enhancement of difference between two images.

Commercially successful and beneficial uses of image subtraction is area of medical imaging called mask mode radiography (MMR).

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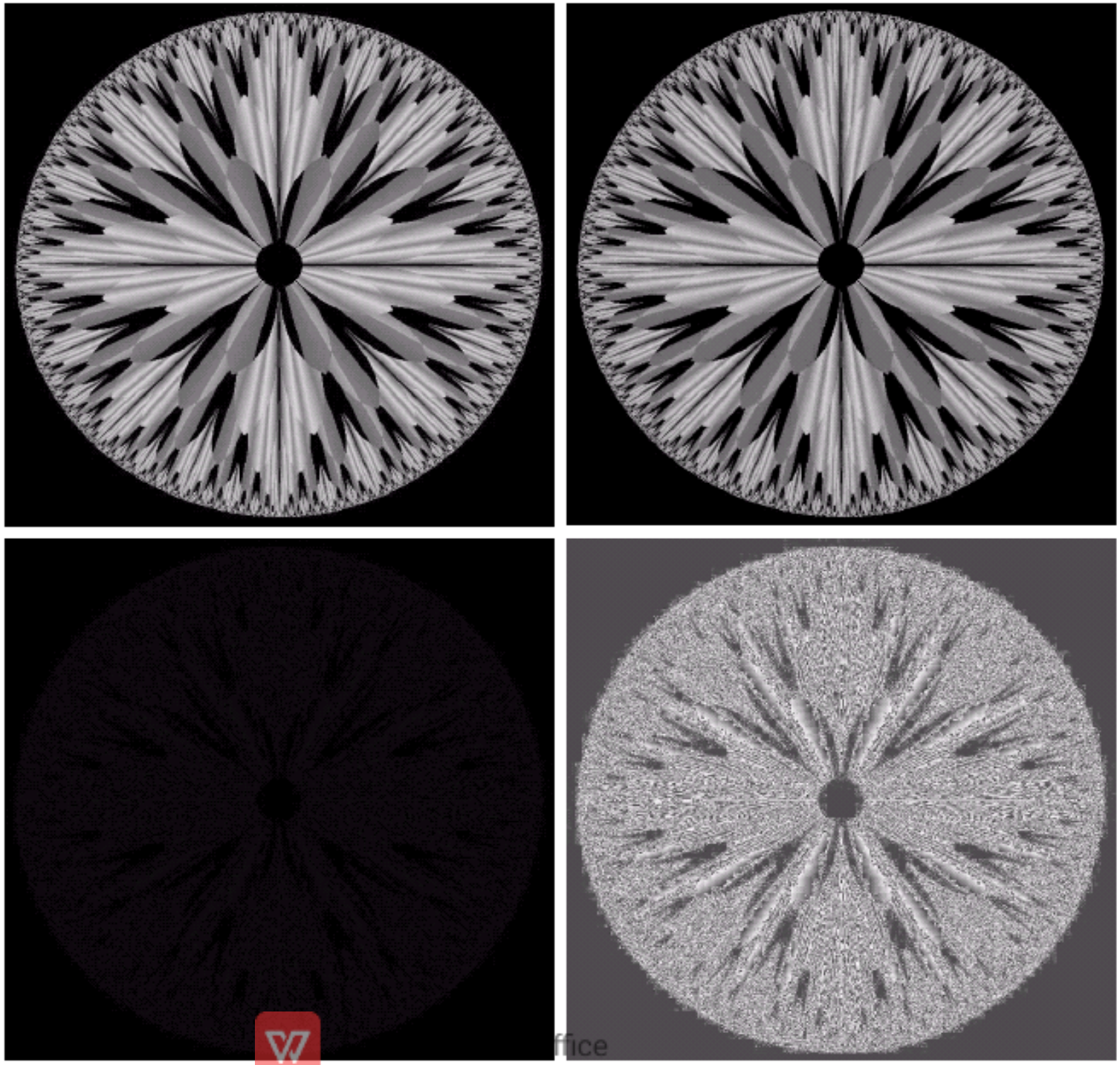
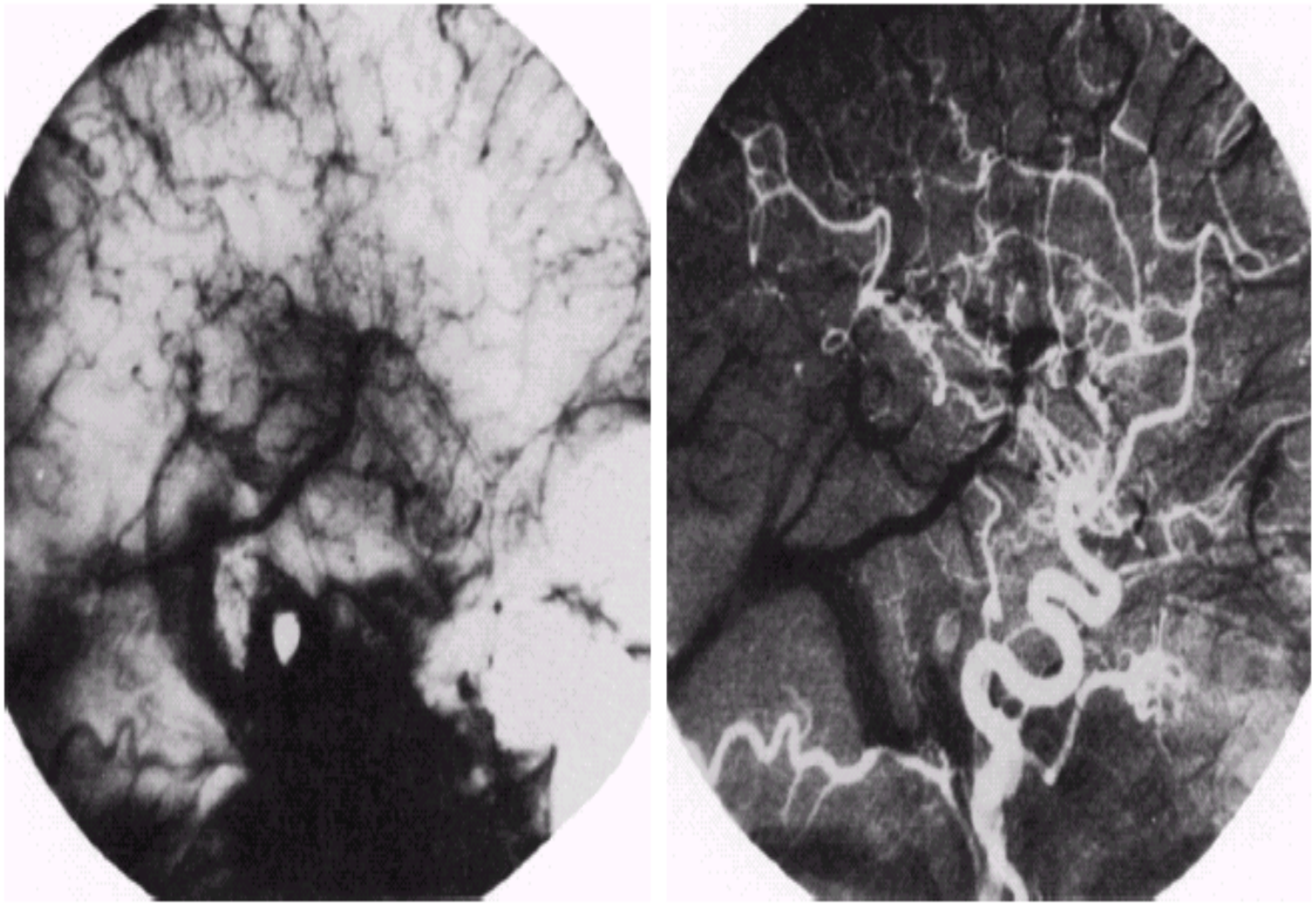


a b
c d

FIGURE 3.28 (a) Original fractal image. (b) Result of setting the four lower-order bit planes to zero. (c) Difference between (a) and (b). (d) Histogram-equalized difference image. (Original image courtesy of Ms. Melissa D. Binde, Swarthmore College, Swarthmore, PA).

Result of Image Subtraction



a b

FIGURE 3.29 Enhancement by image subtraction. (a) Mask image. (b) An image (taken after injection of a contrast medium into the bloodstream) with mask subtracted out.

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- Suppose dynamic range of image is 0 to 255. The subtracted image may contain the intensity values from -255 to +255.

To scale the difference image, 255 is added to every pixel and divided by 2.

But this does not guarantee that the graylevels occupy the complete range. Also, truncation after division by 2 results in loss of accuracy.

For full coverage and more accuracy another technique is used.

Find the minimum difference. Take negative of it and add to all the pixels in the difference image. Hence, all the pixels will be scaled to the level of 0 to 255.

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Image Averaging (Addition)

- Consider a noisy image g (x,y) formed by the addition of noise ή (x,y) to an original image f (x,y).
- Therefore, g (x,y) = f (x,y) + ή (x,y)
- The objective of the following procedure is to reduce the noise content by adding a set of noisy images { gi (x,y) }.
- If an image $\bar{g}$ (x,y) is formed by averaging k different noisy images,

$$\bar{g}(x, y) = 1/k \sum_{i=1}^{k} g_i(x,y)$$

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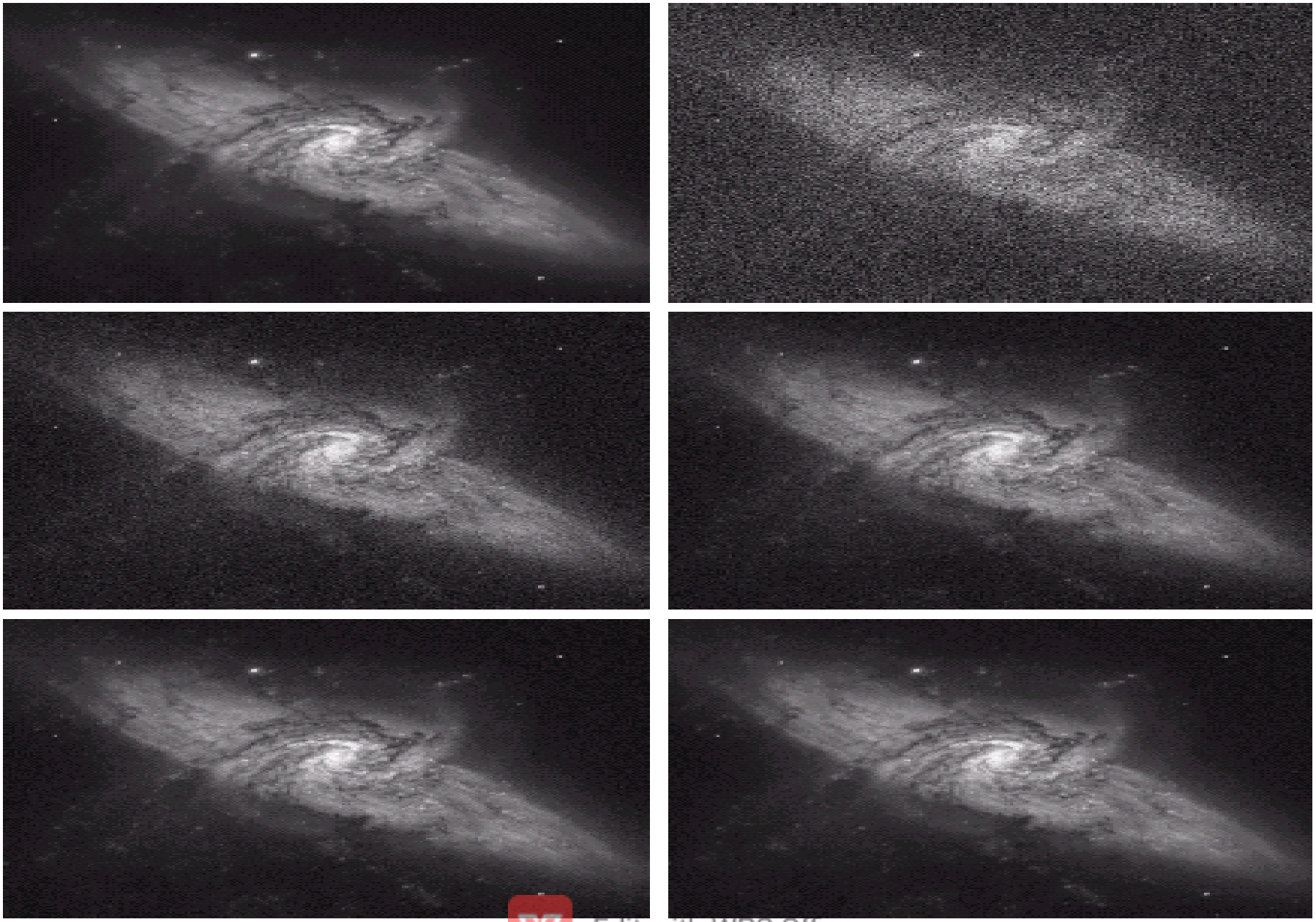
Result of Image Addition



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Basics of Spatial Filtering

- Some neighborhood operations work with the values of the image pixels in the neighborhood and the corresponding values of a sub-image that has the same dimensions as the neighborhood.
- The sub-image is called filter or mask.
- The values in a filter sub-image are referred to as co-efficients rather than pixels.
- The process consists of moving the filter mask from point to point in an image. At each point (x,y), the response of the filter at that point is calculated using a predefined relationship.

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- For linear spatial filtering, the response is given by a sum of products of the filter co-efficients and the corresponding image pixels in the area spanned by the filter mask.
- For the 3 x 3 filter mask at point (x, y) the result R of linear filtering is

$$
\begin{aligned}
R = {} & w(-1,-1)\, f(x-1,y-1) \\
& + w(-1,0)\, f(x-1,y) + \ldots \\
& + w(0,0)\, f(x,y) + \ldots + \\
& + w(1,0)\, f(x+1,y) \\
& + w(1,1)\, f(x+1,y+1)
\end{aligned}
$$

is the sum of products of the mask co-efficients with the corresponding pixels directly under mask.

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Smoothing Spatial Filters

- They are used for blurring and for noise reduction.

- Blurring is used in pre-processing such as removal of smaller details from an image prior to object extraction and bridging of small gaps in lines or curves.

- Noise reduction can be accomplished by blurring with linear filter and also by non-linear filter.

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- The output (response) of a smoothing, linear spatial filter is simply the average of the pixels contained in the neighborhood of the filter mask.
- These filters are called as averaging filters or low pass filters.
- By replacing the value of every pixel in an image by the average of the gray levels in the neighborhood defined by filter mask, this process results in an image with reduced “sharp” transitions in gray levels.
- Random noise typically consist of sharp transitions in gray levels, so obviously application of smoothing is noise reduction.
- Edges are also characterized by sharp transitions in gray levels , so averaging filters have undesirable side effect that they blur edges.
- Smoothing of false contours that result from using an insufficient number of gray levels.

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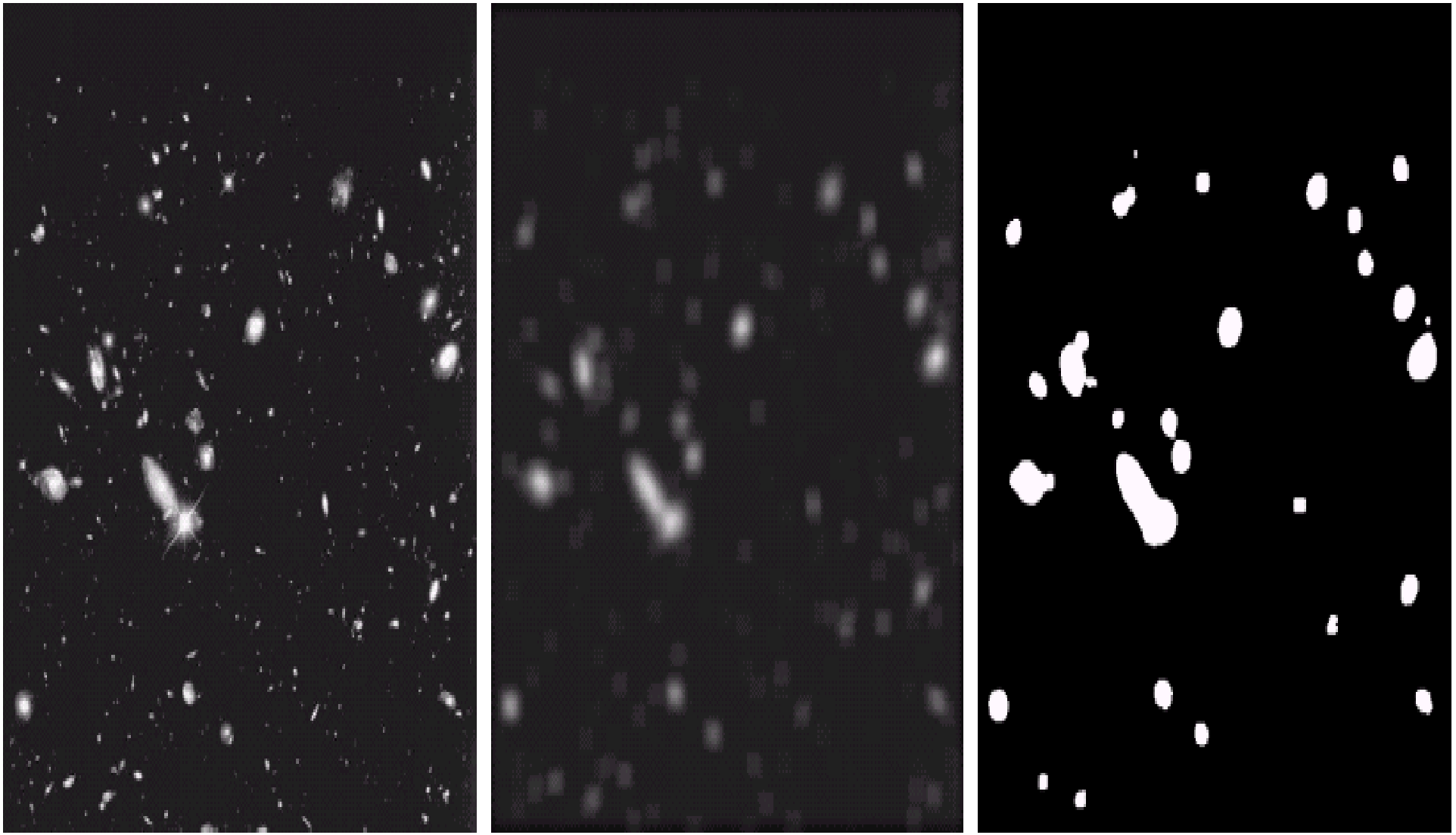

a b c

FIGURE 3.36 (a) Image from the Hubble Space Telescope. (b) Image processed by a 15 × 15 averaging mask. (c) Result of thresholding (b). (Original image courtesy of NASA.)

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Order Statistics Filters (Non-linear)

- They are non-linear spatial filters whose response is based on ordering (ranking) the pixels contained in the image area encompassed by the filter, then replacing the value of the centre pixel with the value determined by ranking result.
- E.g. Median filter which replaces the value of a pixel by the median of the gray levels in the neighborhood of that pixel.
- Median filters provide excellent noise reduction capabilities.
- They are particularly effective in the presence of impulse noise also called salt and pepper noise because of its appearance as white and black dots superimposed on an image

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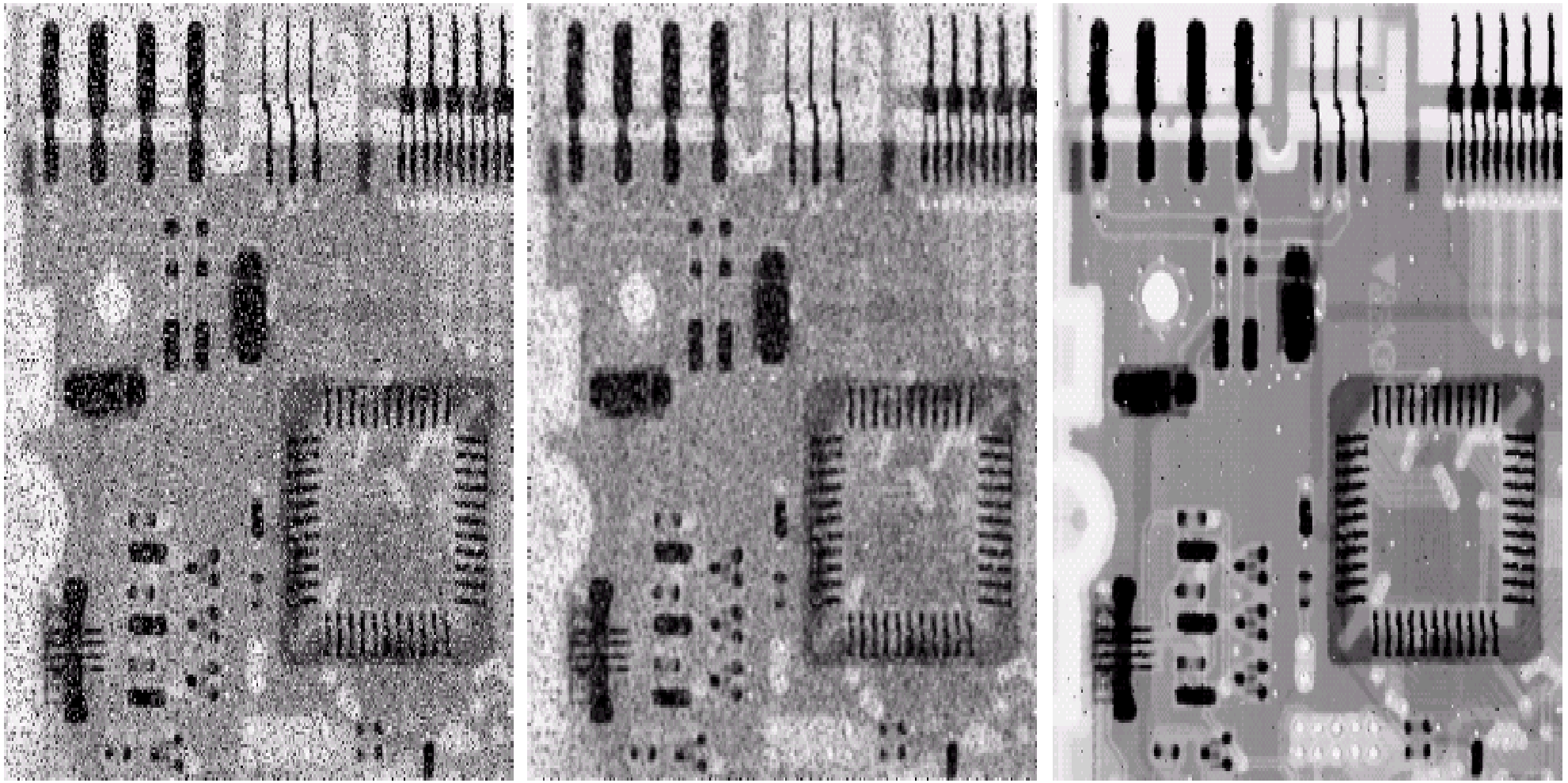

a b c

FIGURE 3.37 (a) X-ray image of circuit board corrupted by salt-and-pepper noise. (b) Noise reduction with a 3×3 averaging mask. (c) Noise reduction with a 3×3 median filter. (Original image courtesy of Mr. Joseph E. Pascente, Lixi, Inc.)

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Sharpening Spatial Filters

- Principal objective of sharpening is to highlight fine detail in an image or enhance detail that has been blurred.
- Image blurring could be accomplished in spatial domain by pixel averaging in neighborhood.
- Since averaging is analogous to integration, it is logical to conclude that sharpening could be accomplished by spatial differentiation.
- Uses: Electronic printing, Medical Imaging, Industrial Inspection, autonomous guidance in military system

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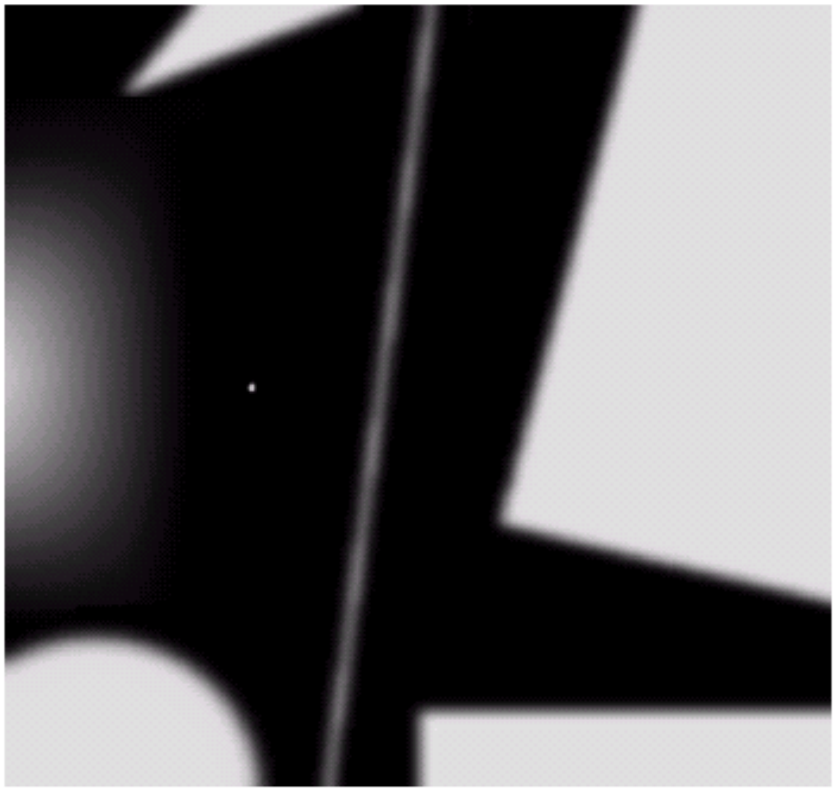
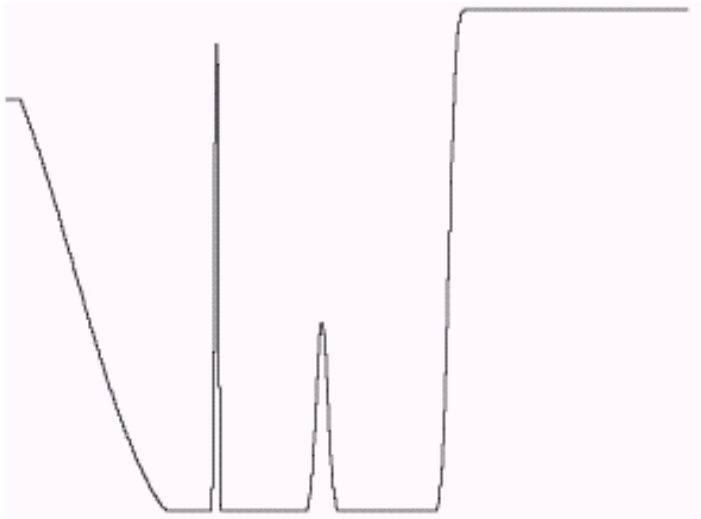
a b
c

FIGURE 3.38
(a) A simple image. (b) 1-D horizontal gray-level profile along the center of the image and including the isolated noise point.
(c) Simplified profile (the points are joined by dashed lines to simplify interpretation).





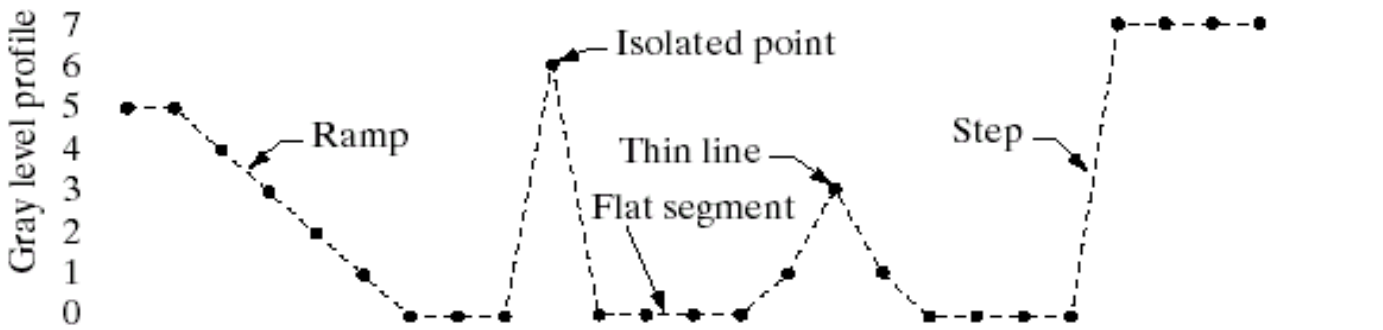


Image strip	5	5	4	3	2	1	0	0	0	6	0	0	0	0	1	3	1	0	0	0	0	7	7	7	7	•	•
First Derivative		−1	−1	−1	−1	−1	0	0	6	−6	0	0	0	1	2	−2	−1	0	0	0	7	0	0	0			
Second Derivative		−1	0	0	0	0	1	0	6	−12	6	0	0	1	1	−4	1	1	0	0	7	−7	0	0			

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- We are interested in behavior of derivatives in areas of constant gray levels (flat segments), onset and end of ramp (discontinuities). It can be used to model noise, lines and edges in an image. Behavior of derivatives during transition is also of interest.
- The derivatives of a digital function are defined in the terms of their differences.
- There are two ways to define these differences :
- I^{st} Order Derivative
- It must be 0 in flat segments (areas of constant gray level values)
- It must be non-zero along entire ramp.

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- IInd Order Derivative
- It must be 0 in flat areas.
- Non-zero at the onset of a gray level and end
- 0 along ramps of constant slope.

Basic definition of Ist Order Derivative of a 1-D function f(x) is

$$\partial f / \partial x = f(x+1) - f(x)$$

Definition of IInd Order Derivative

$$\partial^2 f / \partial x^2 = f(x+1) + f(x-1) - 2 f(x)$$

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Observations

- The image profile has been scanned from left to right and the Ist and IInd order derivatives were found.
- Ist Order Derivative in non-zero along entire ramp, whereas IInd order Derivative is non-zero only at onset and end of ramp.
- Edges in an image follow this type of transitions.
- Therefore, Ist Order Derivative produces thick edges and IInd Order Derivative produces fine edges.
- Second Order derivative is much more aggressive than Ist order derivative to enhance sharp changes.
- Response of the two derivatives is same at gray level steps.

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Laplacian Operator

- Laplacian is a derivative operator used to highlight gray level discontinuities and highlight the reasons with slow gray levels.
- Background features can be recovered preserving the sharpening effect simply by adding the original and laplacian images.
- Whether the original and laplacian image will be added or subtracted will depend on what type of laplacian operator is used.
- If operator with centre co-efficient negative is used , they are subtracted otherwise added.
- Original image – does not have sharpened boundaries and edges but has rest information
- Laplace image- Has only sharpened boundaries and edge and nothing inside. (-ve of photo)
- So we add both these image to get better picture.

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Unsharp masking and High boost Filtering

- A process used for many years in publishing industry to sharpen images consists of subtracting a blurred version of an image from the image itself. This process is called unsharp masking expressed as

  $f_s(x,y) = f(x,y) - \bar{f}(x,y)$ 1

  Where, $f_s(x,y)$ denotes the sharpened image obtained by unsharp masking and $\bar{f}(x,y)$ is blurred version of $f(x,y)$

  Joining together a blurred negative to a corresponding positive film and then developing this combination to produce a sharper image.

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- Further generalization of unsharp masking is called high boost filtering.
- A high boost filtered image f_{hb} is defined at any point (x, y) as

$$f_{hb}(x,y) = A\, f(x,y) - \bar{f}(x,y)$$

Where A>=1 and $\bar{f}$ is blurred version of f.

Equation may be written as

$$f_{hb}(x,y0 = (A-1)\, f(x,y) + f(x,y) - \bar{f}(x,y)$$

By using eq. 1 we can write

$$f_{hb}(x,y) = (A-1)\, f(x,y) + f_s(x,y)$$

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Spatial Domain

- Point Processing
  - Negation, Power Law, Log
  - Bit plane, Gray level slicing
  - Contrast Stretching
- Filtering
  - Smoothing
    eg. Averaging , statistics
  - Sharpening
    1st and 2nd order derivatives

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4. Image Enhancement in Frequency Domain

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Frequency- Number of times a periodic function repeats itself per unit change in the independent variable.

Periodic Function:- Function which have uniform structure throughout.

Fourier Series :- Any function that periodically repeats itself can be expressed as a sum of sines and cosines of different frequencies each multiplied by a constant factor. This sum is known as Fourier series.

Fourier Transform:- The function which are not periodic but finite can be expressed as integral of sines and cosines multiplied by weighting function. This is known as Fourier transform.

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- Functions expressed in either Fourier series or Fourier transform can be reconstructed completely via inverse process with no loss of information.

- We will deal only with functions (images) of finite duration, so we are interested in Fourier transform. Fourier transform provides some ways to study and implement image enhancement techniques.

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1-D Fourier Transform and its Inverse

- F (u)- Fourier Transform

f (x)- single variable continuous function (image)

1-D Fourier transformation equation

$$F(u) = \int_{-\infty}^{+\infty} f(x)\, e^{-j\,2\Pi ux}\, dx$$

Where j= √-1

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1-D Inverse Fourier Transform

$$f(x) = \int_{-\infty}^{+\infty} F(u)\, e^{j2\Pi ux}\, du$$

Given F (u) we can obtain f (x) by inverse Fourier transform. These two equations is Fourier transform pair. It shows function (image) can be recovered from Fourier transform.

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Discrete Fourier Transform

f (x) – discrete function for one variable

x = 0,1,2,...,M-1

$$F(u) = 1/M \sum_{x=0}^{M-1} f(x)\, e^{-j2\Pi ux / M}$$

u= 0,1,2,...,M-1

Inverse

$$f(x) = \sum_{u=0}^{M-1} F(u)\, e^{j2\Pi ux /M}$$

x= 0,1,2,...,M-1

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- **Frequency Domain**

  Each term of the Fourier transform is composed of sum of all values of function f (x).

  The values f (x) are multiplied by sines and cosines of various frequencies. The domain over which the values of F (u) lies is known as **frequency domain**.

  u is frequency of all the components of transform.

  Each term **M** of F (u) is called frequency component of transform.

Fourier transform can be compared with a glass prism.

A prism separates light into various color components each containing different wavelength and frequency.

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- It is a mathematical prism which separates a function (image) into various components each component having different frequency. This concept will be used for filtering purpose.
- Since components of Fourier transform are complex quantities, so we express F (u) in polar co-ordinates.
    - **Magnitude of Fourier transform**:
- **F (u) in polar co-ordinates**

$$F(u) = |F(u)| e^{-j\Phi(u)}$$

where, $|F(u)| = [R^2(u) + I^2(u)]^{1/2}$

and $\Phi(u) = \tan^{-1}(I(u) / R(u))$ is **phase angle or phase spectrum of transform.**

- $P(u) = |F(u)|^2$ Spectral density or Power spectrum
- R (u) and I (u) are real and imaginary part of F (u) respectively.

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2-D DFT and its Inverse

- f (x,y) 2D function (image)
- x=0,1,...,M-1
- y=0,1,2,...,N-1

$$F(u,v) = 1/MN \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)\, e^{-j2\Pi(ux/M + vy/N)}$$

u=0,1,...,M-1

v=0,1,...,N-1

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Inverse

$$f(x,y) = \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u,v)\, e^{j2\Pi(ux/M + vy/N)}$$

u, v frequency variable of image

x,y spatial variable of image (function)

Edit with WPS Office

Fourier transform in 2D

- $I\ F(u,v)I = [R^2\ (u,v) + I^2\ (u,v)]^{1/2}$

- Phase angle in 2D

$$\Phi(u,v) = \tan^{-1}\ [\ I\ (u,v)\ /\ R\ (u,v)]$$

Power Spectrum

$$P\ (u,v) = IF(u,v)I^2$$

$$= R^2\ (u,v) + I^2\ (u,v)$$

R (u,v) –Real part of F (u,v)

I (u,v)- Imaginary part of F (u,v)

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- **Important**
- Before finding the Fourier transform, the function is multiplied by $(-1)^x$ in case of 1D f (x) and $(-1)^{x+y}$ in case of 2D f (x,y).
- This is done to shift the Fourier transform at centre.

- Frequency in image depends on the change in intensity.
- If in some part gray levels are almost same then frequency is less otherwise in abrupt changes frequency is more
- Noise also have frequencies.

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- Fourier transform of a function f (x,y) multiplied by

$(-1)^{x+y}$ is given as F(u-M/2 , v-N/2)

F (0,0) = F(u-M/2 , v-N/2)

u – M/2 =0 v-N/2 =0

u = M/2 v= N/2

If the size of the image is M x N the frequency at centre will be u,v

$$F(u,v) = 1/MN \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)\, e^{-j2\Pi(ux/M + vy/N)}$$

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- When u=0 and v=0

$$F(0,0) = 1/MN \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)$$

This is the average of f (x,y).

At the centre the average of image is there and as you go far it becomes sharper.

If f (x,y) is an image, the value of Fourier transform at the origin is equal to average gray level of image.

Since both the frequencies are 0 at centre, f(0,0) is also known as **dc** component of the spectrum.

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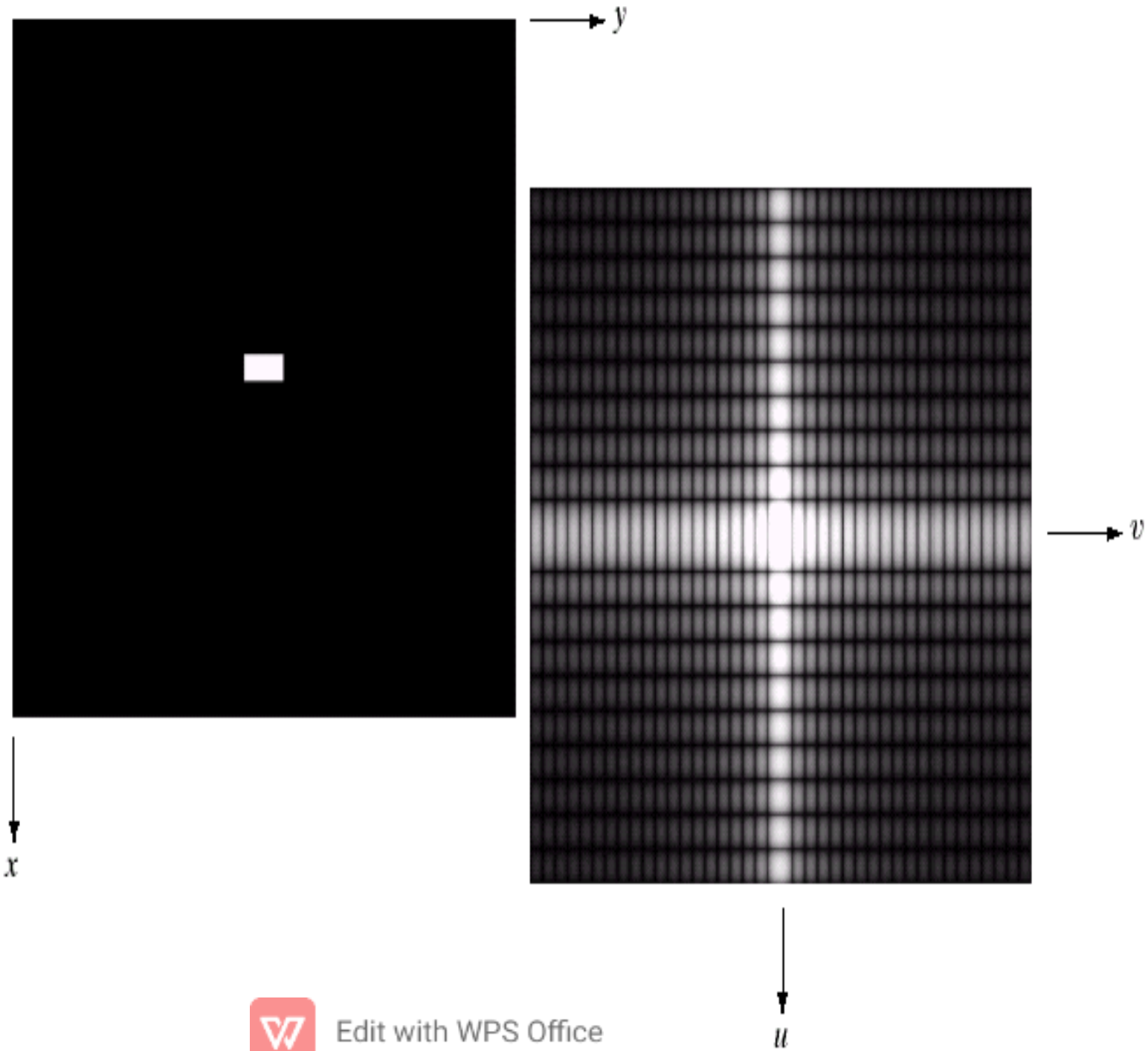
a b

FIGURE 4.3
(a) Image of a 20×40 white rectangle on a black background of size 512×512 pixels.
(b) Centered Fourier spectrum shown after application of the log transformation given in Eq. (3.2-2). Compare with Fig. 4.2.



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- Image is multiplied by $(-1)^{x+y}$ prior to computing Fourier transform to centre the spectrum.
- The separation of spectrum zeros in u direction is twice than v direction because of rectangle.
- Spectrum is enhanced by log function to enhance gray level detail.

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Properties of Frequency Domain

1) Each term of F (u,v) contains modified form of f (x,y). The Fourier transform is centered at the origin.
2) The frequency (0,0) corresponds to average gray level of the image.
3) As we move away from the origin low frequencies occur. These corresponds to slowly varying components of the image. As we move further away the higher frequencies occur which corresponds to faster and faster gray level changes in the image. E.g. edges and noise.

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Basic Steps for Filtering in frequency domain

1) Multiply the input image (function) by $(-1)^{x+y}$ to centre the transform.
2) Compute F (u,v) i.e. the DFT of image.
3) Multiply by a filter function H (u,v)
4) **G (u,v) = F (u,v) H (u,v)**
5) Compute inverse of DFT in step 3 to get f (x,y)
6) Obtain the real part in step 4.
7) Multiply result of 5 by $(-1)^{x+y}$.

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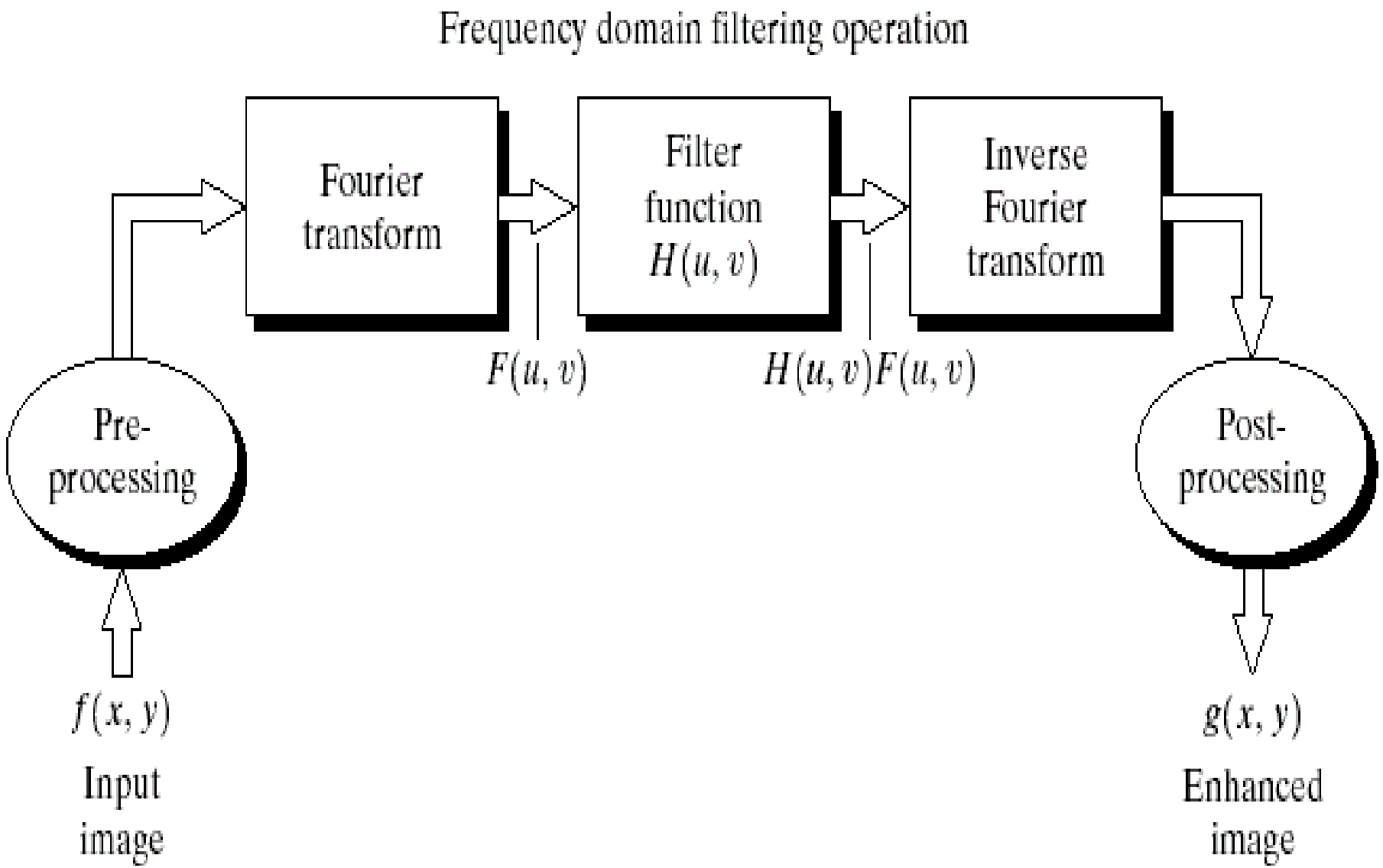

FIGURE 4.5 Basic steps for filtering in the frequency domain.

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- H (u,v) is called filter because it allows some frequency while suppresses others.

$$G(u,v) = F(u,v)\,H(u,v)$$

- Multiplication is on step by step basis.
- Each component of H multiplied by each component of F.
- H is real, gets multiplied by both real and imaginary part of F.

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Basic Filters

- **Low Pass Filters** :- Allows low frequency, used for blurring or smoothing
- **High Pass Filters** :- Allows high frequency , used for sharpening
- Since the low frequencies are responsible for general gray level appearance, the low pass filters are those which passes low frequencies and stops high frequencies. Thus, blurring or smoothing the image.
- High frequencies are responsible for minute details, edges and noise. Therefore the high pass filters attenuates (makes thinner or weaker) low frequencies and allows high frequencies. Thus, sharpening the image.

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- **Notch Filter (empty area or hole)**

$$H(u,v) = 0 \quad \text{if } (u,v) = (M/2, N/2)$$
$$= 1 \quad \text{otherwise}$$

This filter is known as notch filter because it creates a notch or a hole at the origin. Drop in overall average graylevel.

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Smoothing Frequency Domain Filters

Low Pass Filters

Ideal (very sharp)

Butterworth

Gaussian (very smooth)

Edges and Noise have high frequency, so blurring / smoothing is required , so attenuate high frequency of F (u,v).

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1). <u>Ideal Low Pass Filters</u> (very sharp)

Define a frequency or distance **Do** from centre of transform known as **cut off frequency**.

$$H(u,v) = 1 \quad \text{if } D(u,v) <= Do$$
$$= 0 \quad \text{if } D(u,v) > Do$$

D (u,v) is distance from (u,v) to origin of frequency rectangle.

Size of frequency rectangle (image) is M x N

Centre will be M/2, N/2.

Instead of value we consider the distance from the centre.

Distance from (u,v) to origin (centre)

$$D(u,v) = ((u-M/2)^2 + (v-N/2)^2)^{1/2}$$

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where, (u,v) is frequency of point

(M/2, N/2) is frequency at centre.

The ideal filter indicates that all the frequencies inside a circle with radius Do are passed and others are attenuated .

Fourier transform is symmetric about centre so, a circle is formed of radius Do.

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2). Butterworth low pass filters

Do :- distance of cutoff frequency

n :- order of filter

$$H(u,v) = 1 / \; 1 + [D(u,v) / Do]^{2n}$$

As n increases, BLPF goes more and more closer to ILPF.

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3). **Gaussian Low pass filters**

$$H(u,v) = e^{-D2(u,v)/2\sigma 2}$$

σ is measure of Gaussian Curve.

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Sharpening Frequency Domain Filters

- High Pass Filters

  $$H_{hp}(u,v) = 1 - H_{lp}(u,v)$$

Ideal High Pass Filters

$$H(u,v) = 0 \text{ if } D(u,v) < Do$$
$$= 1 \text{ if } D(u,v) > Do$$

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2). Butterworth High Pass Filters

$$H(u,v) = 1/\ 1+ (Do / D(u,v))^{2n}$$

3). Gaussian High Pass Filters

$$H(u,v) = 1-e^{-D2(u,v) / 2\sigma 2}$$

$$\sigma = Do^2$$

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5. Image Restoration

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- We do not have the original image but have an image which has been degraded or corrupted due to any reasons and we have to remove.

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Model of Image Degradation / Restoration Process

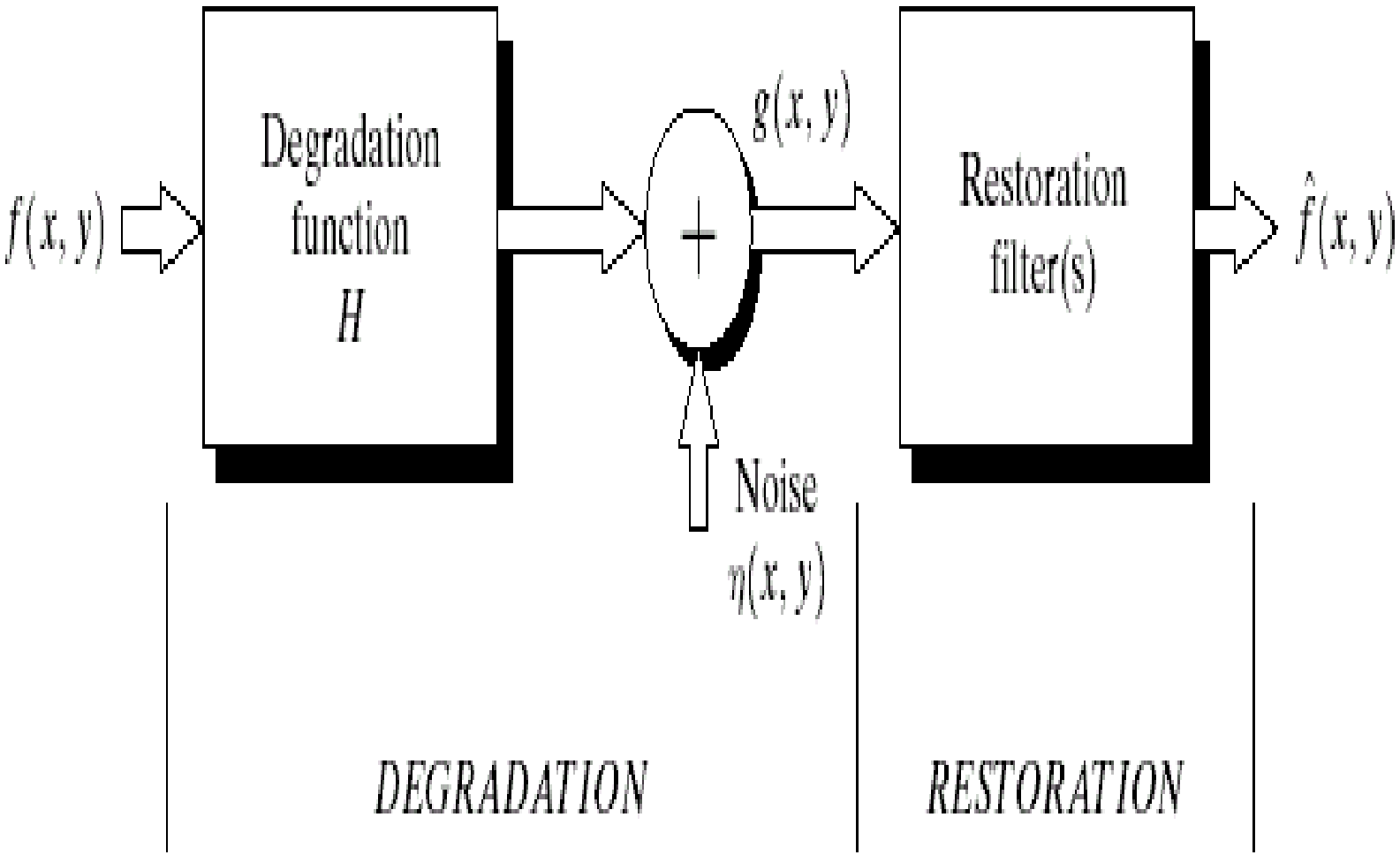

FIGURE 5.1 A model of the image degradation/ restoration process

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- f (x,y) :- Input Image
- g (x,y) :- Degraded Image
- h (x,y) :- Degradation Function
- η :- Noise
- Given g (x,y), some knowledge about degradation function and noise , objective of restoration is to obtain an estimate of original image. More we know about g and η more we are closer to f (x,y).

$$g(x,y) = h(x,y) * f(x,y) + \eta(x,y)$$

$$G(u,v) = H(u,v) * F(u,v) + N(u,v)$$

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Noise

- **Sources of Noise**

➤ During digitization and or during transmission

➤ Performance of sensors.

➤ Conditions like light levels, sensor temperature, interference with transmission channels, lightning and atmospheric disturbances during wireless transmissions.

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Spatial and Frequency properties of Noise

- Noise is a random variable.
- **WHITE NOISE** :- When Fourier spectrum of noise is constant.
- Noise is independent of spatial co-ordinates uncorrelated with intensity levels.

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Noise probability density functions

- Gaussian Noise (Normal noise)
- Rayleigh Noise
- Erlang (Gamma) Noise
- Exponential Noise
- Uniform Noise
- Impulse Noise (Salt and Pepper Noise)

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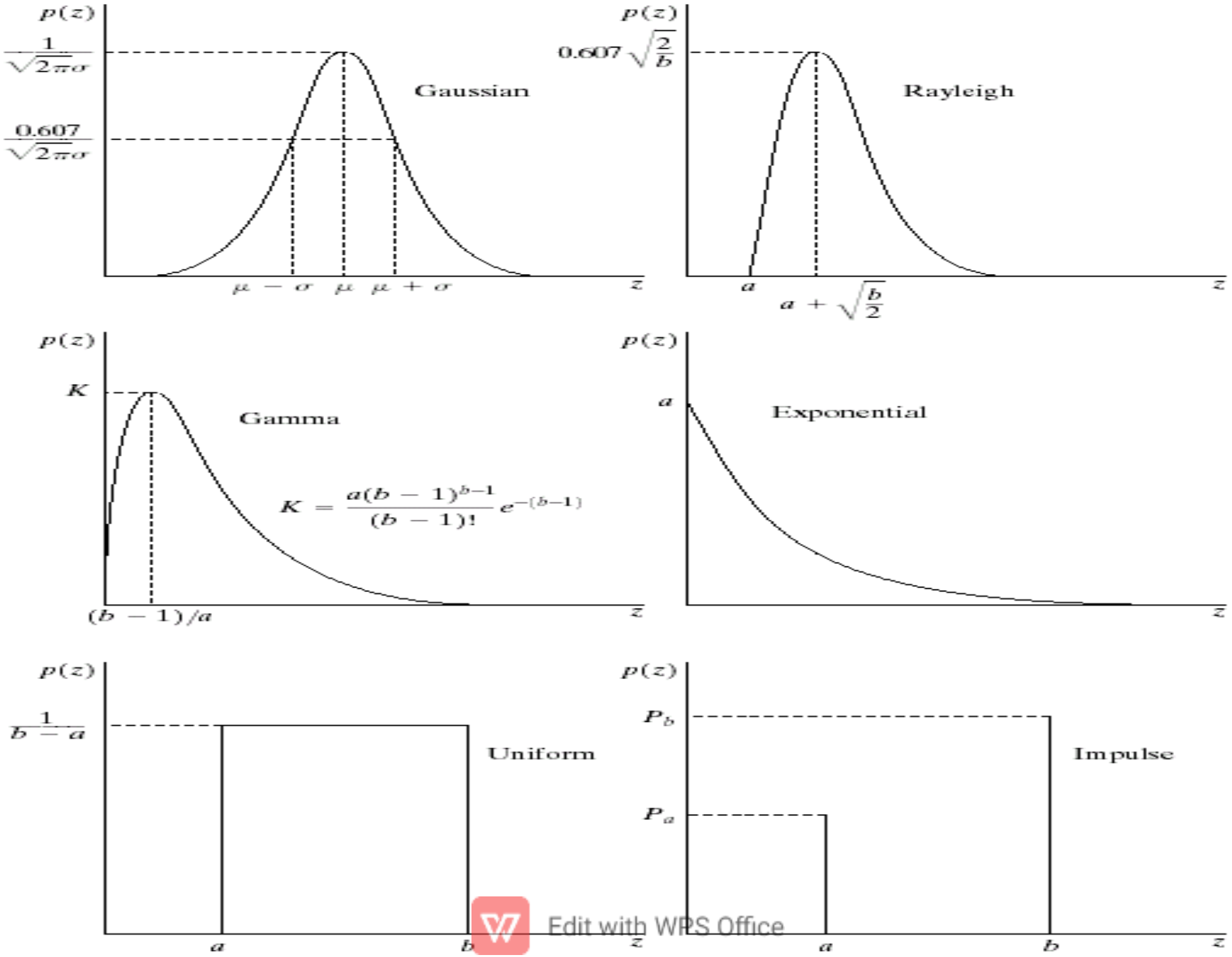

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Spatial Filtering

- Restoration in presence of Noise only

1) Mean Filters
   - Arithmetic mean filters
   - Geometric mean filters
   - Harmonic mean filters
   - Contra harmonic mean filters
2) Order Statistics Filters
   - Median
   - Max and Min
   - Midpoint
   - Alpha trimmed
3) Adaptive Filters
   - Adaptive Local Noise Reduction Filters
   - Adaptive Median Filter

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Mean Filters

1) **Arithmetic Mean Filter**

$$\hat{f}(x,y) = 1/mn \sum_{(s,t) \varepsilon S_{x,y}} g(s,t)$$

$S_{x,y}$:- set of co-ordinates in rectangular subimage window of size m x n

g (x,y):- corrupted image

- Simplest mean filter.
- Noise is reduced as a result of blurring.

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2) **Geometric mean filter**

$$\hat{f}(x,y) = \left[\prod_{(s,t)\varepsilon S_{x,y}} g(s,t) \right]^{1/mn}$$

- More smoothing than previous but tends to lose less image details

3) **Harmonic mean filter**

$$f(x,y) = mn / \sum_{s,t\ \varepsilon\ S_{x,y}} 1/g(s,t)$$

- Works well for salt noise but fails for pepper noise.
- Does well for Gaussian noise.

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4) Contra harmonic mean filter

$$\hat{f}(x,y) = \sum_{(s,t)\,\varepsilon\, S_{x,y}} g(s,t)^{Q+1} \Big/ \sum_{(s,t)\,\varepsilon\, S_{x,y}} g(s,t)^{Q}$$

- Well suited for reducing or eliminating effects of salt and pepper noise.

Q :- Order of filter

Q>0 :- Pepper noise

Q<0 :- Salt noise

Q =0 :- Arithmetic mean

Q = -1 :- Harmonic mean

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Order Statistics Filter

1) **Median filter**

$$\hat{f}(x,y) = \underset{(s,t) \varepsilon S_{x,y}}{\text{median}} \; g(s,t)$$

- Replaces pixel value by median of gray levels in neighborhood.
- Appropriate for impulse noise.

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2) Max and Min filters

Max :- finding brightest points in image. Pepper noise is removed

$$\hat{f}(x,y) = \max_{(s,t)\varepsilon S_{x,y}} \{ g(s,t) \}$$

Min :- Finding darkest point in image. Reduce salt noise.

$$\hat{f}(x,y) = \min_{(s,t)\varepsilon S_{x,y}} \{ g(s,t) \}$$

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3) Midpoint filter

$$\hat{f}(x,y) = \frac{1}{2}\left[\max_{(s,t)\varepsilon S_{x,y}} \{g(s,t)\} + \min_{(s,t)\varepsilon S_{x,y}} \{g(s,t)\}\right]$$

- Combines order statistics and average filter.
- Best for random noise like Gaussian or uniform noise.

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4) Alpha trimmed mean filter

$$\hat{f}(x,y) = 1/mn-d \sum_{(s,t)\varepsilon S_{x,y}} g_r(s,t)$$

Remove d/2 lowest gray level values.

Remove d/2 highest gray level values.

g_r (s,t) represents remaining mn-d pixels

d can range from 0 to mn-1

d=0 means mean filter

d= (mn-1)/2 means median filter

Useful in case involving multiple types of noise like salt and pepper , Gaussian noise.

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Adaptive Filters

- Behavior changes according to statistical characteristics of filter inside defined by window Sx,y of area mxn.
- **Adaptive Local Noise Reduction Filter:**
- Consider a local region Sx,y.
- Response of filter at any point (x,y) is based on four quantities.

1) g (x,y) :- value of noisy image at (x,y)
2) $\sigma^2 n$:- variance of noise corrupting f (x,y) to form g (x,y)
3) m_L :- local mean of pixels in Sx,y
4) σ^2_L :- local variance of pixels in Sx,y

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Behavior is as follows:-

- If $\sigma^2 n = 0$, filter returns value of g (x,y). This is zero noise case where g (x,y) = f (x,y)

- $\sigma^2_L > \sigma^2 n$ filter returns value close to g (x,y). High local variance is associated with edges, and should be preserved.
- If two variances are equal, filter returns Arithmetic mean of value of pixels in Sx,y.
- It occurs when local area has same property as overall image and local noise has to be reduced by averaging.

$$\hat{f}(x,y) = g(x,y) - \sigma^2 n / \sigma^2_L \; [\, g(x,y) - m_L]$$

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- If $\sigma^2 n = 0$ then $\hat{f}(x,y) = g(x,y)$
- $\hat{f}(x,y)$ is adaptive expression for obtaining $\hat{f}(x,y)$ based on above assumptions.
- It is not possible to have the exact value of $\sigma^2 n$. Therefore, wherever $\sigma^2 n > \sigma^2_L$ the ratio is made to 1 but this produces negative gray level values because of lack of knowledge about the variance of noisy image. For that the gray level values can be scaled at end. This will result in dynamic loss of the image.

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Adaptive median filter

- It is used for removing impulsive noise.
- The special property of this filter is the size of the filter increases during the filter operation.
- Sx,y :- rectangular window area
- zmin:- minimum gray level value in Sx,y (if 0 black pepper noise)
- zmax:- maximum gray level value in Sx,y (if 255 white salt noise)
- zmed:- median of gray level in Sx,y
- zx,y :- gray level of co-ordinates (x,y)
- Smax:- maximum allowed size of Sx,y

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ALGORITHM

- **LEVEL A:-**
- A : A1= zmed – zmin

  A2= zmed – zmax

If A1>0 and A2<0 goto LEVEL B (zmin< zmed < zmax i.e. not an impulse)

else

increase size of window

If window size <= Smax repeat LEVEL A

else

output zx,y

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- **LEVEL B :-**

  B1 = zx,y −zmin

  B2 = zx,y − zmax

If B1>0 and B2<0 output zx,y (zmin < zx,y < zmax i.e. not impulse)

else

output zmed

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- The purpose of LEVEL A is to find if the median (zmed) filter output is impulse or not.
- The condition in LEVEL A is used to check that median is not an impulse.
- If zmed is proper i.e. not impulse then we go to LEVEL B to check if zx,y i.e. point in the centre of filter is itself an impulse.
- If zx,y is an impulse then the median calculated in LEVEL A is the output else zx,y is the output.
- If LEVEL A finds to be an impulse the algorithm increases the size of the window and LEVEL A is repeated.
- The loop continues until non- impulsive median is found or the size of the window has reached up to the maximum level.

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- After one element zx,y is processed the filter moves to next element. This way whole image is processed.

- The purpose of this algorithm is
- Remove impulsive noise
- Smoothen out other types of noise
- Reduce distortion like excessive thinning or thickening of boundaries.
- The values zmin and zmax are considered as impulsive noise components.

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PERIODIC NOISE REDUCTION BY FREQUENCY DOMAIN FILTERING

PERIODIC NOISE :- It arises from electrical and electromechanical interference during image acquisition. This is the only type of noise which is spatially dependent. This noise has various frequencies and hence the Fourier transform can be found. It won't be constant.

Filters for removing periodic noise

- Band Reject Filters
- Band Pass Filters

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BAND REJECT FILTERS

- Removes or attenuates band of frequencies about origin of Fourier Transform. It is given by the expression

$$
\begin{aligned}
H(u,v) &= 1 \quad \text{If } D(u,v) < Do - W/2 \\
&= 0 \quad \text{If } Do - W/2 <= D(u,v) <= Do + W/2 \\
&= 1 \quad \text{if } D(u,v) > Do + W/2
\end{aligned}
$$

D(u,v) is distance from origin of frequency

W= width of band

Do = Radial centre

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- Butterworth Band Reject of order n
- Gaussian Band Reject filter

Band Pass Filters

(Performs opposite of Band Reject)

$$
\begin{aligned}
H(u,v) &= 0 \quad \text{If } D(u,v) < Do - W/2 \\
&= 1 \quad \text{If } Do - W/2 <= D(u,v) <= Do + W/2 \\
&= 0 \quad \text{if } D(u,v) > Do + W/2
\end{aligned}
$$

Isolates the effect of an image of selected frequency bands.

Allows certain band (of width w) of frequencies.

$$B_{PF} = 1 - B_{RF}$$

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Estimating the Degradation Function

- ✔ Estimation by observing
- ✔ Estimation by experiment
- ✔ Estimation by modeling

Blind Convulation:- Process of restoring an image by using a degradation function which has been estimated by some means is called blind convulation because in estimating process the actual degradation function is not known.

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1) **Estimation by image observation**

One way to estimate the degradation function while the degraded image is known is to get the information form the image itself. We would look for areas with strong signal.

e.g. if the image is blurred a small section of an image can be taken using the gray levels and the background.

We can construct unblurred image of the same size and characteristics as observed of sub image.

Let the observed sub image represented by gs(x,y), the constructed sub image represented by $\hat{f}s(x,y)$ assuming the noise to be negligible the degradation function can be obtained as

$$Hs(u,v) = Gs(u,v) / \hat{F}s(u,v)$$

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2) **Estimation by experimentation**

If the equipment similar to the equipment used to acquire the degraded image is available it is possible to obtain accurate estimation of degradation. The idea is to obtain the impulse response of degradation by imaging an impulse using the same system settings.

An impulse is simulated by bright dot of light. If the strength of impulse is A, then the Fourier transform of degradation function is given as

$$H(u,v) = G(u,v) / A$$

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3) **Estimation by modeling**

Degradation modeling is used to take into account environmental conditions which cause degradation.

e.g. A degradation model based on physical characteristics of atmospheric turbulence is given by

$$H(u,v) = e^{-k(u2+v2)5/6}$$

k is known as turbulence factor

k=0.0025 severe turbulence

k=0.001 mild turbulence

k=0.00025 low turbulence

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Inverse Filtering

Simplest approach to restoration is direct inverse filtering , where,

$\hat{F}(u,v)$ = transform of estimated image

$G(u,v)$ = transform of degraded image

$H(u,v)$ = transform of degradation function

$$\hat{F}(u,v) = G(u,v) / H(u,v)$$

Divisions are between individual elements of function

$$\hat{F}(u,v) = F(u,v) + N(u,v) / H(u,v)$$

$G/H = F + N/H$ (Replacing values of G)

Therefore, $G(u,v) = H(u,v)\,F(u,v) + N(u,v)$

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Disadvantage:-

1) The undegraded image F (u,v) cannot be recovered until N (u,v) is known which is Fourier transform of noise. Since noise is a random variable Fourier transform of noise is not known.
2) If the degradation function has 0 or very small values we cannot find the ratio N (u,v) / H (u,v). One way is limit the filter frequencies of H (u,v) to the values near the origin.

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Minimum mean square error filtering (Wiener filtering)

- Inverse filtering approach makes no provision for handling noise. We discuss an approach which incorporates both the degradation function and statistical characteristics of noise into restoration process. Method is founded by considering images and noise as random process and objective is to find an estimate $\hat{f}$ of the uncorrupted image f such that mean square error between them is minimized.

  f :- uncorrupted image

  $\hat{f}$:- estimate of uncorrupted image

Error is given by :- $e^2 = E\{(f - \hat{f})^2\}$ $(f - \hat{f})^2$ = mean square error, E { } := expected value

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Assumptions:-

1) Noise and image are uncorrelated.
2) One of them has zero mean.
3) Gray levels of estimate are linear functions of gray levels of degraded image.

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- This filter is known as Wiener filter and finds the Fourier transform of restored image such that the mean square error between the restored and the original image is minimized.
- The restored image in spatial domain can be found by taking the inverse Fourier transform of F (u,v).
- If the noise is 0 Wiener filter reduces to inverse filter. In the case of white noise power spectrum is constant.
- The power spectrum Sf (u,v) of undegraded image is seldom known.
- **Disadvantage:**

Sη (u,v) and Sf (u,v) should be known.

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6. COLOR IMAGE PROCESSING

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Why color image processing?

- Color simplifies object identification and extraction from scene.
- Thousands of color shades can be discerned by human eye whereas only few gray levels shades can be discerned.

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Categories of Color Image Processing

- **Full Color Processing** :- Images acquired with full color sensor like color TV , camera or color scanner.

- **Pseudo color Processing**:- Assign color to particular monochrome intensity or range of intensities.

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Color Fundamentals

- Sir Isaac Newton discovered that white light when passes through prism, breaks into seven colors

  VIBGYOR while each color smoothly blends into other.
- Color is perceived as the wavelength reflected back from object .
- When the object reflects all seven colors in equal proportion it appears white.
- When an object reflects wavelength corresponding to green color and absorbs all other wavelengths it will appear green.
- When an object does not reflect at all i.e. absorbs all wavelengths it appears black.

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Color Spectrum

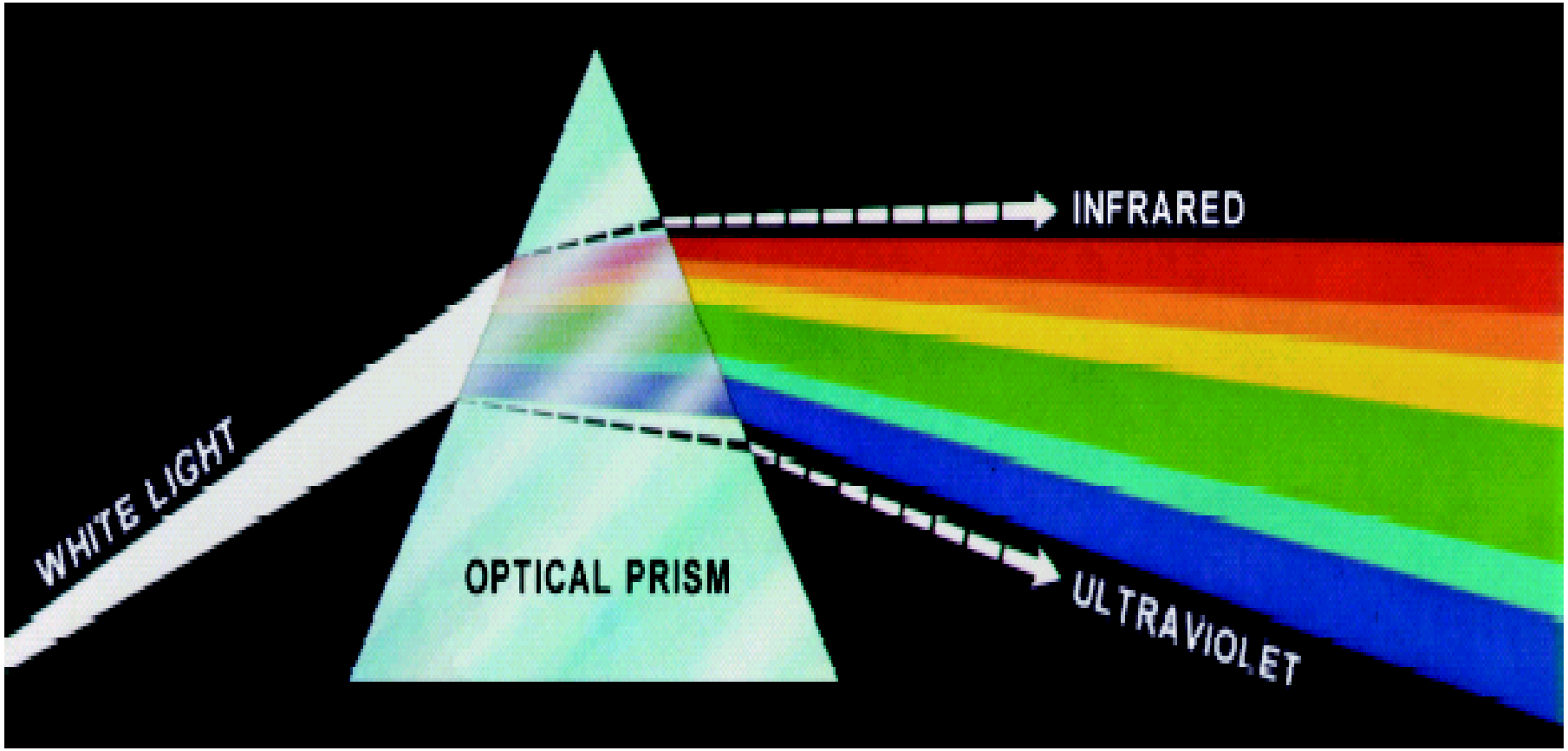

FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

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Electromagnetic Spectrum

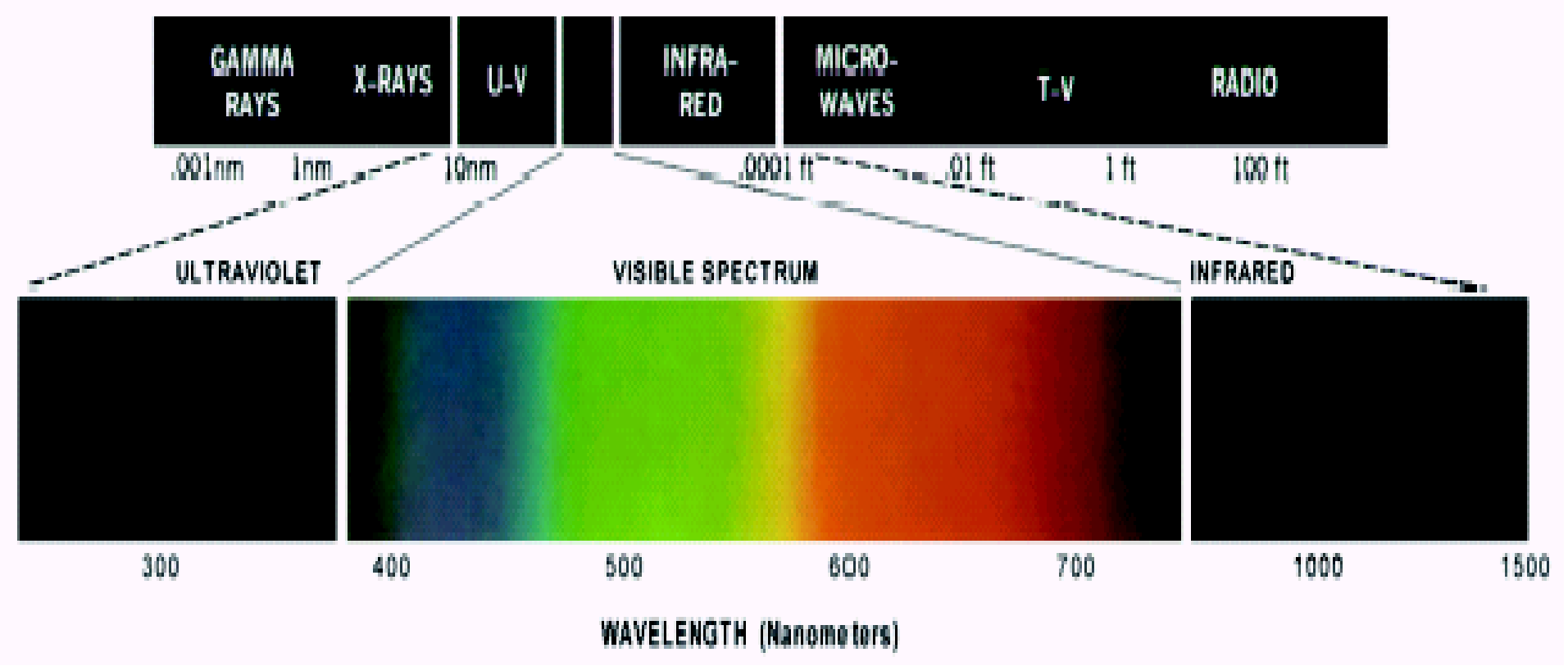

FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Attributes of Light

- Monochromatic Light:- Only one attribute which is **intensity**.

- Color Light:- Three attributes:

Radiance, Luminance and Brightness

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Primary and Secondary Colors

- In human eye cones and sensors are responsible for color vision.
- There are 6 to 7 million cones in human eye which can be divided into 3 categories red, green and blue.
- 65% are sensitive to red
- 35% are sensitive to green
- 2% are sensitive to blue.
- Due to these absorption characteristics colors are seen as combinations of 3 primary colors i.e. RED, BLUE, GREEN.

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- No single color can be called as RED, BLUE or GREEN since colors blend with each other. Therefore, for Standardization CIE designated 3 primary colors the following frequencies.
- Blue = 435.8nm
- Green= 546.1nm
- Red = 700nm
- Primary colors add to form secondary colors.
- Magenta = Red + Blue
- Cyan = Green + Blue
- Yellow = Red + Green

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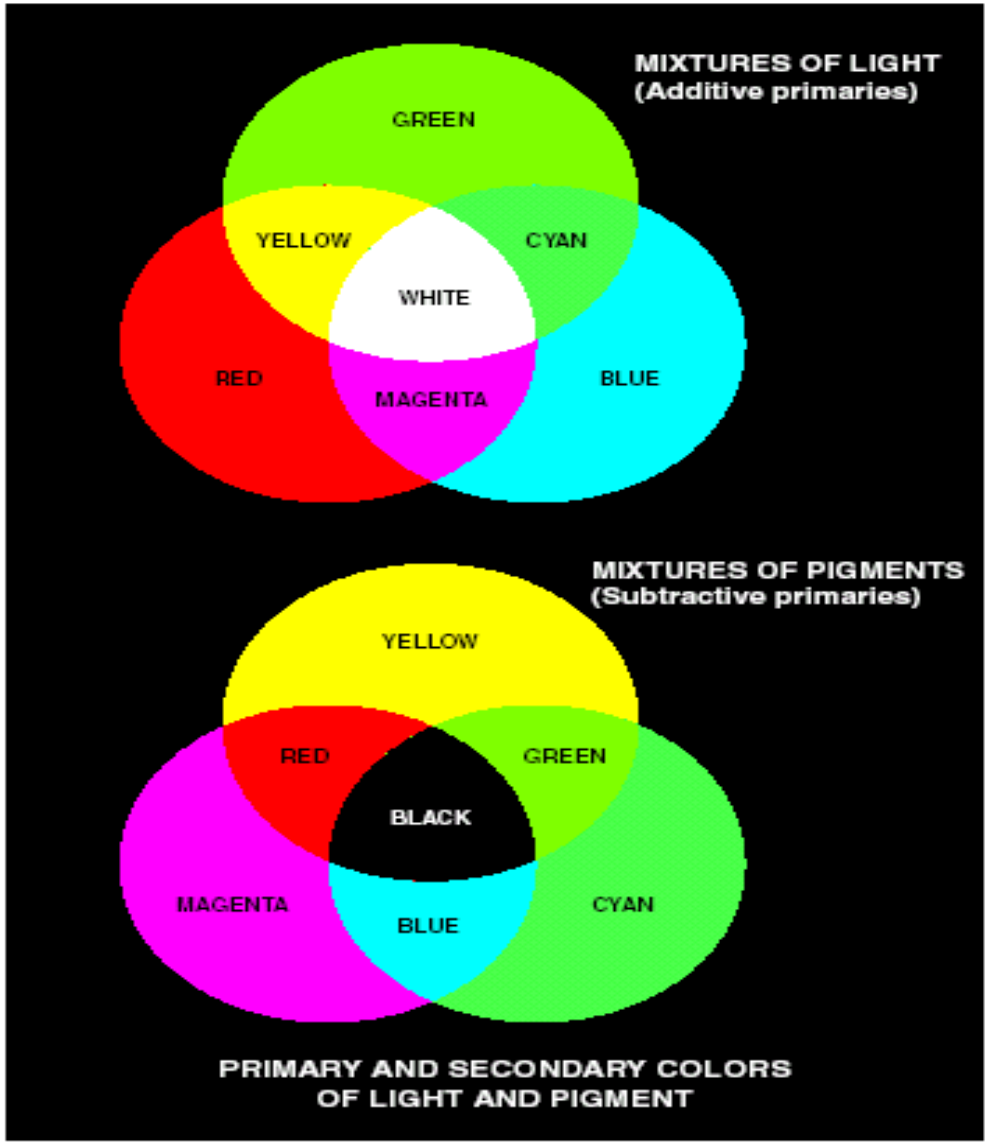

a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

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Characteristics of Color

- **Hue** :- Dominant wavelength in mixture of light waves. Dominant color perceived by observer.
- **Saturation**:- Relative purity or amount of white light mixed with hue.
- **Brightness**:- chromatic notion of intensity.

Pure spectrum colors are fully saturated. Colors such as pink (Red + white), lavender (violet + white) are less saturated.

CHROMATICITY:- Hue and saturation taken together.

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TRISTIMULUS VALUES

- Amount of red, blue or green needed to form a color are called tristimulus values represented by X, Y, Z respectively. The color is defined as:-

$$x = X / X+Y+Z$$

$$y = Y/X+Y+Z$$

$$z = Z/X+Y+Z$$

$$x + y + z = 1$$

X:- amount of red required for color

Y:- amount of green required for color

Z:- amount of blue required for color.

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CIE Chromaticity Diagram

- The various colors VIBGYOR are around tongue shape chromaticity diagram.
- These are **pure** colors.
- Other points in diagram represents mixture of colors.
- All points on boundaries are fully saturated.
- As point leaves boundary and approaches point of equal energy, it becomes less saturated.
- Saturation at point of equal energy (WHITE) is zero.
- Straight line joining any two colors on the chromaticity diagram represents colors which can be formed by mixing two colors.

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COLORS MIXED USING
RED AND GREEN

RED → GREEN

ALL SHADES OF RED

RED → WHITE

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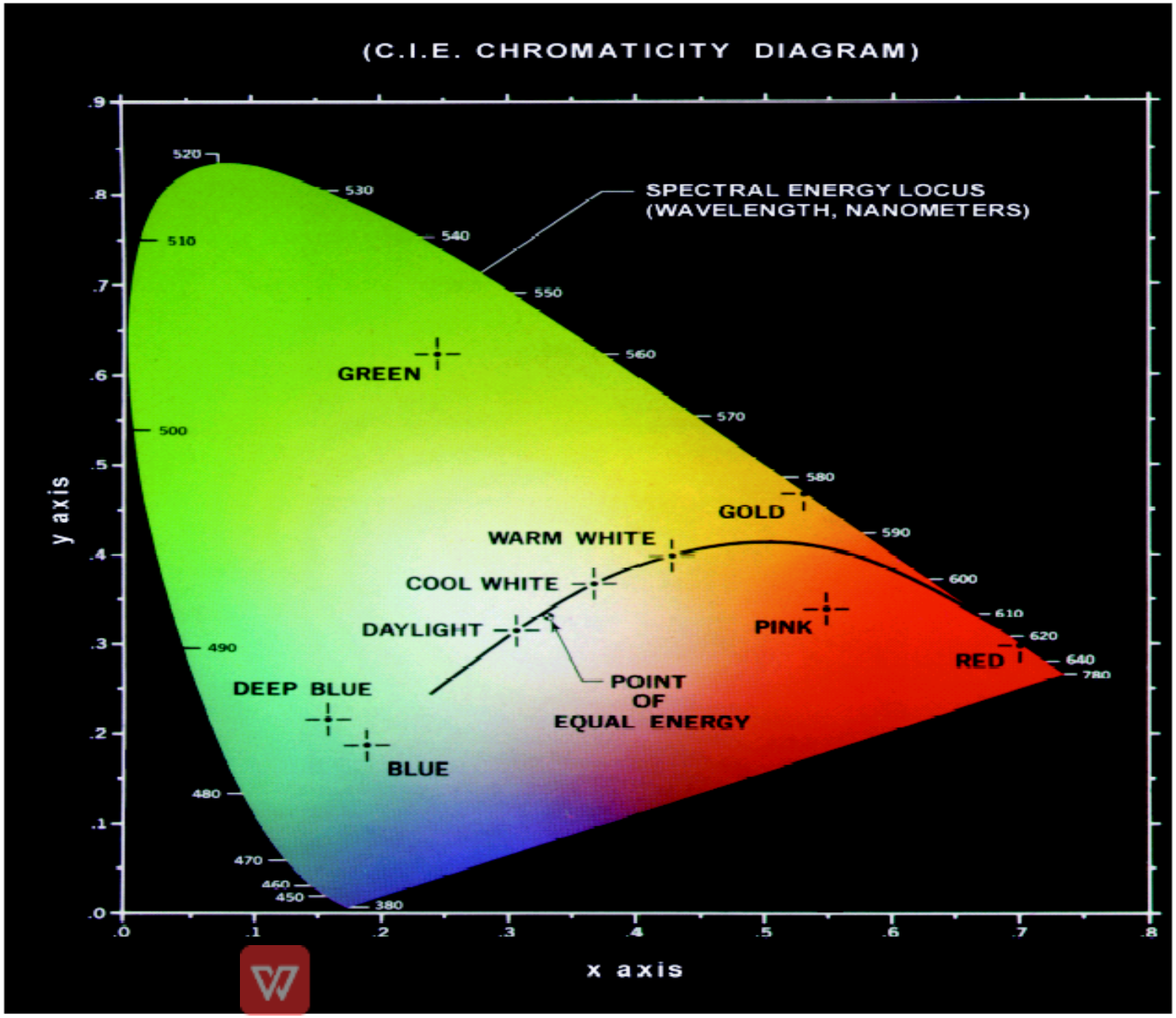
CIE Chromaticity Diagram

FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)



COLOR MODELS

- Color is specification of co-ordinate system and a subspace within that system where each color is represented by single point.

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RGB Color Model

- Model based on Cartesian co-ordinate system.
- Color space is a cube.
- RGB are 3 corners of cube.
- Black is at origin.
- White is at corner farthest from origin.
- Line joining 2 points form gray scale.
- Different colors are points on or inside the cube.
- Cube is unit cube.
- Value of R,G,B are in the range [0,1].

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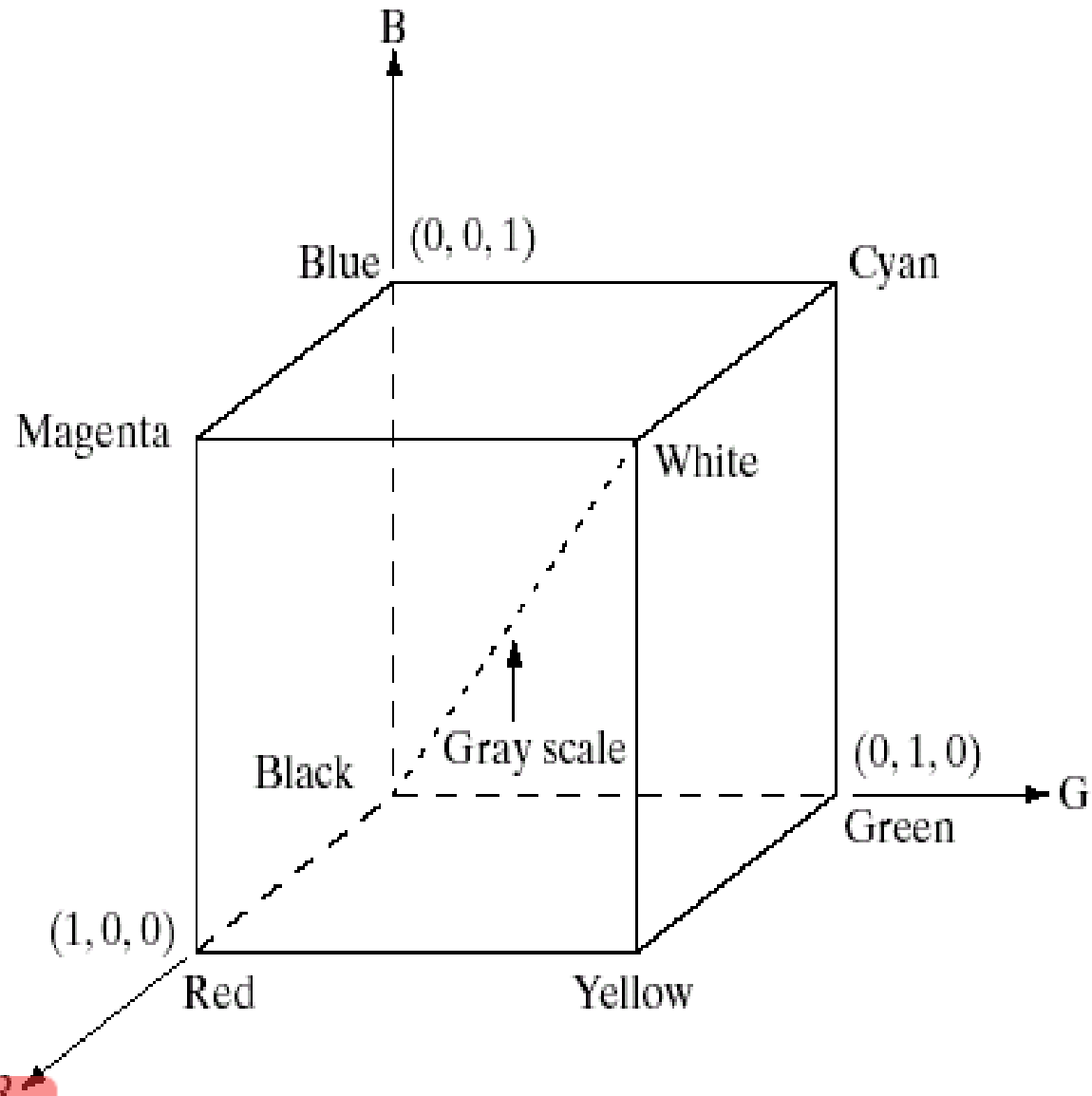
RGB Color Model

FIGURE 6.7
Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).



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Pixel Depth:- Number of bits used to represent each pixel in RGB space is called pixel depth.

If depth = 24 bits , each image plane is of 8 bits. Such type of image is called full color image.

Total number of colors in 24-bit RGB image is

$(2^8)^3 = 16,777,216$

All systems safe colors:- Subset of colors that can be produced by any system. 256 is the safe colors for any system.

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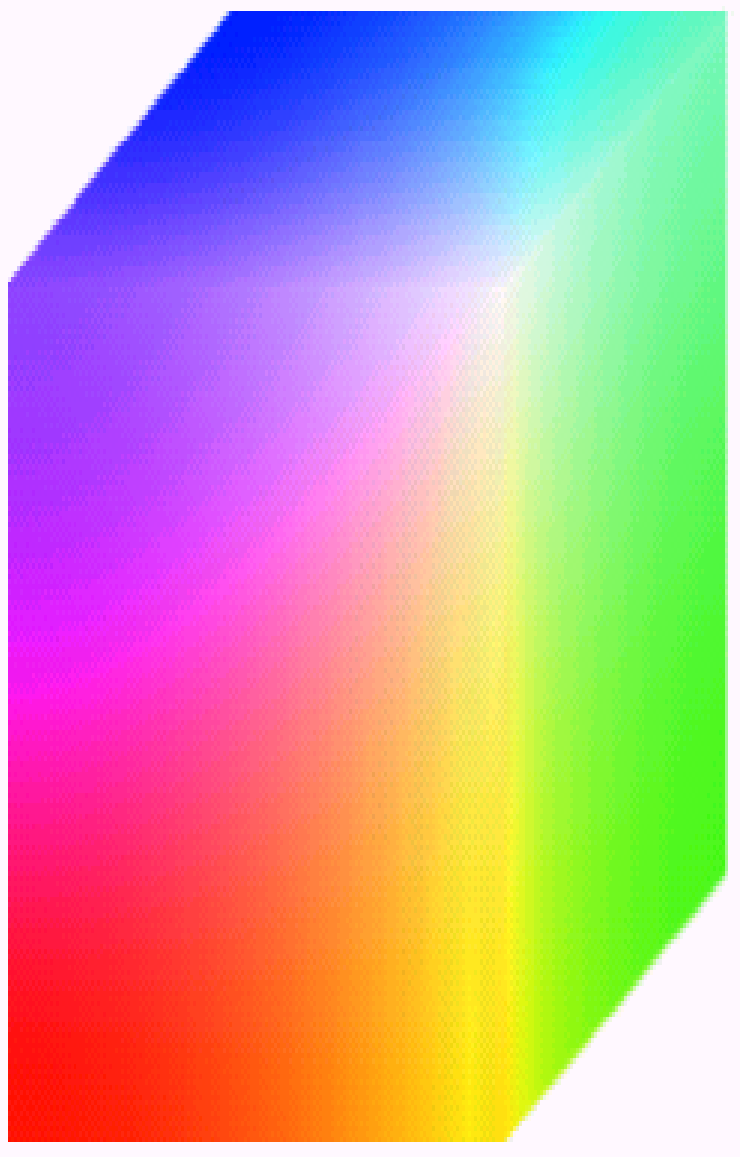

FIGURE 6.8 RGB 24-bit color cube.

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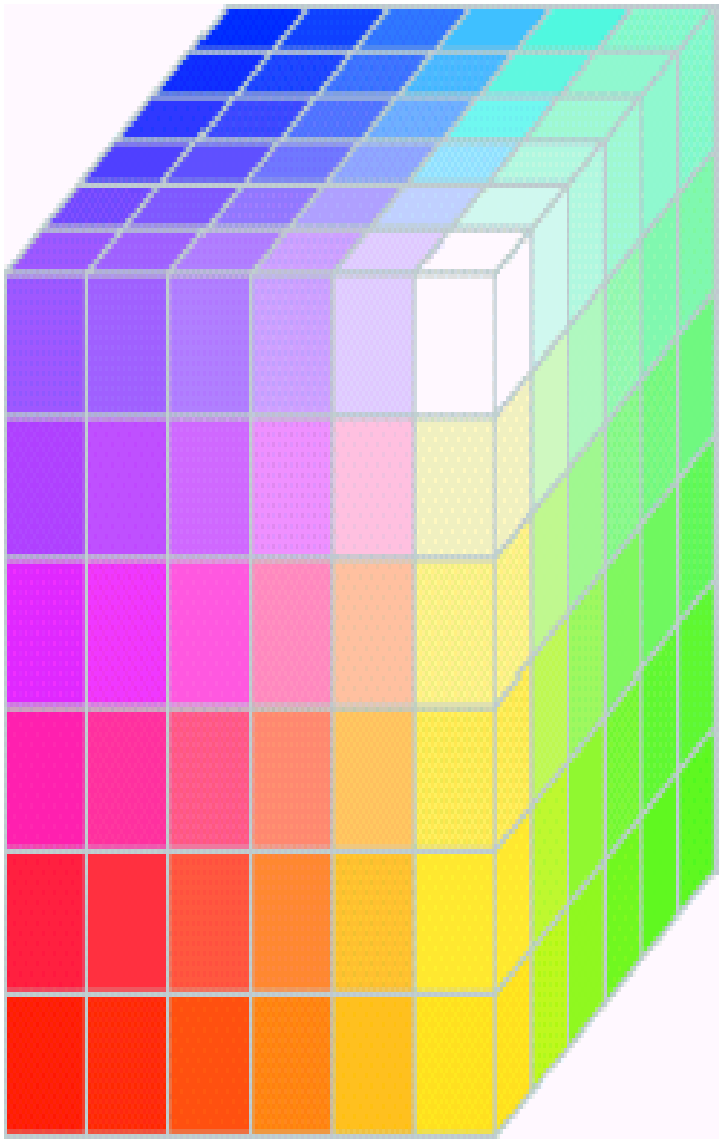

FIGURE 6.11 The RGB safe-color cube.

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CMY AND CMYK color models

- CMY :- Cyan , Magenta , Yellow color model
- Many color printers and copiers require this model.
- [C,M,Y] = [1 1 1] – [R,G,B]
- Therefore, pure cyan does not reflect red
- Pure magenta does not reflect green
- Pure yellow does not reflect blue.
- Similarly,
- [R,G,B] = [1 1 1] – [C,M,Y]
- Combining CMY produces muddy looking black. To produce pure black, fourth pure black color is added. So model known as CMYK where K is black . The printing techniques using these four colors is known as four color printing.

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HSI COLOR MODEL
(Hue ,Saturation and Intensity)

- RGB and CMY describes color by giving its composite colors. But this is not practical method for human interpretation.
- When humans view a color object, they describe by its hue, saturation and brightness.

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Obtaining HSI from RGB

- **Intensity**:- Take the RGB cube and stand it on the black (0, 0,0) vertex with (1,1,1) white directly above it.
- Intensity is along line joining these vertices.
- To find intensity component of any color, pass a plane perpendicular to intensity axis containing the color point.

- **Saturation**:-Saturation of color increase as we move away from intensity axis.
- Saturation point at intensity axis is 0 by the fact that all points are gray.

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- **Hue:-** Form plane take 3 points : Black, white and a color.
- All points in the plane segment and points on boundaries of cube have the same hue.
- By rotating the plane on vertical axis, different hues are obtained.

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CONVERSION AMONG DIFFERENT COLOR MODELS

RGB to HSI

- Assumed that RGB values have been normalized to [0,1] and angle θ is measured with respect to red axis of HSI space.
- Conversion equations
- **HSI to RGB**

➤ RG sector (0° <= H <= 120°)

➤ GB sector (120° <= H <= 240°)

➤ BR sector (240° <= H <= 360°)

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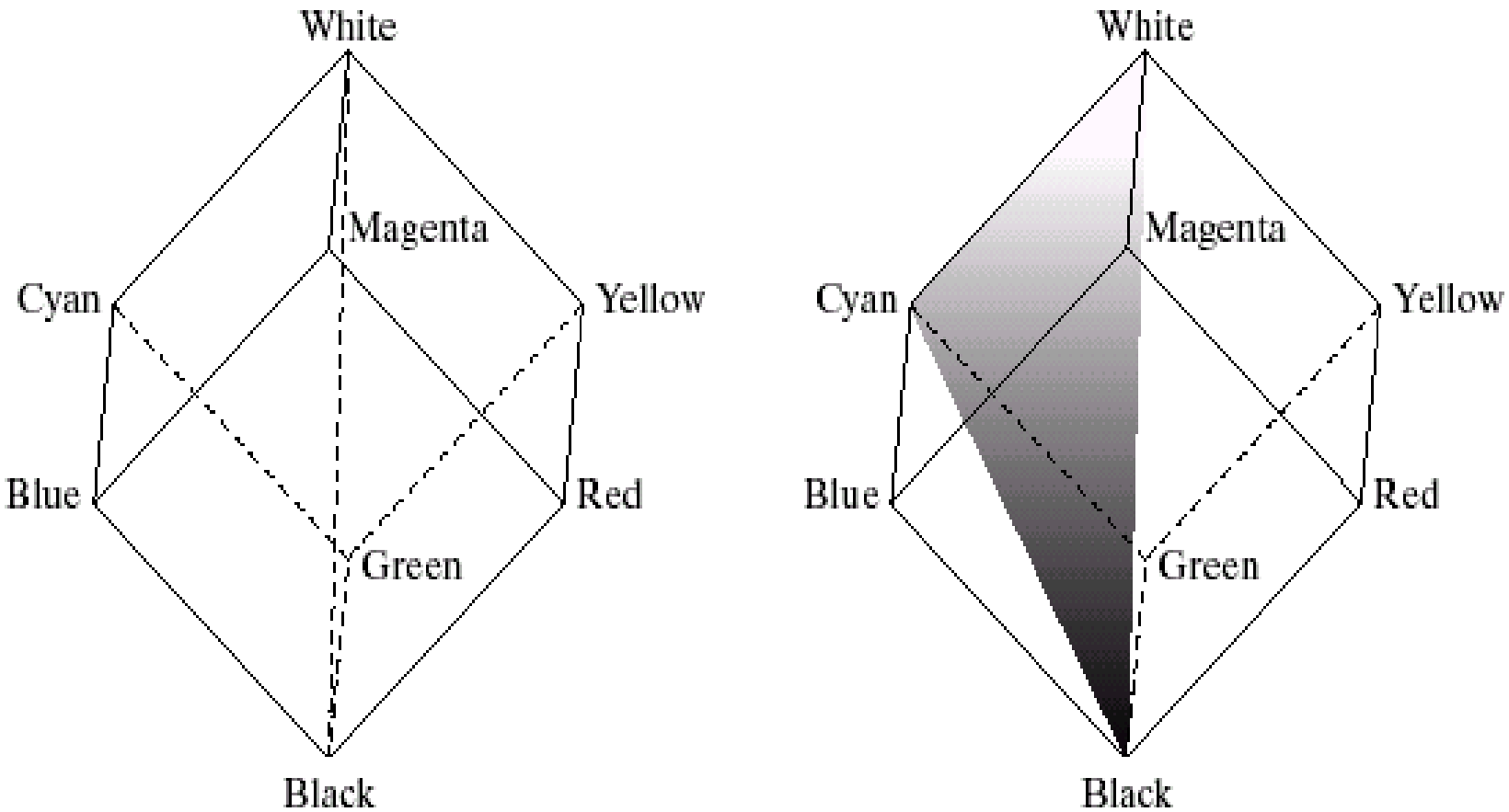
Relation between RGB and HSI Model



a b

FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.

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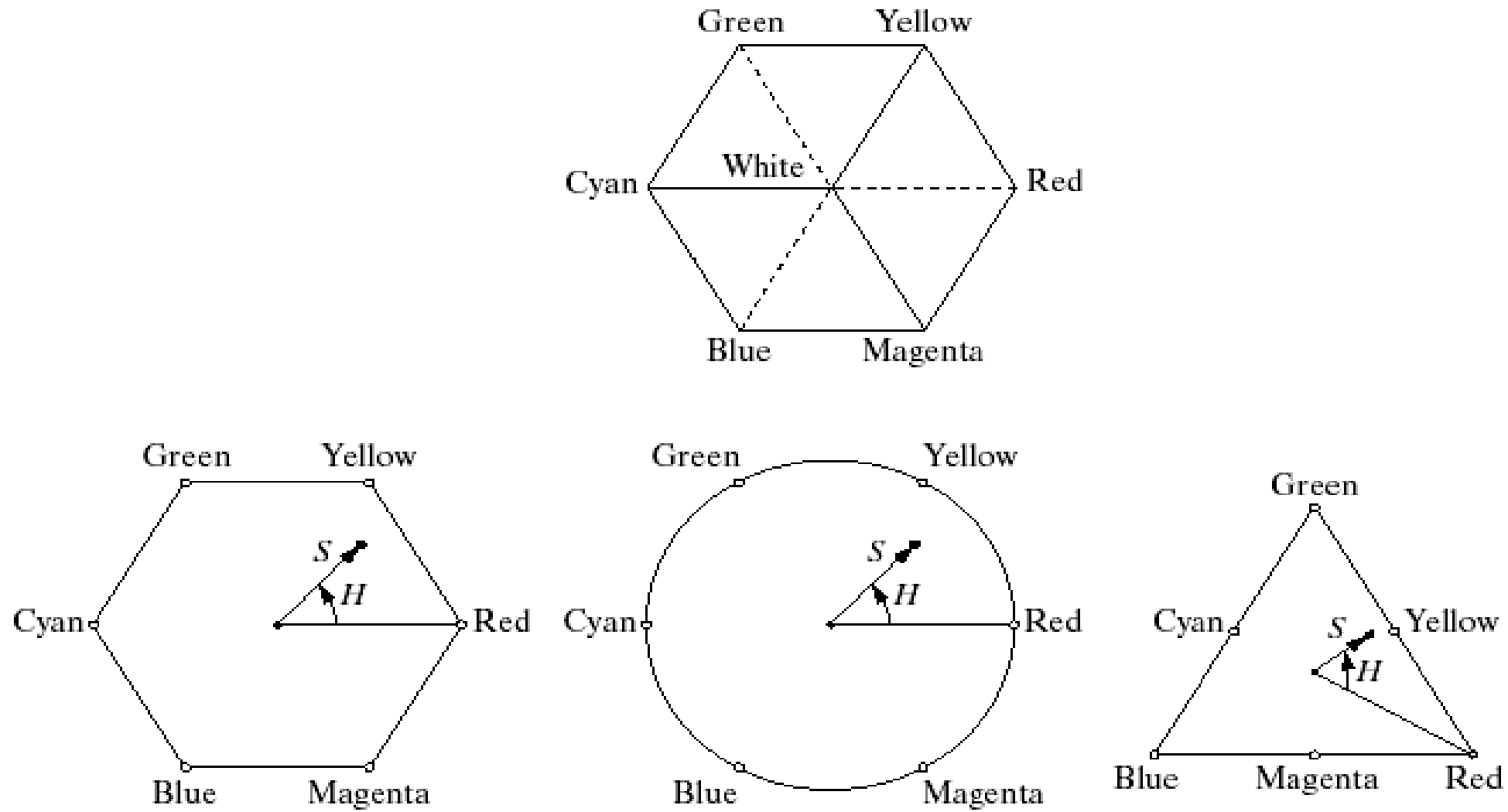

a
b c d

FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

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PSEUDOCOLOR IMAGE PROCESSING

- Assigning colors to gray level values based on certain criteria.
- Major use is interpretation of gray level images.
- Two techniques are used:-
- ✓ Intensity slicing
- ✓ Gray level to color transformations

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INTENSITY SLICING

- Let [0 – L-1] gray scale. This scale is divided into L levels where l_0 represents black f (x,y) =0 and level l_{L-1} represents white f (x,y) = L-1. Total P planes are defined perpendicular to intensity axis defined at levels $l_1, l_2, \ldots, l_p$ and 0 <P< L-1.
- P planes partition gray scale into P+1 intervals $V_1, V_2, \ldots, V_{p+1}$
- Gray to color assignments are made as

  $f(x,y) = c_k$ if $f(x,y) \varepsilon V_k$

V_k :- interval formed by partitioning planes at l = k-1 and l=k

c_k :- color associated with k^{th} intensity interval V_k.

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- Any plane slice the image function into two levels.
- Different color is assigned to each plane. Any pixel whose gray level is above the plane will be coded with one color and below the plane will be coded with other.
- Pixels on the plane can be assigned any color.
- Result is two color image.
- When more colors are used, mapping function takes staircase form.

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Intensity Slicing

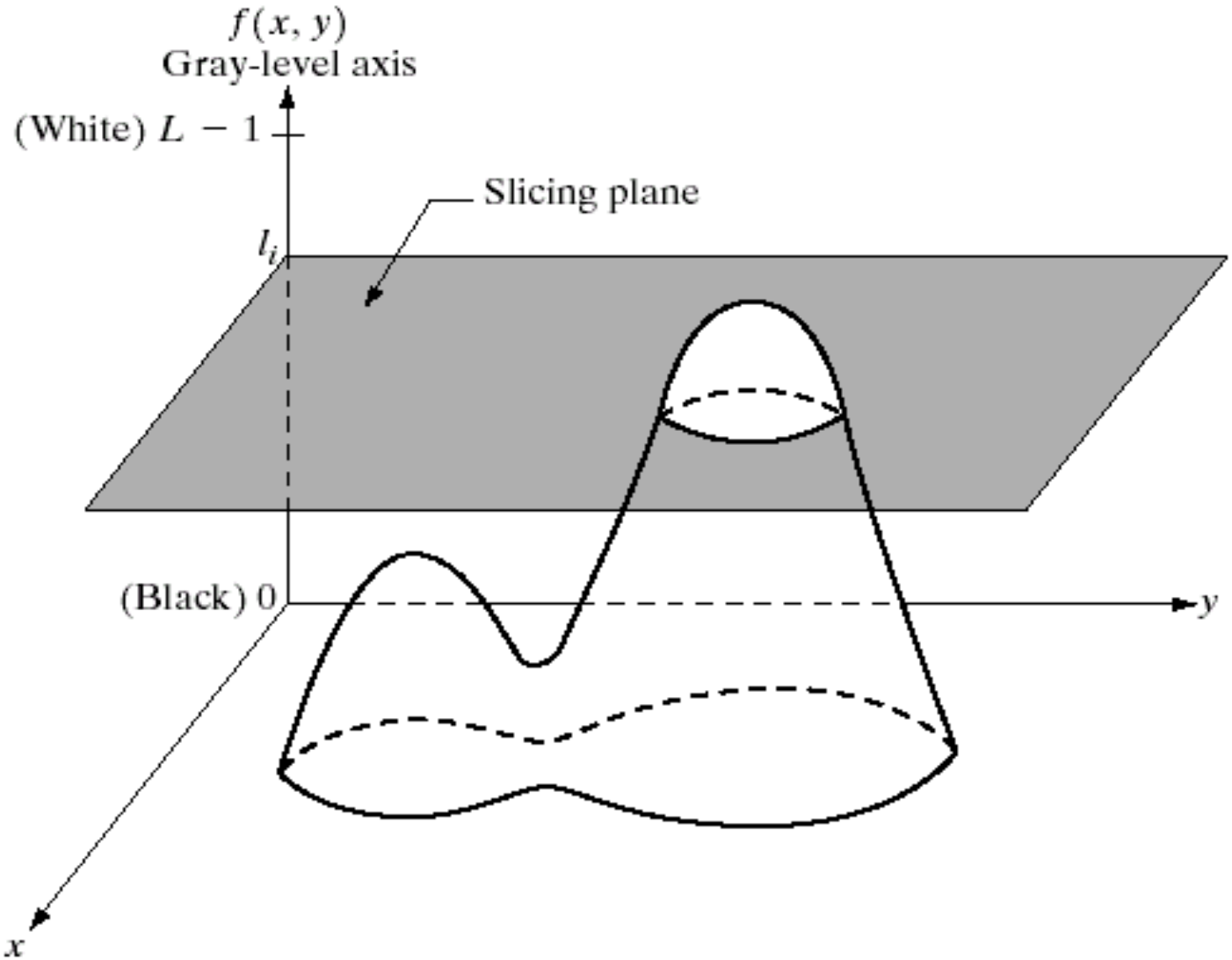

FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

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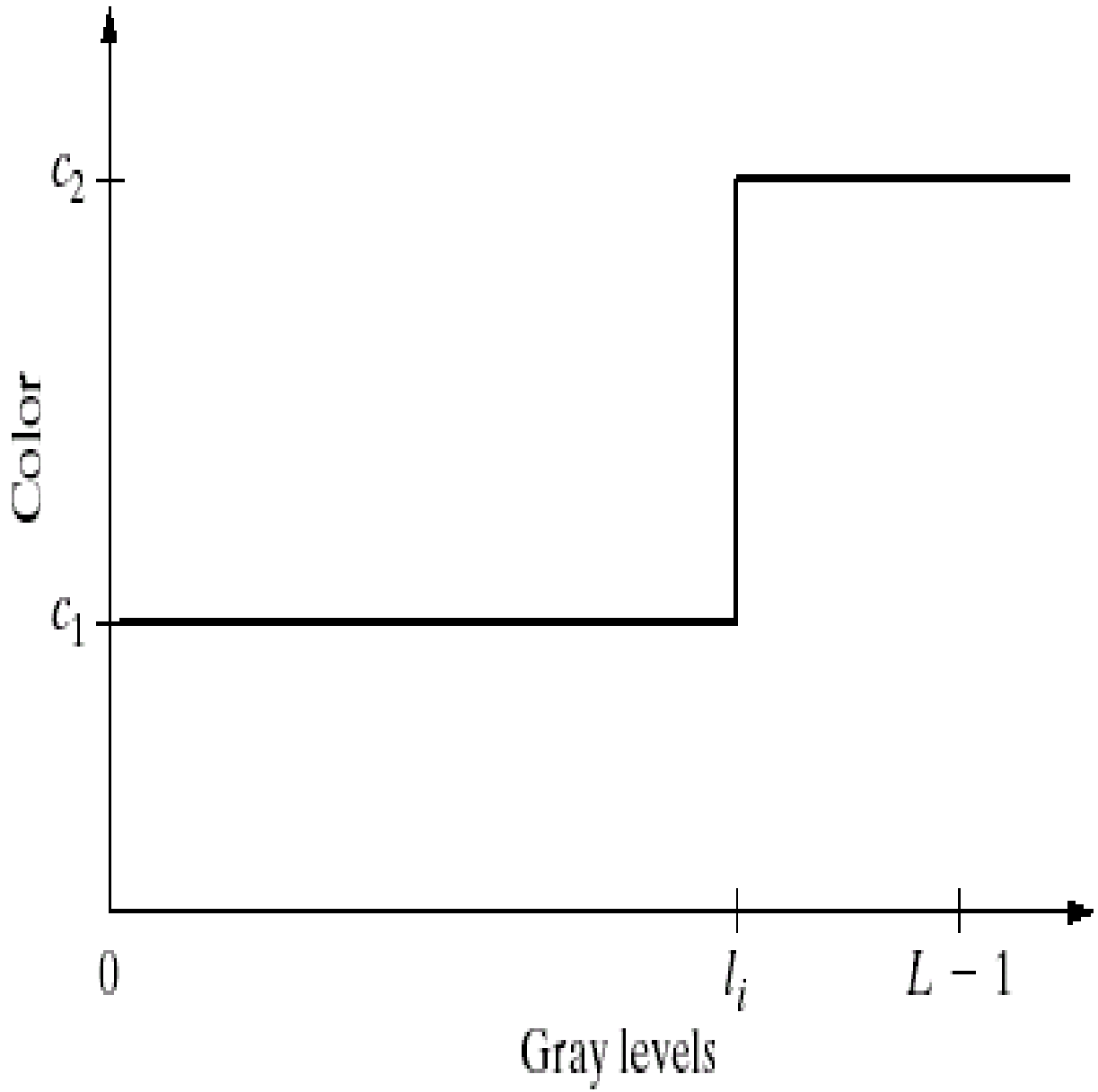

FIGURE 6.19 An alternative representation of the intensity-slicing technique.

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Gray level to Color Transformation

- Perform three independent transformations on gray levels.
- The three results are fed separately into red, green and blue channels of TV.
- Intensity slicing is a special case where piecewise linear function of gray levels is used.
- Here transformation function can be smooth , non-linear function.
- Many monochrome images can also be combined to form single color composite image. Application is in multispectral imaging where different sensors produce individual monochrome images each in different spectral band.

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Color Transformation

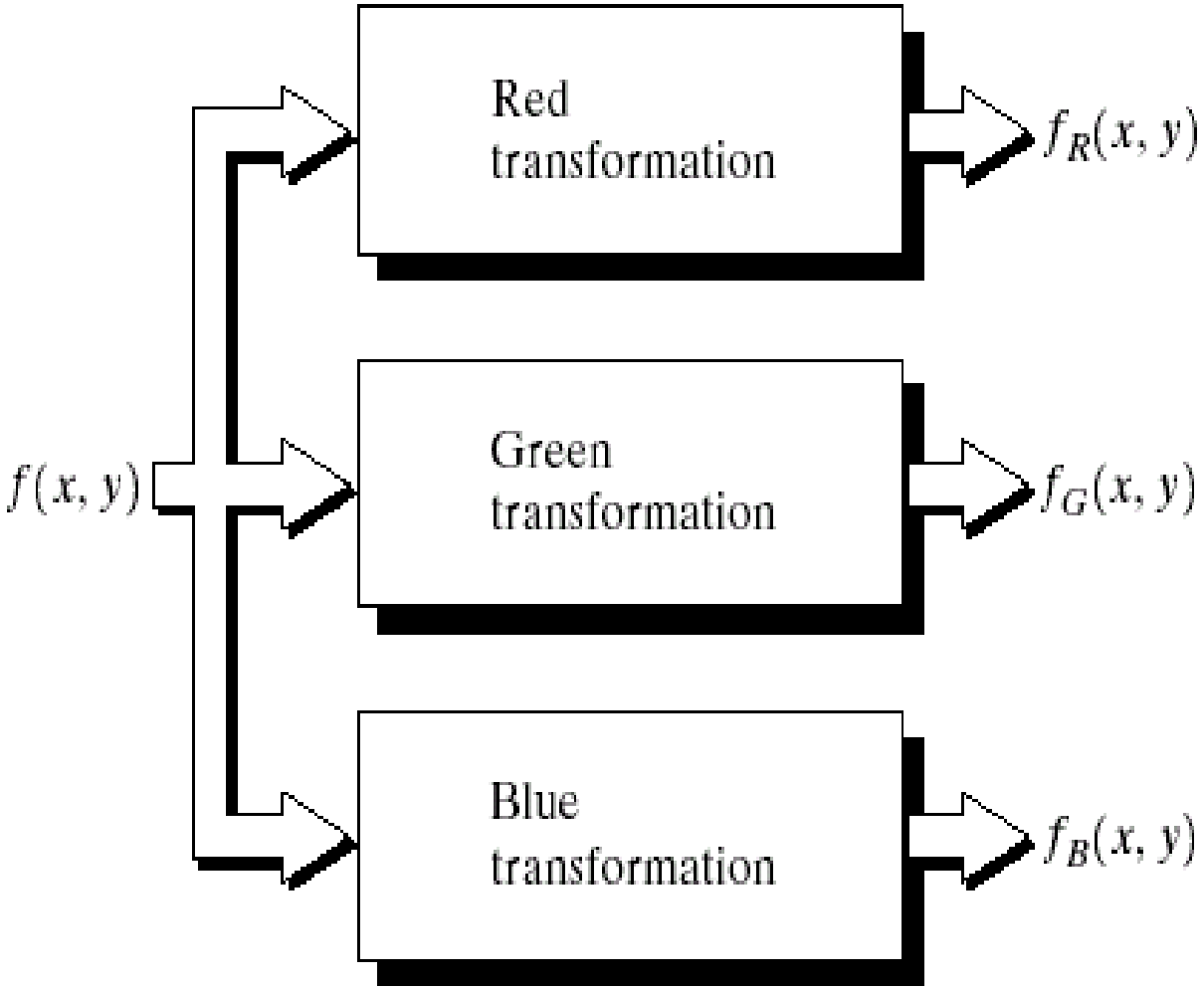

FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

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Pseudo color Processing

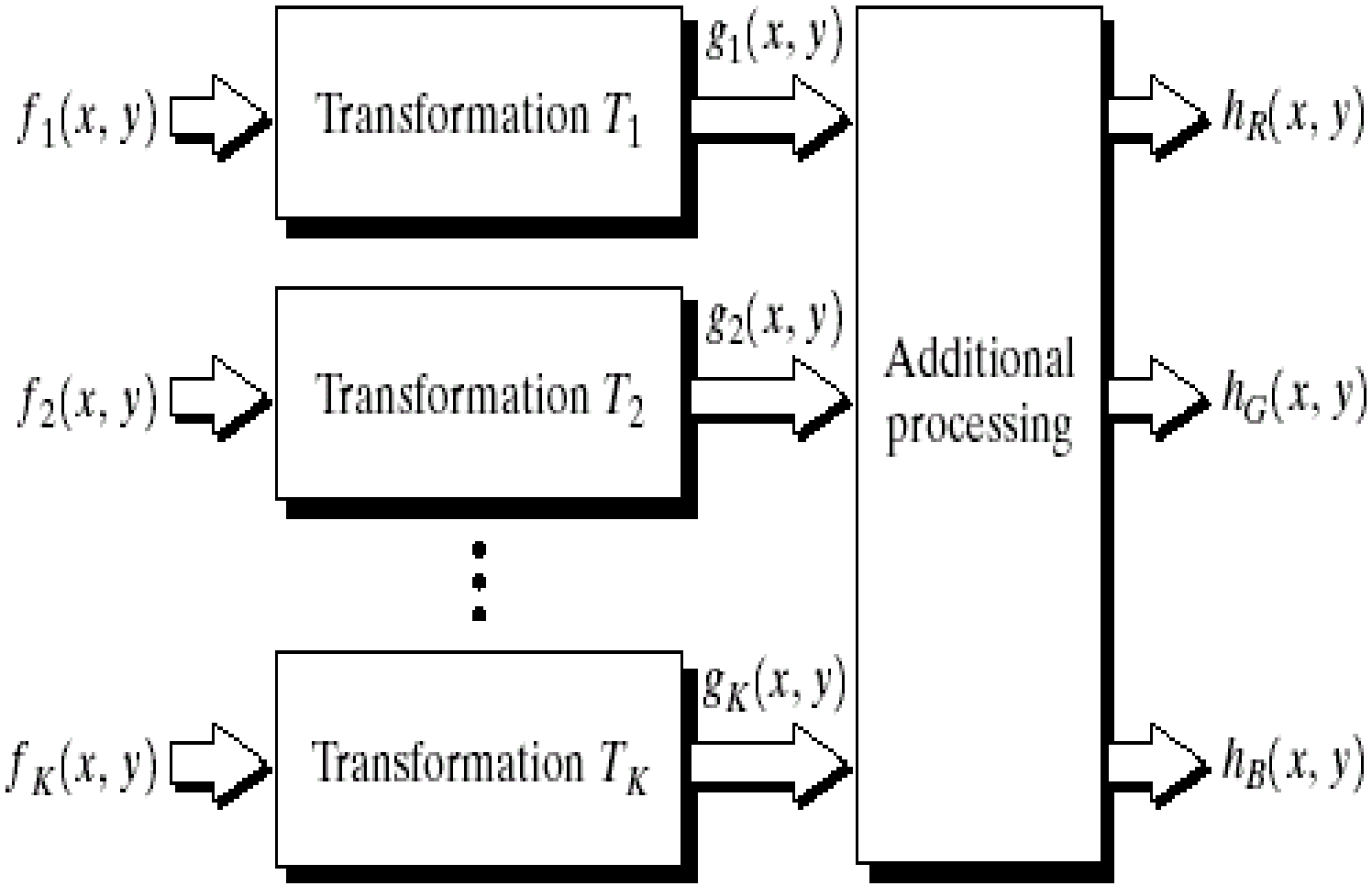

FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.

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Full Color Image Processing

- Processing techniques applicable to full color images.
- Two techniques.

1) Process each component image individually and form processed composite color image.
2) Work with color pixels directly.

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COLOR TRANSFORMATIONS

- $g(x,y) = T[f(x,y)]$
- T is the transformation on colored image f (x,y). g (x,y) is transformed image.
- Difference between color and gray level transformation is color transformation pixels are group of triplets. Color transformation have the form

  $s_i = T_i(r_1, r_2, \ldots, r_n) \quad i=1,2,\ldots,n$

n=3 or 4

n=3 for RGB and HSI

N=4 for CMYK

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- Any transformation can be performed in any color model. For choosing a particular color model, cost of conversion should be considered.
- example.:- If intensity has to be modified, HSI color space can be used

  $s3 = k\ r3$ only r3 is modified.

  But for RGB all the 3 components must be transformed.

  $si = k\ ri \quad i=1,2,3$

  and for CMY $si = k\ ri + (1-k) \quad i=1,2,3$

  Here intensity transformation in HSI space is simple but calculations for converting RGB and CMY to HSI are more complicated. But independent of color space output is always same.

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Color Complements (Here directly opposite to each other in color circle. Equal to gray level negative.)

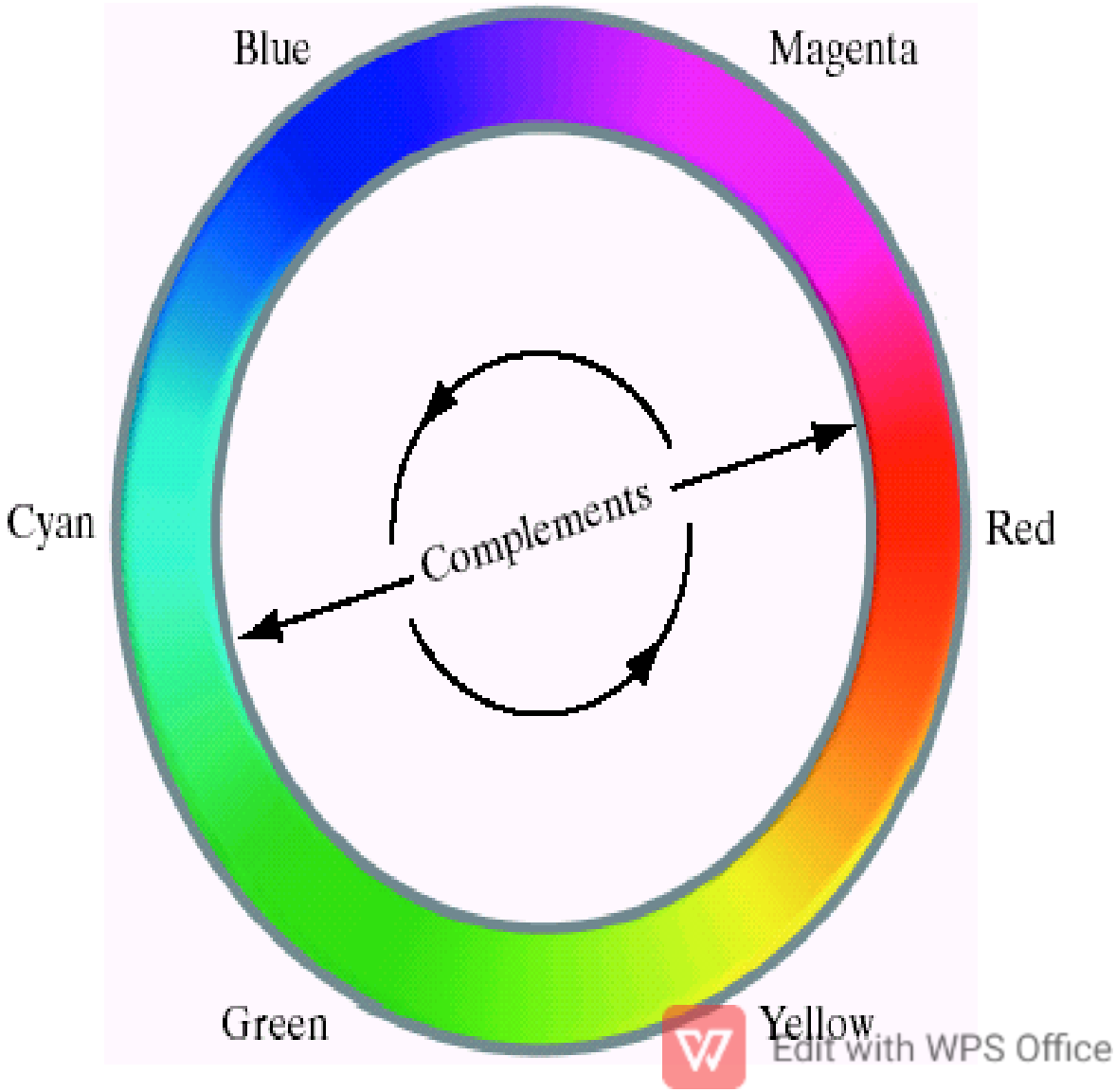

FIGURE 6.32 Complements on the color circle.

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COLOR SLICING

- Highlighting specific range of colors in an image for the purpose of separating objects from surroundings.
- Two approaches:-

1. Display colors of interest so they stand out from background.
2. Use region defined by colors as a mask.

One way to slice a color image is to map the colors outside some range of interest to a neutral color. Suppose colors of interest are enclosed by average color with components a1,a2,…,an then set of transformations is:

This transformation highlight the color around the prototype by forcing all other colors to midpoint of reference color space. e.g. for RGB suitable neutral point is (0.5,0.5,0.5).

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HISTOGRAM PROCESSING

- Color images are composed of different components.
- Therefore, erroneous colors are obtained by independently equalizing individual components of color image.
- More logically approach is to spread color intensities uniformly leaving color unchanged.
- Therefore, HSI color space should be used where intensity is spread keeping hue unchanged.

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SMOOTHING AND SHARPENING

- **SMOOTHING** (Averaging):-
- S x,y denote set of co-ordinates defining neighborhood centered at (x,y) in RGB color image. Average of RGB component vectors in neighborhood is

$$c(\overline{x,y}) = 1/k \sum_{x,y \varepsilon S_{xy}} c(x,y)$$

Matrix form:

COLOR IMAGE SHARPENING:

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NOISE IN COLOR IMAGES

- The color channels may be affected by noise due to the malfunctioning of the electronics of that particular channel.
- Also, the noise can be due to the differences in relative strength of illumination available to each color channel.
- CCD sensors are noisier at low levels of illumination.
- If we have used a red reject filter in CCD camera the red component of the RGB image would be much noisier.

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