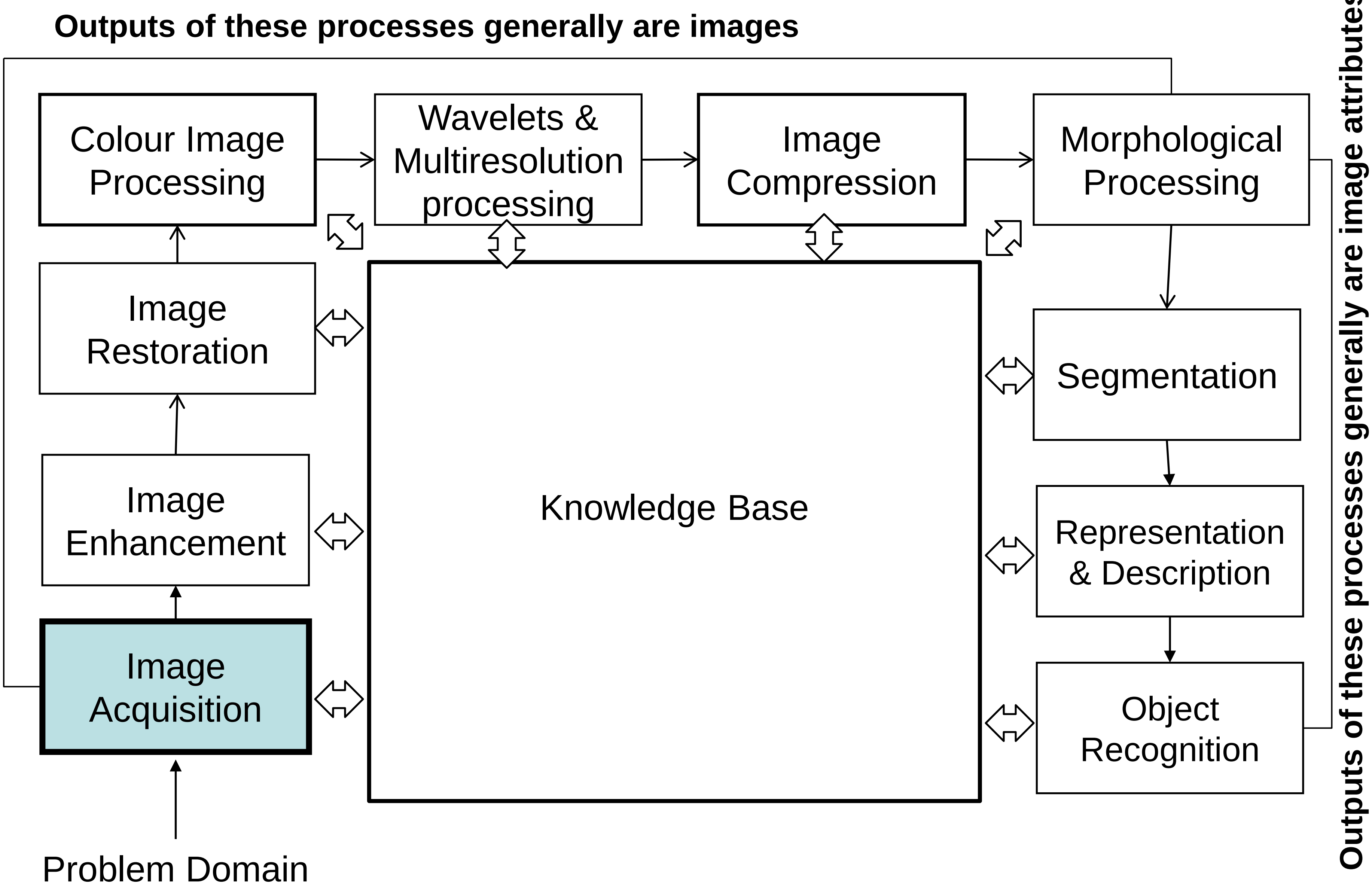
Digital Image Processing

Introduction

Digital Image Definition

- An image can be defined as a two-dimensional function f(x,y)
- x,y: Spatial coordinate
- F: the amplitude of any pair of coordinate x,y, which is called the intensity or gray level of the image at that point.
- X,y and f, are all finite and discrete quantities.

Fundamental Steps in Digital Image Processing:



Fundamental Steps in DIP:

Step 1: Image Acquisition

The image is captured by a sensor (eg. Camera), and digitized if the output of the camera or sensor is not already in digital form, using analogue-to-digital convertor

Fundamental Steps in DIP:

Step 2: Image Enhancement

The process of manipulating an image so that the result is more suitable than the original for specific applications.

The idea behind enhancement techniques is to bring out details that are hidden, or simple to highlight certain features of interest in an image.

Fundamental Steps in DIP:

Step 3: Image Restoration

- Improving the appearance of an image

- Tend to be mathematical or probabilistic models. Enhancement, on the other hand, is based on human subjective preferences regarding what constitutes a “good” enhancement result.

Fundamental Steps in DIP:

Step 4: Colour Image Processing

Use the colour of the image to extract features of interest in an image

Fundamental Steps in DIP:

Step 5: Wavelets

Are the foundation of representing images in various degrees of resolution. It is used for image data compression.

Fundamental Steps in DIP:

Step 6: Compression

Techniques for reducing the storage required to save an image or the bandwidth required to transmit it.

Fundamental Steps in DIP:

Step 7: Morphological Processing

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

In this step, there would be a transition from processes that output images, to processes that output image attributes.

Fundamental Steps in DIP:

Step 8: Image Segmentation

Segmentation procedures partition an image into its constituent parts or objects.

Fundamental Steps in DIP:

Step 9: Representation and Description

- **Representation:** Make a decision whether the data should be represented as a boundary or as a complete region. It is almost always follows the output of a segmentation stage.
  - **Boundary Representation:** Focus on external shape characteristics, such as corners and inflections (انحناءات)
  - **Region Representation:** Focus on internal properties, such as texture or skeleton (هيكلية) shape

Fundamental Steps in DIP:

Step 9: Representation and Description

- Choosing a representation is only part of the solution for transforming raw data into a form suitable for subsequent computer processing (mainly recognition)

- **Description:** also called, ***feature selection***, deals with extracting attributes that result in some information of interest.

Fundamental Steps in DIP:

Step 9: Recognition and Interpretation

Recognition: the process that assigns label to an object based on the information provided by its description.

Fundamental Steps in DIP:

Step 10: Knowledge Base

Knowledge about a problem domain is coded into an image processing system in the form of a knowledge database.

image → 2-D fn → f(x,y)

x & y → spatial co-ordinates.

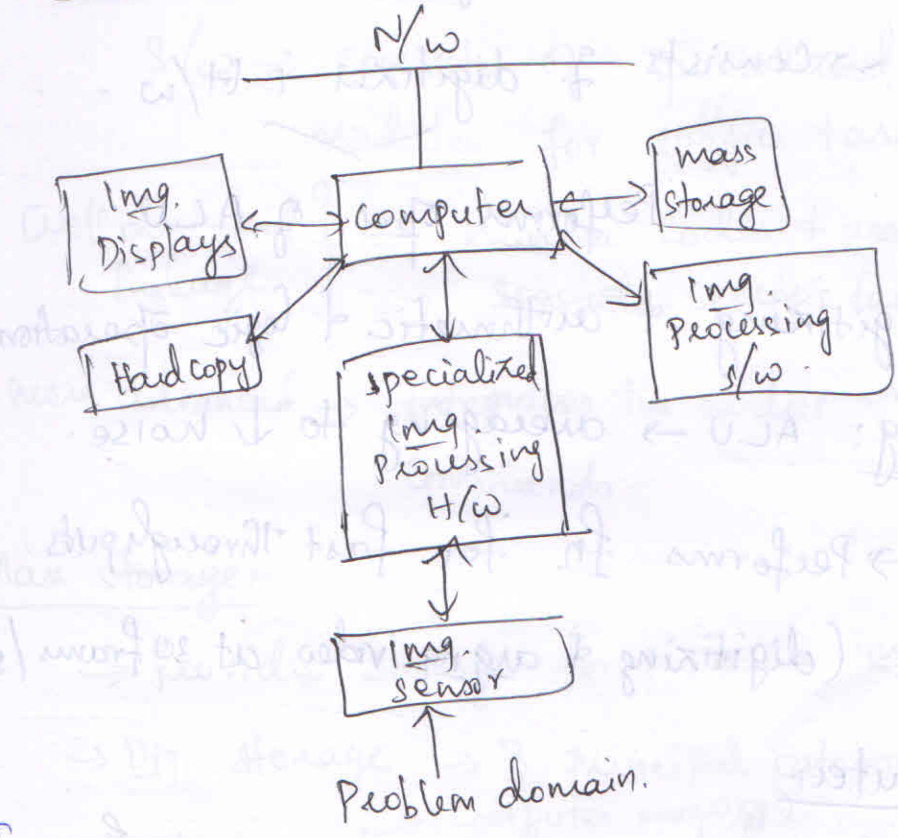
amp. of f → for (x,y) pair → called intensity or gray level of img.

when → x, y & amp. of f → are finite & discrete → the image is called digital image.

DIP → Processing of dig. img.

→ img. is composed of picture elements called pixels.

Elements of DIP :



Img Sensor → 2 devices.

1 → Physical device sensitive to energy rad. by the obj

2 → digitizer (convert o/p of phy. dev. to digital form).

Specialized Img. processing H/w:

→ Consists of digitizer + H/w.

Performs oper. of ALU.

digitizing + arithmetic + logic operation

eg: ALU → averaging to ↓ noise.

→ Performs fn. for fast throughputs.

(digitizing + avging video at 30 frames/se

Computer:

→ img. processing system range from PC to a super computer.

→ dedicated app. (spl.) custom computers are used to achieve req. performance.

Img. Processing S/w:

S/w → consists of specialized modules for specific task.

Well designed Package } → minim. codes & uses. ~~Speciati~~ specific tasks.

more advanced → integrates the modess. & Commands.

Mass storage:

→ Provides storage for processing img.

→ Dig. storage → 3 principal categories.

1. Short-term storage ~~for~~ → (computer memory) used during Processing.

2. On-line storage for fast recall (opt. media, disks)

3. archival storage (infrequent access) (mag. tapes)

image → 2-D fn → $f(x,y)$

x & y → spatial co-ordinates.

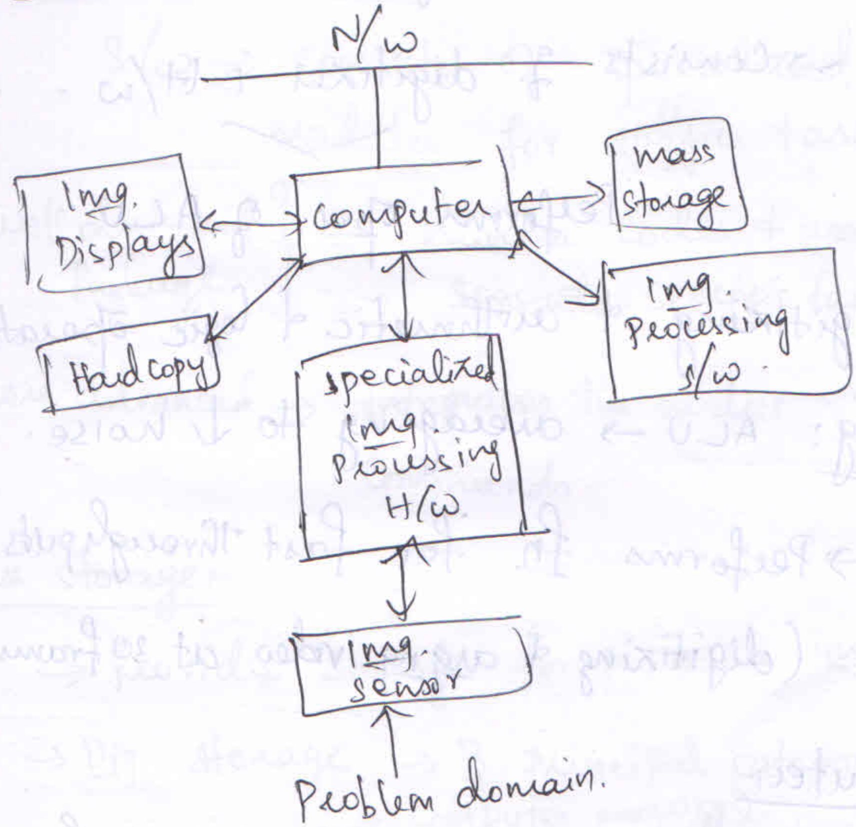
amp. of f → for (x,y) pair → called intensity or gray level of img.

when → x, y & amp. of f → are finite & discrete → the image is called digital image.

DIP → Processing of dig. img.

→ img. is composed of picture elements called pixels.

Elements of DIP :



Img sensor → 2 devices.

1 → Physical device sensitive to energy rad. by the obj.

2 → digitizer (convert o/p of phy. dev. to digital form).

Specialized Img. processing H/w:

→ Consists of digitizer + H/w.

Performs oper. of ALU.

digitizing + arithmetic + logic operation

eg: ALU → averaging to ↓ noise.

→ Performs fn. for fast throughputs.

(digitizing + avg ng video at 30 frames/se

Computer:

→ img. processing system range from PC to a super computer.

→ dedicated app. (spl.) custom computers are used to achieve req. performance.

Img. Processing S/w:

S/w → consists of specialized modules for specific task.

Well designed Package } → minim. codes & uses. ~~Speciati~~ specific tasks.

more advanced → integrates the modes. & Commands.

Mass storage:

→ Provides storage for processing img.

→ Dig. storage → 3 principal categories.

1. Short-term storage ~~for~~ → (computer memory) used during processing.

2. On-line storage for fast recall (opt. media, disks)

3. archival storage (infrequent access) (mag. tapes)

Img. displays:

→ color TV monitors.

→ monitors driven by the o/p of images graphics display cards that are an integral part of the computer system.

Hard Copy:

↳ devices for recording images

→ includes laser printers, film cameras, inkjet units,

→ digital units such as optical & CD-Rom disks.

(2)

N/working:

→ default fn. in any computer sys.

→ ↑ data used in img Processing app.

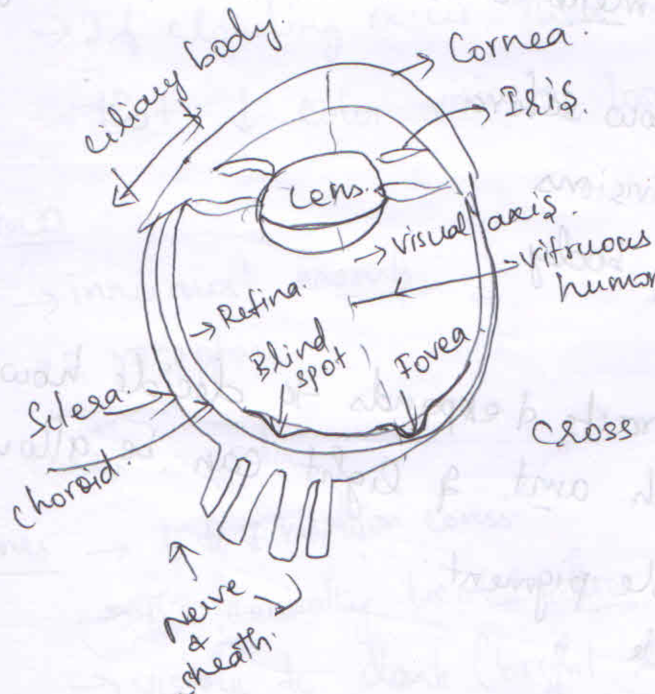
imp. thing is BW (tr. ↑ data)

Elements of Visual Perception:

→ DIP is based on mathematical & probabilistic formulations, human intuition & analysis.

→ img. formation → Perceived by humans.

Structure of the Human eye:



Cross section of human eye.

diameter → approx. 20 mm.

membranes → cornea, sclera.

Corner:

→ a transparent tissue that covers the anterior part of the eye.

Sclera

→ opaque memb covers other side of the eye.

choroid → below sclera.

→ 2 divisions

1. Ciliary body
2. Iris

Iris → contracts & expands to decide how much amt. of light can be allowed

front → visible pigment.

back → black "

Lens → Concentric layers of fibrous cells.
→ Suspended by ciliary body.
→ 60-70% water, 6% fat & ↑ protien than other parts of eye.
→ Contains yellow pigmentation, changes on age.
→ If clouding occurs, then it is called cataract that ↓ color vision & loss of clear vision.

Retina
→ innermost memb.
→ 2 receptors
Cones rods.

Cones → 6 to 7 million cones.
→ The centrally located elem is called fovea.
→ visible to dark (bright light)
→ each fovea indiv connected to the nerve end.

Cone vision → called as bright light vision or photopic.

Rods: → the no. is ↑, 75 to 150 million

→ spreaded in Retina.

→ many rods have common nerve end

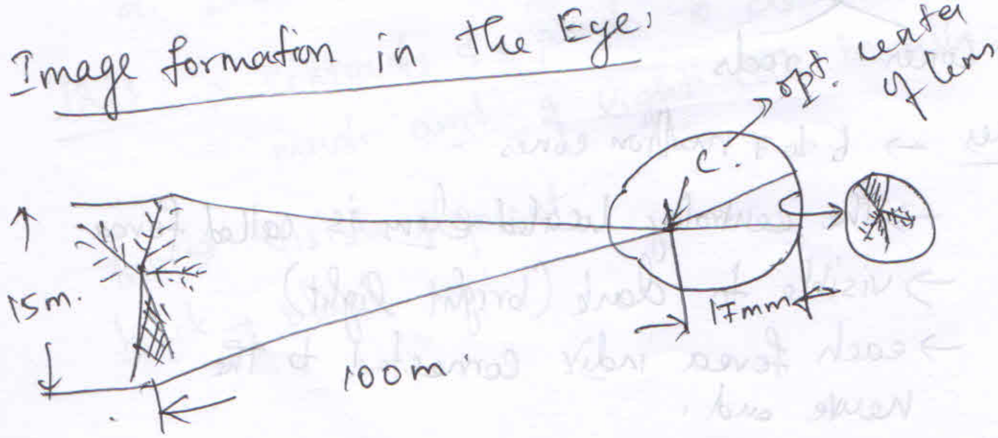
→ so ↓ visible to bright light

→ Sensitive to ↓ levels of illumination.

eg: Obj in sun appears → ~~than~~ diff when appears in moonlight. (3)

Rod vision → called Scotopic or dim-light vision.

Image formation in the Eye:



~~Image~~

Camera → distance adjust, focal length (fixed)

eye → dist. is fixed → change focal length by thickening or flatening the lens.

17 mm → dist. b/w retina & centre of ~~vision~~ lens.

14 - 17 mm → changes when eye is focussed & relaxed.

17 mm → to change focus upto 3 m.

Calc: dimens. of img. in retina.

tree → 15 m height.
dist. → 100 m.
h → ht. of retinal img.

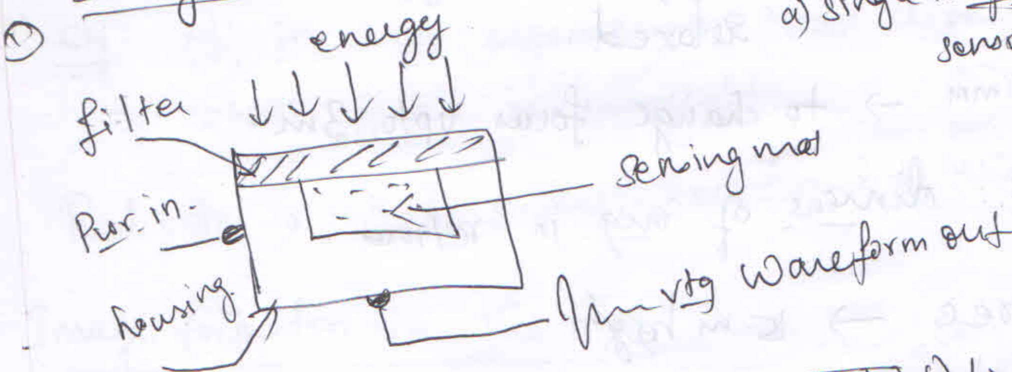
$$\frac{15}{100} = \frac{h}{17} ; \quad h = 2.55 \text{ mm}.$$

first → img. falls on fovea

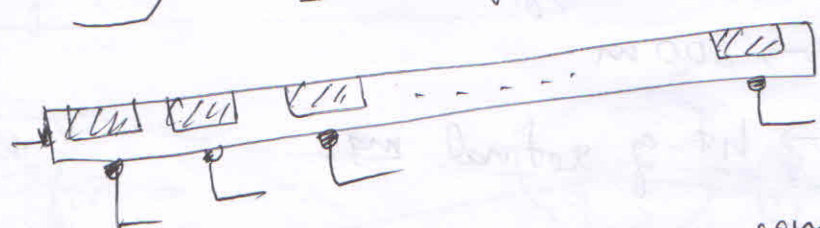
then light receptors → transform radiation energy to electrical impulses & send to brain

→ brain decodes it.

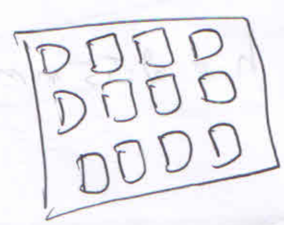
Image Sensing & Acquisition:



a) single imaging sensor



b) line



c) Array sensor

of sensors → transform illumination energy to digital images.

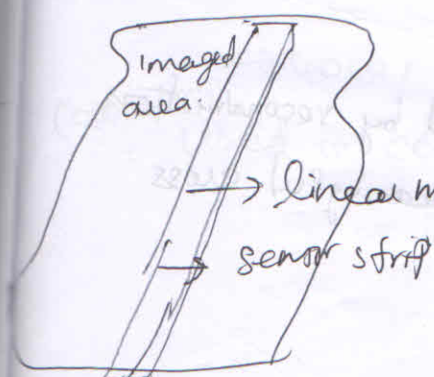
I/p energy ~~to~~ → into vtg, by combining I/p electric Pwr & sensor.

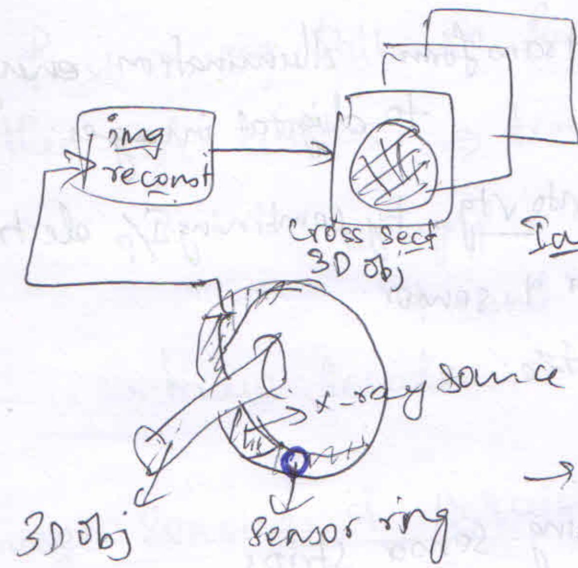
O/p vtg → digitize.

② Img. Acq. using sensor strips

strip → ~~Placed~~ on in-line arrangement of sensors in the form of strip.

used in aircraft → mounded on aircraft.





Img. acq. using circular sensor strip

→ used in medical & industrial img.

→ used to obtain cross sec 3-D images.

rotating x-ray source → illuminates

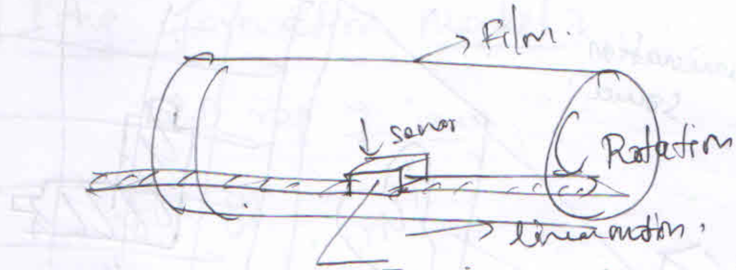
sensors → opp to source collects the x-ray en

passes through obj

o/p of sensor → be processed by reconstruction

to obtain meaningful cross

sect. img.



One img line out / increment of rotation & full linear displacement of sensor from left to right.

Comb. single sensor with motion to gen a 2-D img.

<u>Img. Acquisition using sensor arrays.</u>

→ 2D array

→ 4000 x 4000 elem are used.

(CCD sensors) used in CCD cameras

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

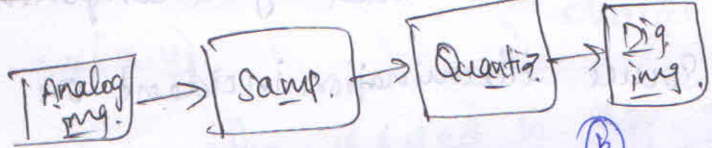
$0 < r(x,y) < 1$

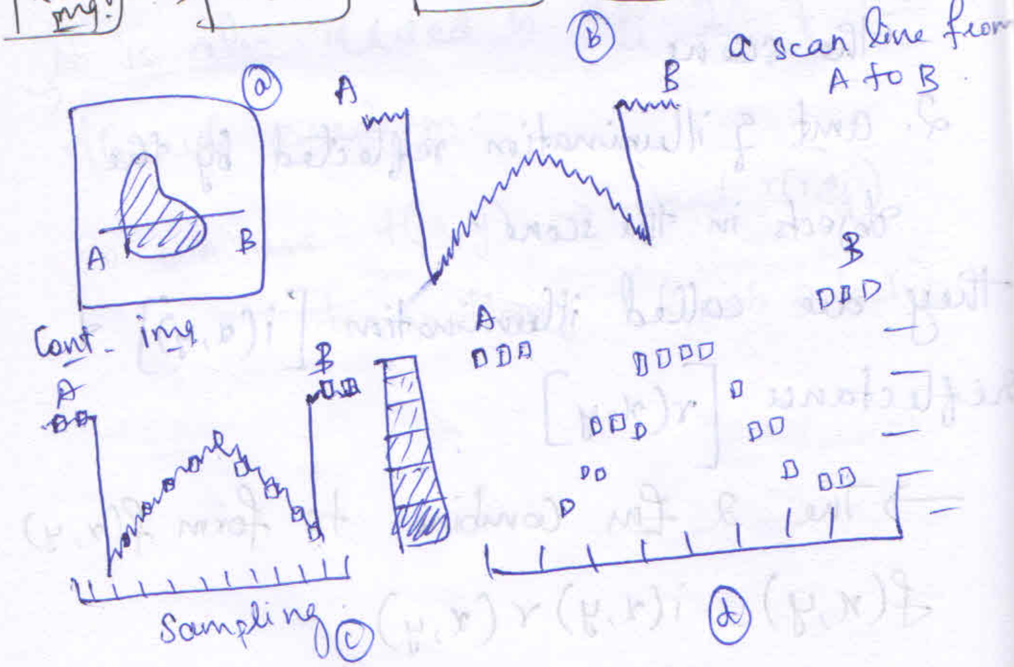
$r(x,y) \rightarrow 0$ to $1 \rightarrow$ (total reflection).
↓
(absorption)

(6)

(7)

Image Sampling & Quantization:





Continuous img. → $f(x,y)$.

" with x & y co-ordinates & also in amplitude.

To convert in dig. form.,

→ have to sample the fn. ~~for~~ both co-ordinates & in amp.

Digitizing the co-ordinate values is called sampling.

" the amp. values is called quantising.

→ Samp. & quant. is applied to the line AB.

(b) → is the plot of amp.

→ Variation → due to noise.

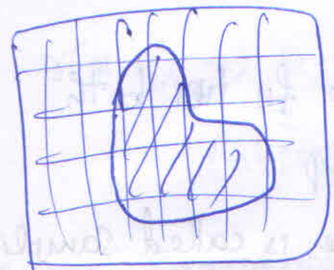
(c) ~~x~~ → to sample, we take equally spaced samples along line AB.

to form dig. fn. → intensity values corr. to discrete quantities.

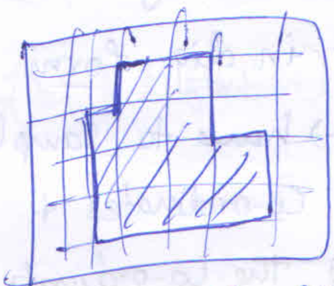
intensity scale → 8 intensity intervals.

assign any one level } → to each sample (matching)

→ Thus samp. & quant. are carried out in line by line process.

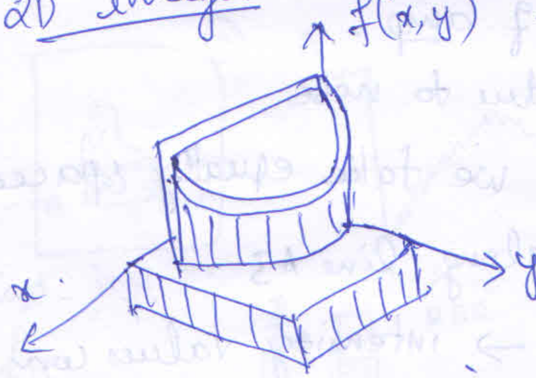


Cont. img. (to sensor array)



img. after samp & quantized.

2D image: $f(x,y)$ → to sample cont. i[...]
it contains M rows
N columns.



$f(x,y)$ → discrete co-ordina[...]

Origin of dig. img } starts at → $f(0,0)$

next → $f(0,1)$

Co-ordinats of img called } → spatial domain.

x & y → spatial co-ordinats

x & y → determines location.

f → intensities.

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

Image Interpolation:

→ used as zooming, shrinking, rotating & geom operations.

Interpolation → process of using known data to estimate values at unknown locations.

eg: an img. 500x500 pixels,

need to make it 750 x 750 pixels & fit

Create img grid ∓ 750 x 750 grid & shrink to orig with ~~500x500 pixel~~.

→ expand to specified size to obtain the

zoomed image.

This method is called nearest neighbour in

new loc. in orig image } → filled by the intensity the nearest neigh ~~img~~. the orig img.

bilinear interp: → we use 4 nearest neigh. to estimate the intensity at a given locat

bicubic interp: → use 16 nearest neighbours

→ used in Adobe photoshop & in editing pgms.

Brightness:

→ sensation associated with the amt. of light stimulus.

→ light intensity depends on total light emitted & the angle in which light is emitted.

Contrast:

→ diff. in luminance of the obj.

→ The perceived brightness on the surface depends on location background.

eg: same shade box when loc in black & white screen.

Img. formation model :

2-D rep of img.

$f(x, y)$

$(x, y) \to$ determined by the source of img.

to gen some o/p $f(x,y) \neq 0$.

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

$f(x,y) \to 2$ components.

1. the amt. of source illumination incident on the scene being viewed &
2. the amt of illumin. reflectanced by the obj in the scene.

Called as illumination & reflactance comp

$\underbrace{i(x, y), r(x, y)}_{f(x,y)}$.

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

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

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

reflactance → bounded to 0 & 1

→ $i(x,y)$ is determined by ~~r(x,y)~~ illum sou

→ $r(x,y)$ " " " charac. of imaged obj

→ it is also used in ~~app~~. Ex. of illum. through medium.

So we use $f(x,y)$ → instead $r(x,y)$

transmittivity. (limits 0 to 1).

Img. → generated by a physical process, its intensity is prop. to energy radiated by a physical source.

So $f(x, y)$ is a non-zero & finite,

$$0 < f(x,y) < \alpha.$$

The fn $f(x,y)$ characterized by 2 components.

1. amt of source illumination incident on the scene
2. amt. of illumination reflected by the objects in the scene.

they are called illumination $[i(x,y)]$ & reflectance $[r(x,y)]$

→ The 2 fns. combine to form $f(x,y)$

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

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

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

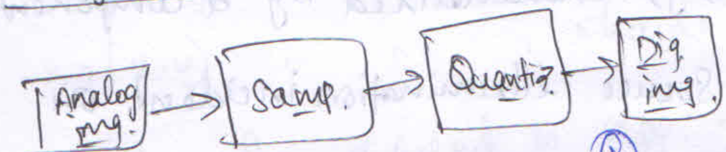
$r(x,y) \to 0$ to 1 → (total reflection). (6)

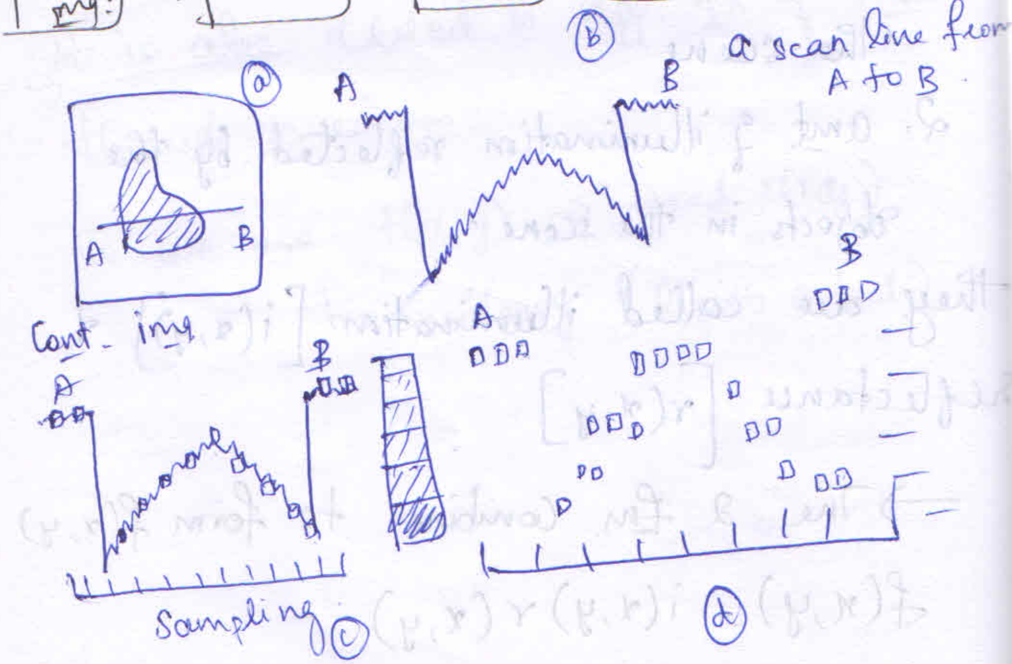
↓

(absorption)

(7)

Image Sampling & Quantization:





Digital Image Processing

Elements of Visual Perception

- Structure of the human eye

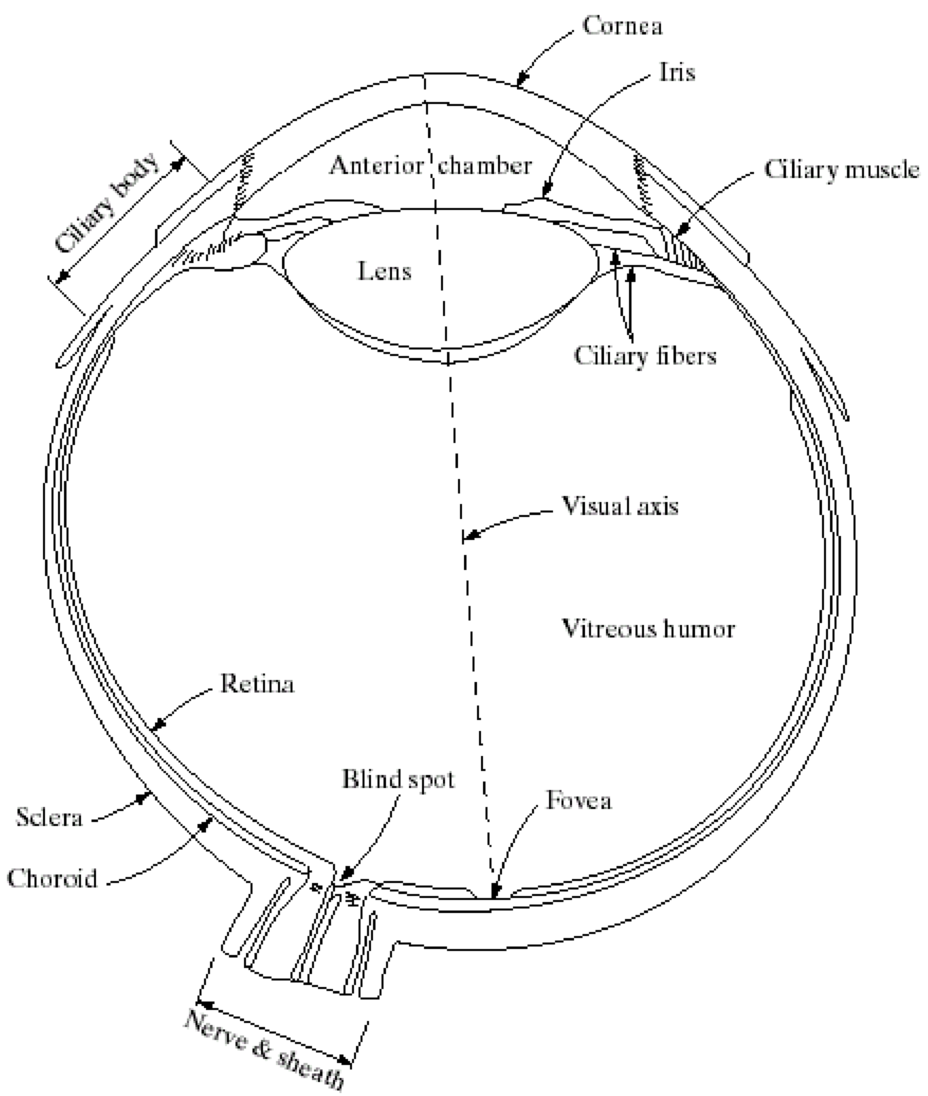


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

- Image formation in the eye

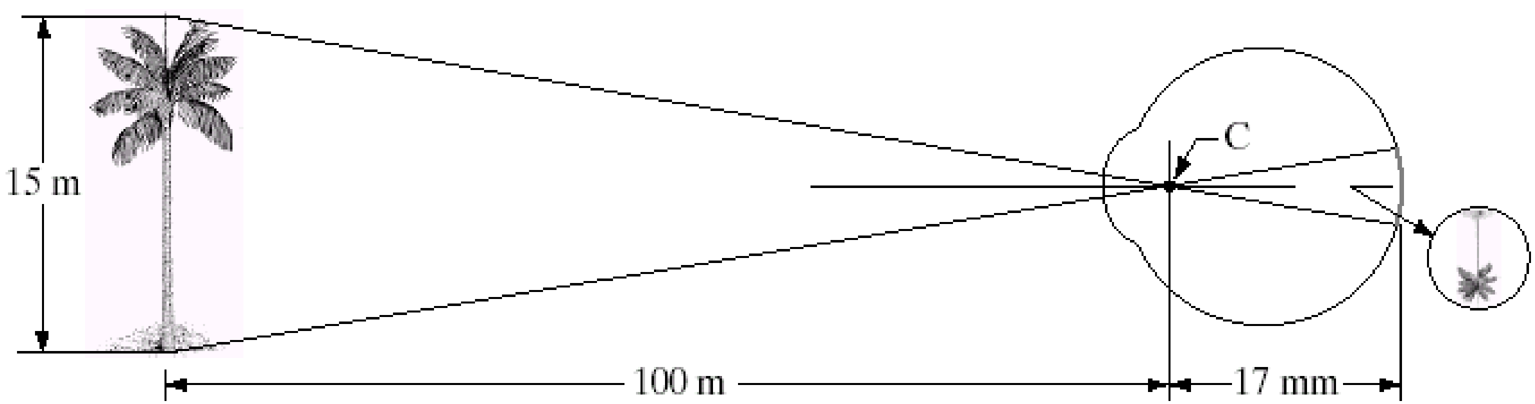
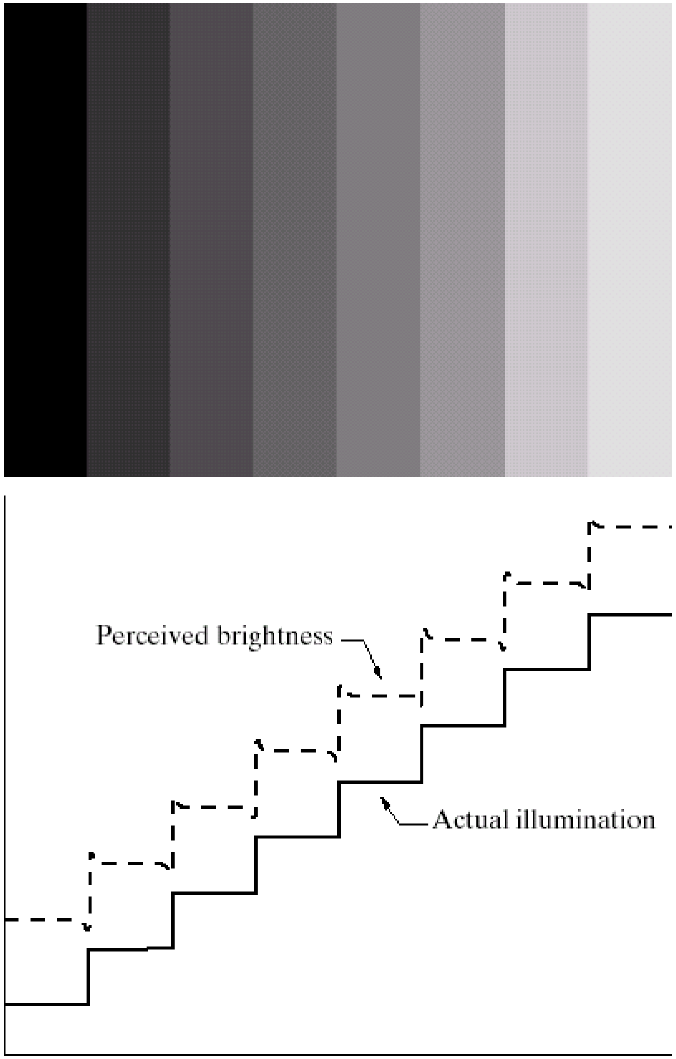


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

MATCHBAND EFFECT

- Perceived brightness



a
b

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

- Simultaneous contrast

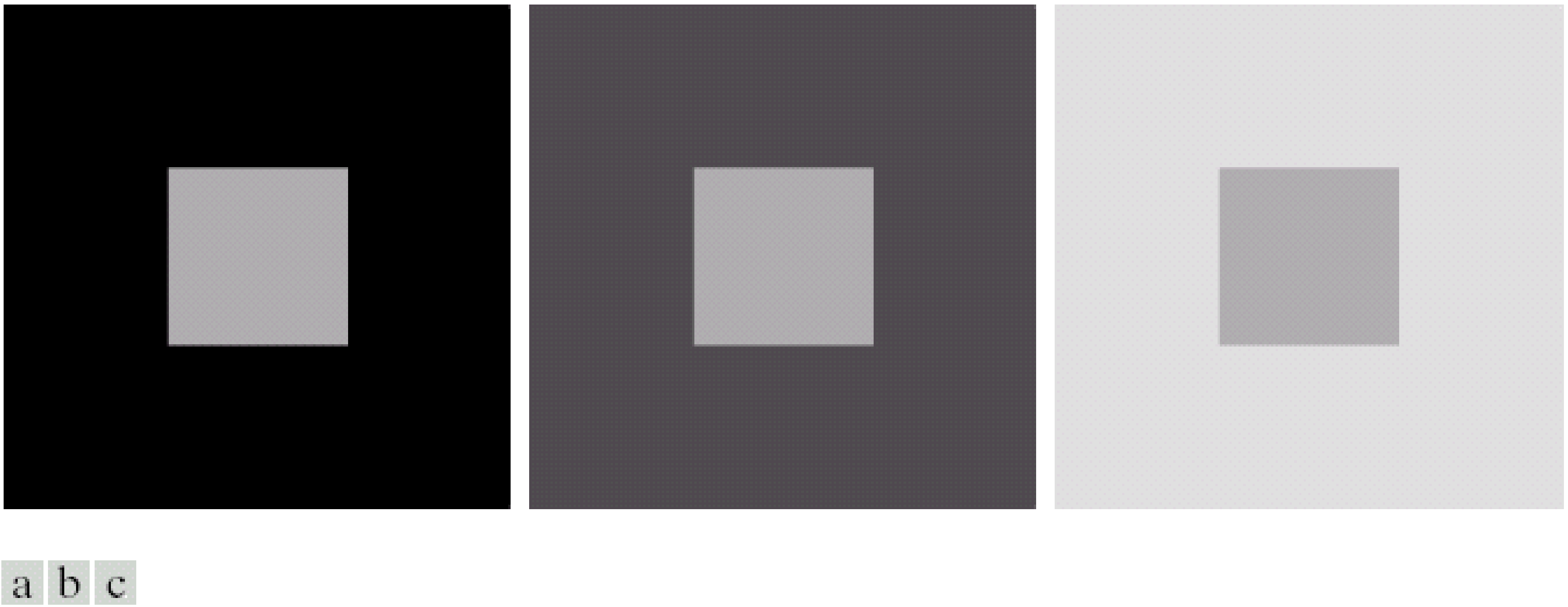


FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

- Optical illusion

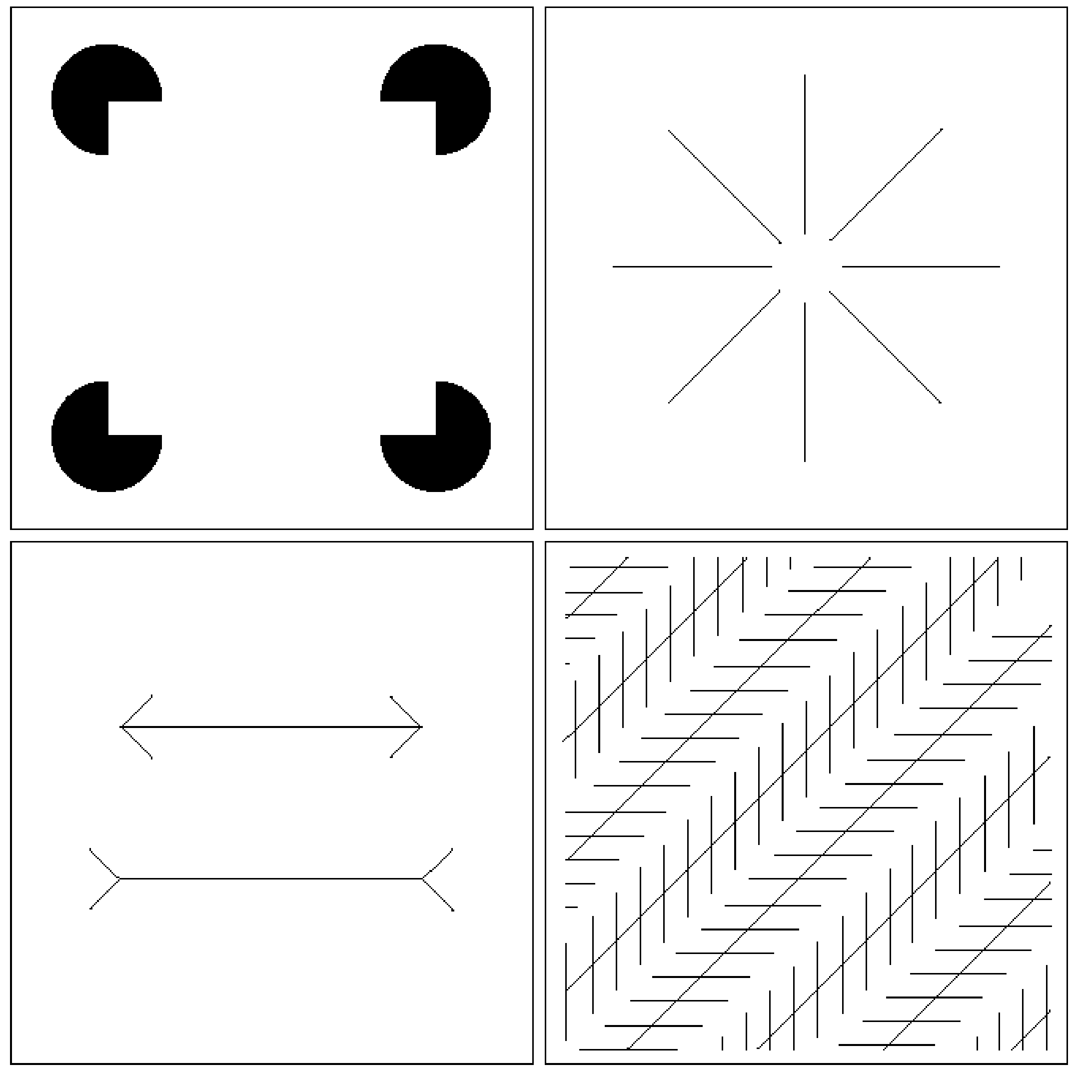


FIGURE 2.9 Some well-known optical illusions.

Image Sensing and Acquisition

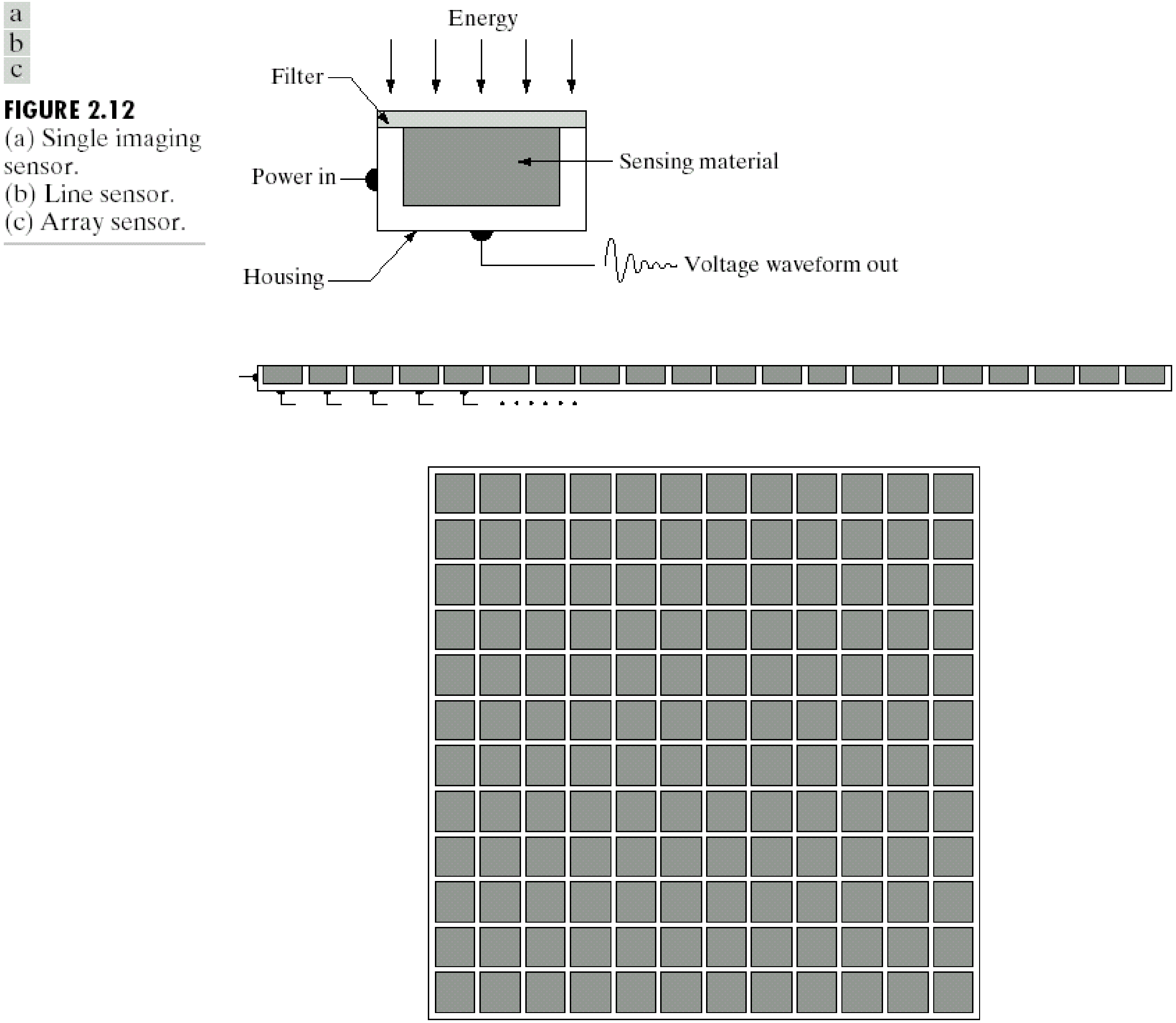


FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

- Image acquisition using a single sensor

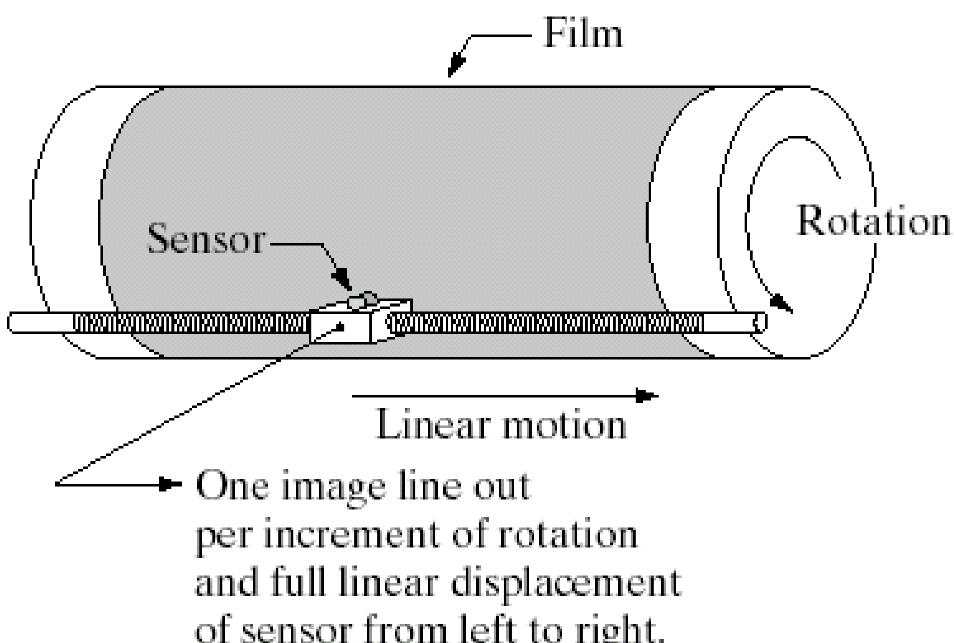
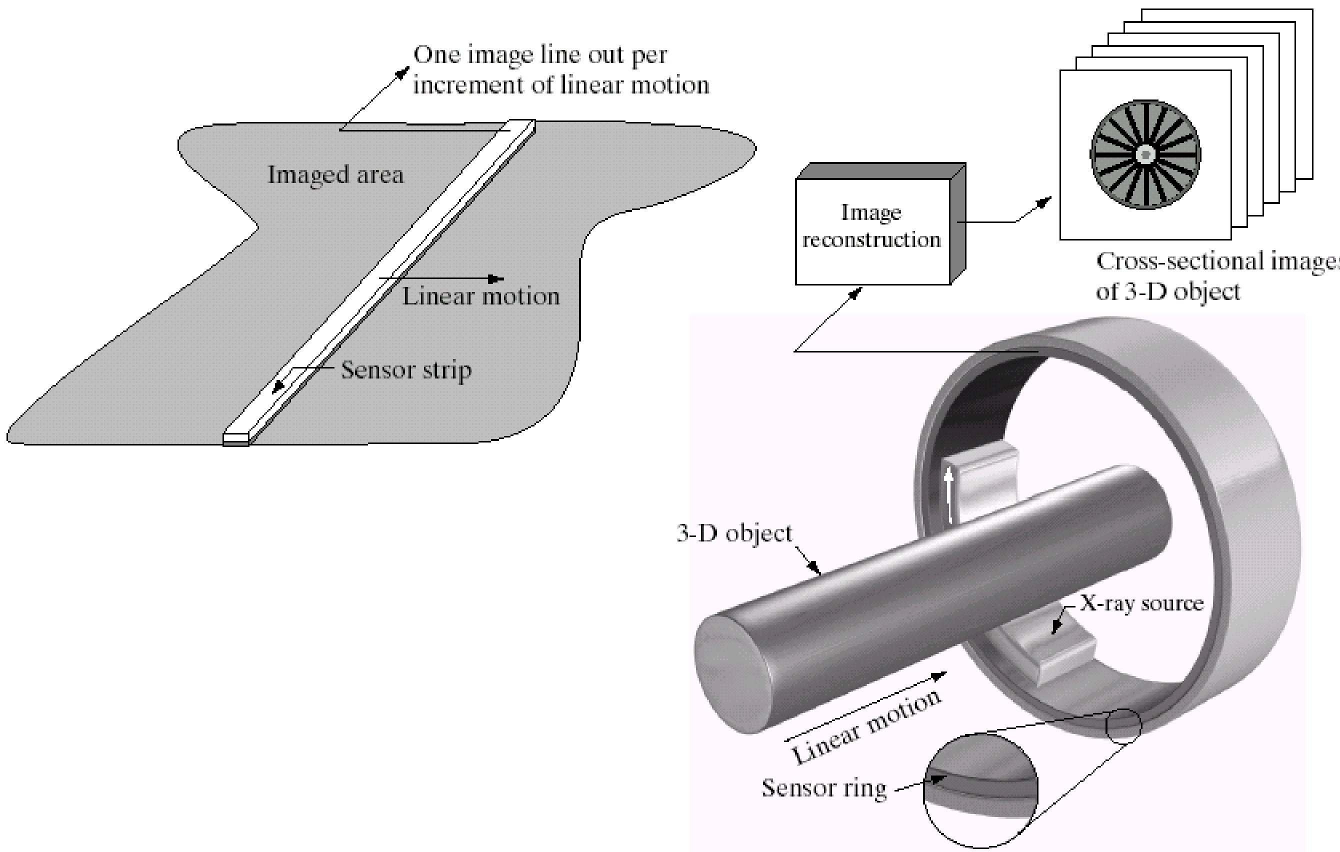


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

- Using sensor strips



a b

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

A simple image formation model

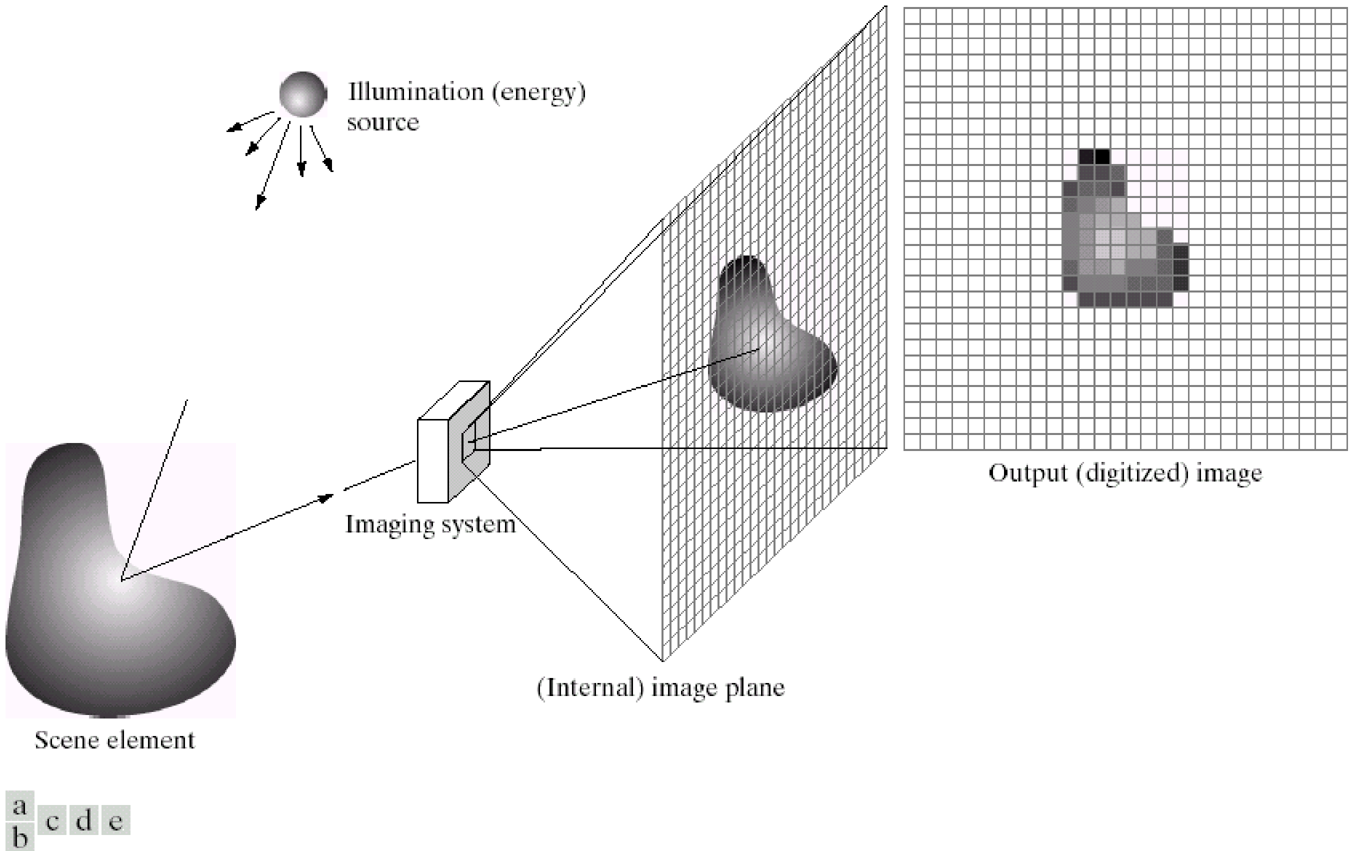


FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

- Illumination and reflectance
- Illumination and transmissivity

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

Image Sampling and Quantization

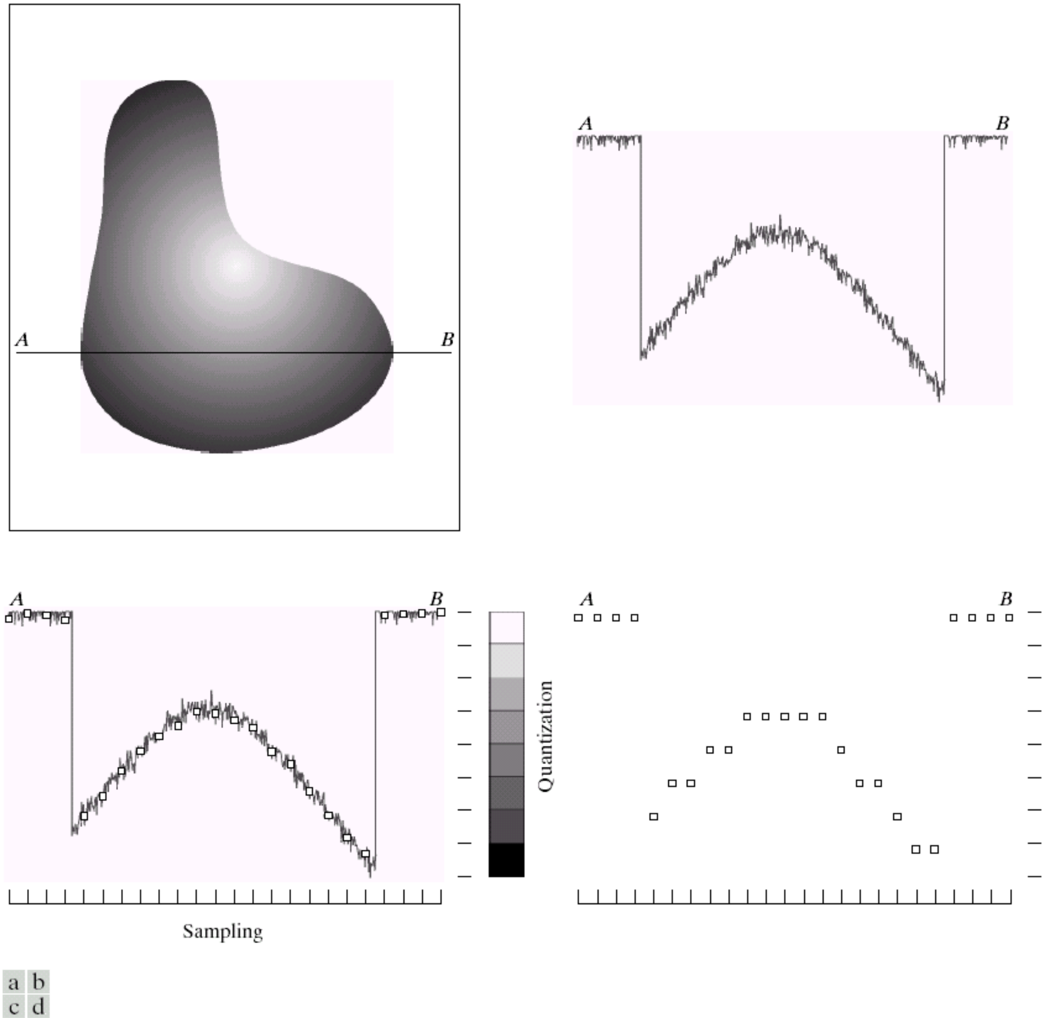
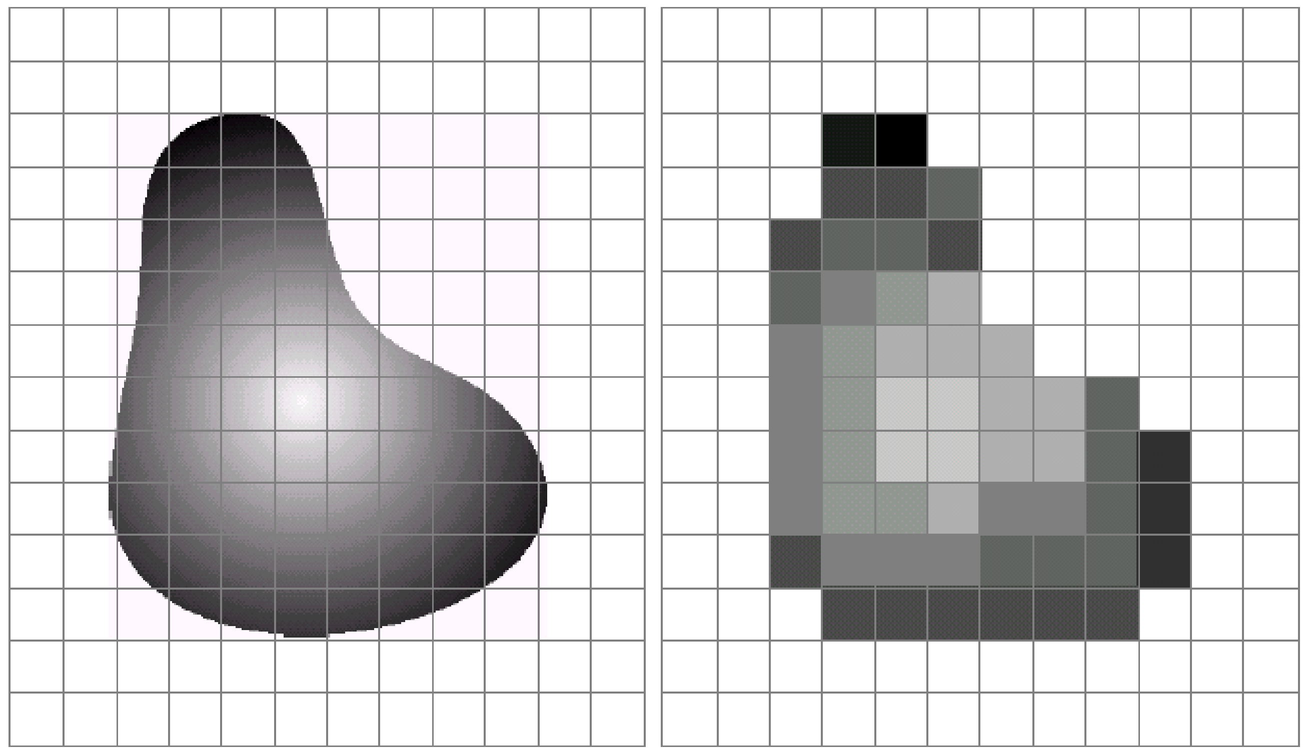


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

- Sampling and quantization



a b

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

- Representing digital images

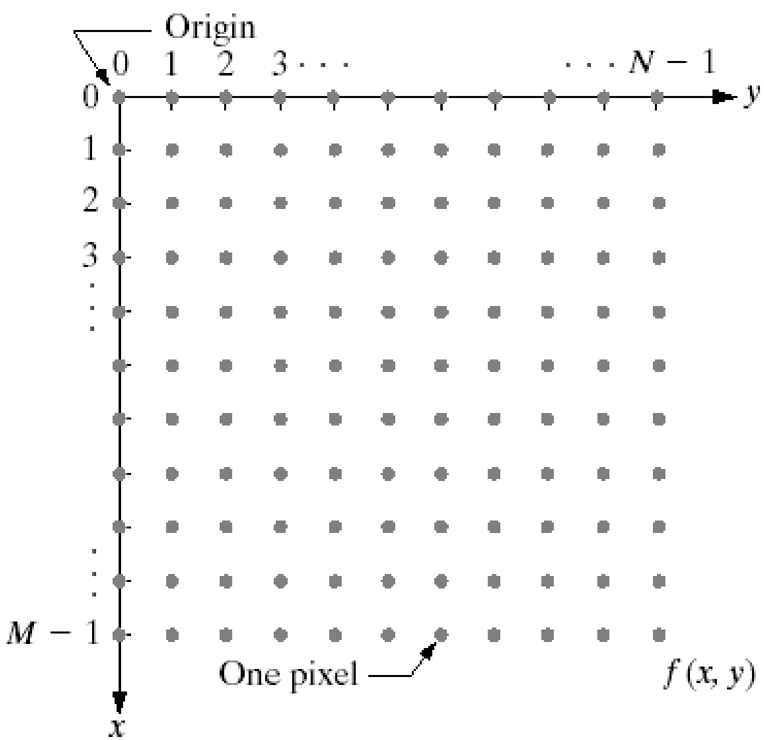


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

Some Basic Relationships Between Pixels

- Neighbors of a pixel
  - $N_4(p)$: 4-neighbors of p

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

$N_D(p)$: four diagonal neighbors of p

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

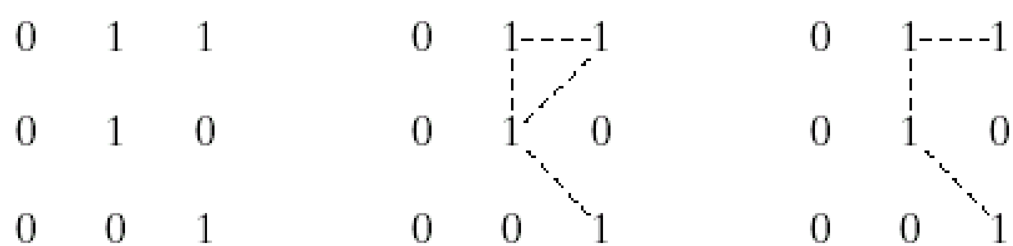
$(x-1, y+1)$

$N_8(p)$: 8-neighbors of p

$N_4(p)$ and $N_D(p)$

- Adjacency
  - V: The set of gray-level values used to define adjacency
  - 4-adjacency: Two pixels p and q with values from V are 4-adjacency if q is in the set $N_4(p)$
  - 8-adjacency: Two pixels p and q with values from V are 8-adjacency if q is in the set $N_8(p)$

- m-adjacency (mixed adjacency): Two pixels p and q with values from V are m-adjacency if
  - q is in $N_4(p)$, or
  - 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 b c

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

- Subset adjacency
  - S1 and S2 are adjacent if some pixel in S1 is adjacent to some pixel in S2
- Path
  - A path from p with coordinates (x, y) to pixel q with coordinates (s,t) is a sequence of distinct pixels with coordinates
  - (x_0, y_0), (x_1, y_1) ,…, (x_n, y_n)

  where (x_0, y_0)= (x, y) , (x_n, y_n) = (s,t) , and pixels (x_i, y_i) and (x_{i-1}, y_{i-1}) are adjacent

- Region
  - 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
- Edge
  - Pixels with derivative values that exceed a preset threshold

- Distance measures
  - Euclidean distance

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

  - City-block distance

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

  - Chessboard distance

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

- D_m distance: The shortest m-path between the points

- Linear operation
  - H is said to be a linear operator if, for any two images f and g and any two scalars a and b,

$$H(af + bg) = aH(f) + bH(g)$$

Basic Relationships Between Pixels

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

Neighbors of a Pixel

- Any pixel p(x, y) has two vertical and two horizontal neighbors, given by

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

- This set of pixels are called the 4-neighbors of P, and is denoted by N_4(P).

- Each of them are at a unit distance from P.

Neighbors of a Pixel (Contd..)

- The four diagonal neighbors of p*(x,y)* are given by,

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

- This set is denoted by $N_D(P)$.

- Each of them are at Euclidean distance of 1.414 from P.

Neighbors of a Pixel (Contd..)

- The points $N_D(P)$ and $N_4(P)$ are together known as 8-neighbors of the point P, denoted by $N_8(P)$.

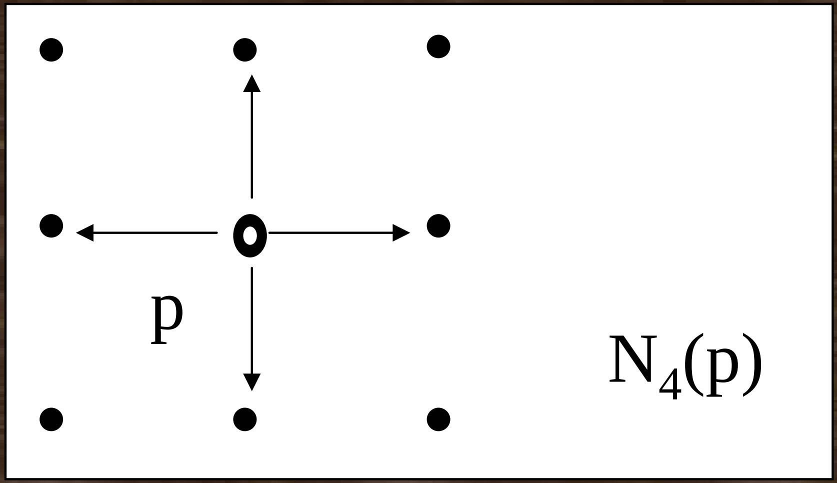
- Some of the points in the N_4, N_D and N_8 may fall outside image when P lies on the border of image.

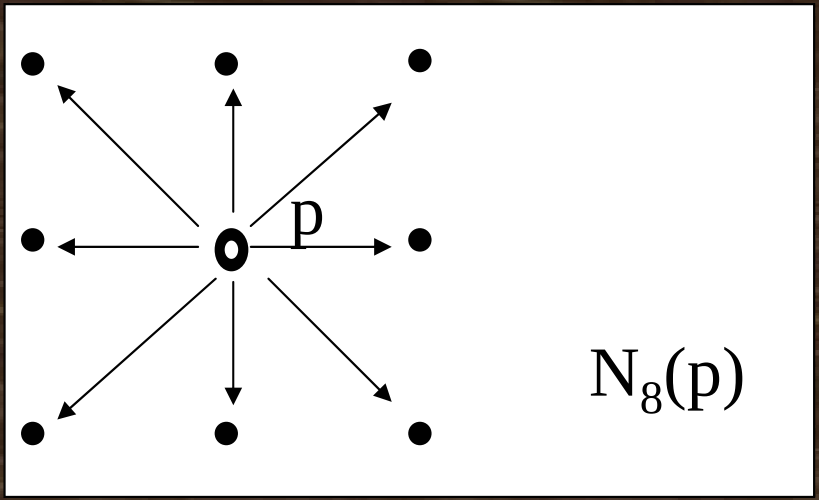
Neighbors of a Pixel (Contd..)

Neighbors of a pixel

a. 4-neighbors **of a pixel p are its vertical and horizontal neighbors denoted by $N_4(p)$**

b. 8-neighbors **of a pixel p are its vertical horizontal and 4 diagonal neighbors denoted by $N_8(p)$**





Neighbors of a Pixel (Contd..)

N_D	N_4	N_D
N_4	**P**	N_4
N_D	N_4	N_D

- N_4 - 4-neighbors
- N_D - diagonal neighbors
- N_8 - 8-neighbors (N_4 U N_D)

Adjacency

- **Two pixels are connected if they are neighbors and their gray levels satisfy some specified criterion of similarity.**
- **For example, in a binary image two pixels are connected if they are 4-neighbors and have same value (0/1).**

Adjacency (contd.)

- Let V be set of gray levels values used to define adjacency.
- 4-adjacency: Two pixels *p* and *q* with values from V are 4-adjacent if q is in the set $N_4(p)$.
- 8-adjacency: Two pixels *p* and *q* with values from V are 8-adjacent if q is in the set $N_8(p)$.
- m-adjacency: Two pixels *p* and *q* with values from V are m-adjacent if,
  - q is in $N_4(P)$.
  - q is in $N_D(p)$ and the set [$N_4(p) \cap N_4(q)$] is empty (has no pixels whose values are from V).

Connectivity :

To determine whether the pixels are adjacent in some sense.

Let V be the set of gray-level values used to define connectivity; then Two pixels p, q that have values from the set V are:

a. 4-connected, **if q is in the set $N_4(p)$**

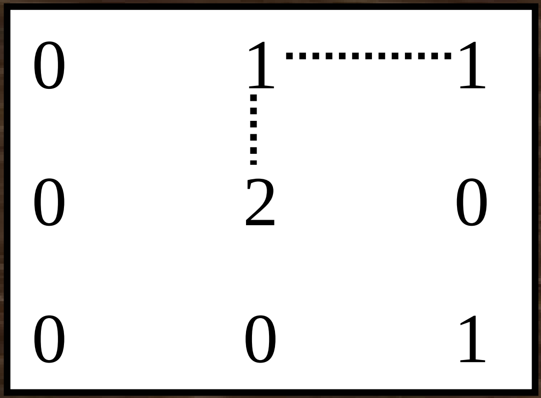
b. 8-connected, **if q is in the set $N_8(p)$**

c. m-connected, **iff**

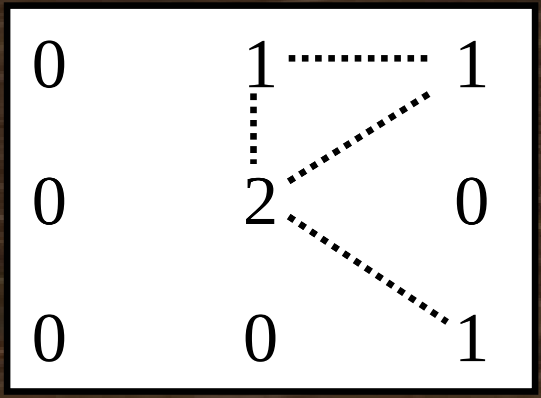
   i. q is in $N_4(p)$ or

   ii. q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ **is empty**

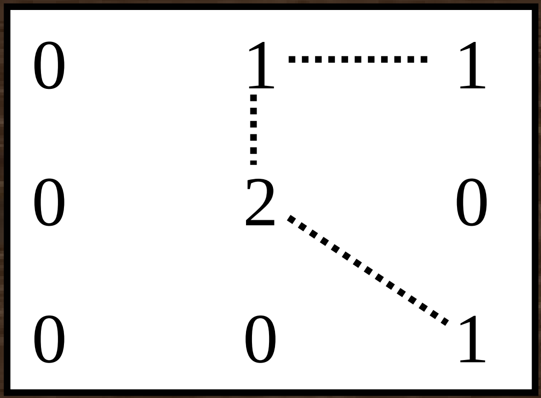
V = {1, 2}



a.

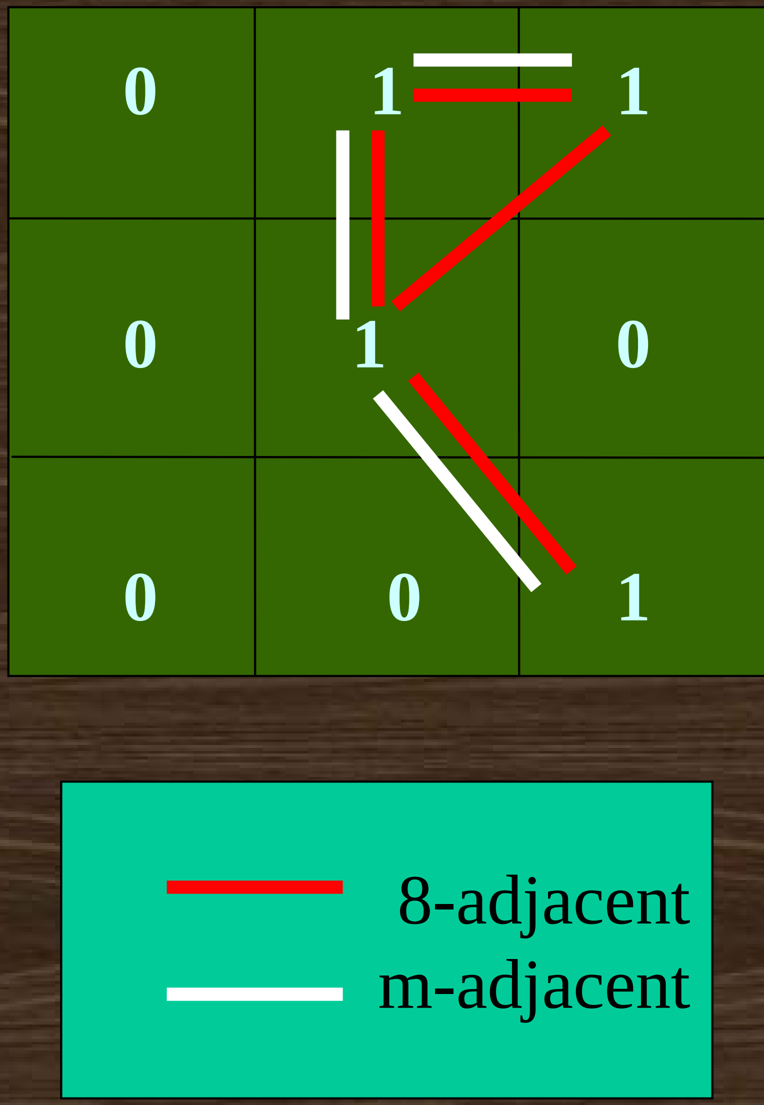


b.



c.

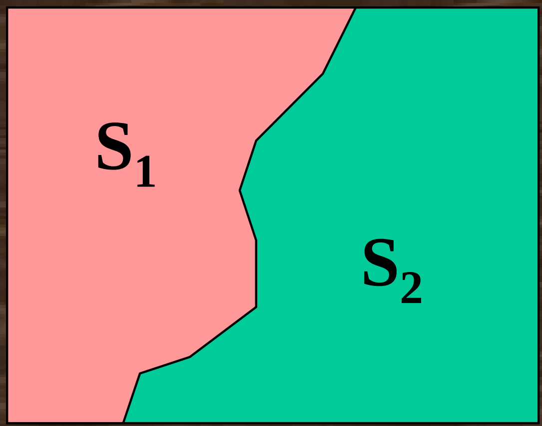
Adjacency/Connectivity



Adjacency/Connectivity

- **Pixel p is *adjacent* to pixel q if they are connected.**

- **Two *image subsets* S_1 and S_2 are adjacent if some pixel in S_1 is adjacent to some pixel in S_2**



Paths & Path lengths

- **A *path* from pixel p with coordinates *(x, y)* to pixel *q* with coordinates *(s, t)* is a sequence of distinct pixels with coordinates:**
  $(x_0, y_0), (x_1, y_1), (x_2, y_2) \dots (x_n, y_n)$,
  where $(x_0, y_0)=(x, y)$ and $(x_n, y_n)=(s, t)$; (x_i, y_i) is adjacent to (x_{i-1}, y_{i-1}) $1 \le i \le n$
- **Here *n* is the *length* of the path.**
- **We can define 4-, 8-, and m-paths based on type of adjacency used.**

Connected Components

- If *p* and *q* are pixels of an image subset S then *p* is ***connected*** to *q* in S if there is a path from *p* to *q* consisting entirely of pixels in S.
- For every pixel *p* in S, the set of pixels in S that are connected to *p* is called a ***connected component*** of S.
- If S has only one connected component then S is called ***Connected Set.***

Regions and Boundaries

- A subset R of pixels in an image is called a *Region* of the image if R is a connected set.
- The *boundary* of the region R is the set of pixels in the region that have one or more neighbors that are not in R.
- If R happens to be entire Image?

Distance measures

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

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

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

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

The following are the different Distance measures:

- **Euclidean Distance :**

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

b. City Block Distance: →

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

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

c. Chess Board Distance: →

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

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

Relationship between pixels (Contd..)

Arithmetic/Logic Operations:

- Addition : $p + q$
- Subtraction: $p - q$
- Multiplication: $p*q$
- Division: p/q
- AND: p AND q
- OR : p OR q
- Complement: NOT(q)

Neighborhood based arithmetic/Logic :

Value assigned to a pixel at position 'e' is a function of its neighbors and a set of window functions.

		:		
	a	b	c	
...	d	e	f	..
	g	h	i	
		:		

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

$$p = (w_1\mathbf{a} + w_2\mathbf{b} + w_3\mathbf{c} + w_4\mathbf{d} + w_5\mathbf{e} + w_6\mathbf{f} + w_7\mathbf{g} + w_8\mathbf{h} + w_9\mathbf{i})$$

$$= \sum w_i f_i$$

Arithmetic/Logic Operations

- Tasks done using neighborhood processing:
  - Smoothing / averaging
  - Noise removal / filtering
  - Edge detection
  - Contrast enhancement

- Issues
  - Choice of w_i's (N^2 values)
  - Choice of N, window size
  - Computation at boundaries
    - Do not compute at boundaries
    - Pad with zeros and extend image boundary
    - Pad assuming periodicity of image
    - Extrapolation of image

END of Neighborhood

and Connectivity

Digital Image Processing

Colour Image Processing

Introduction

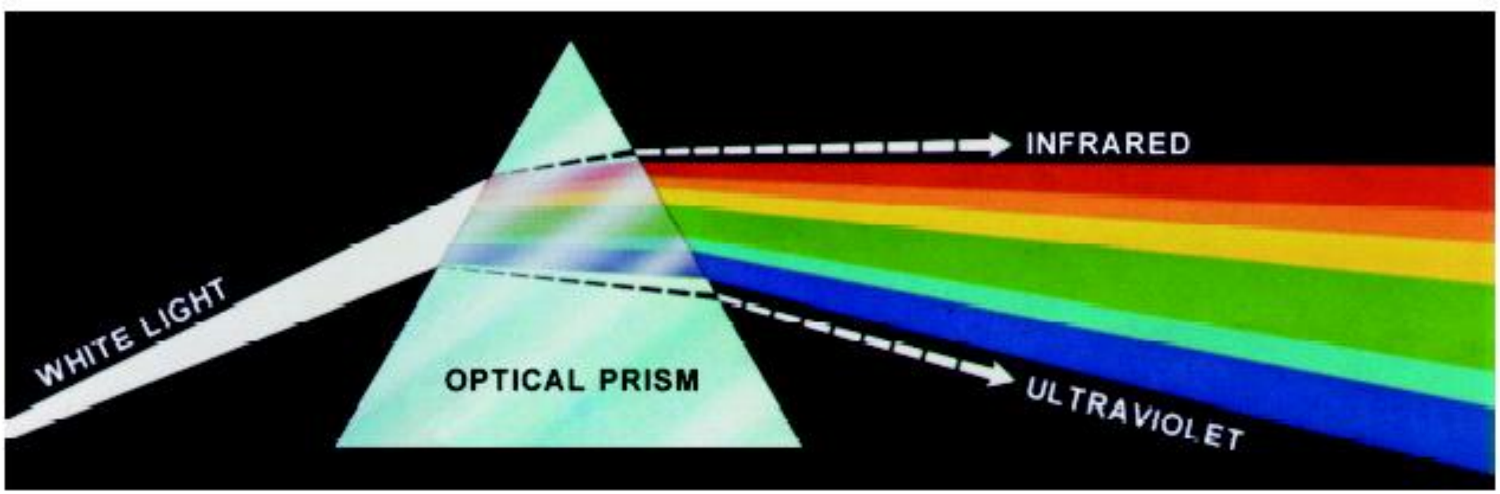
Today we'll look at colour image processing, covering:

– Colour fundamentals

– Colour models

Colour Fundamentals

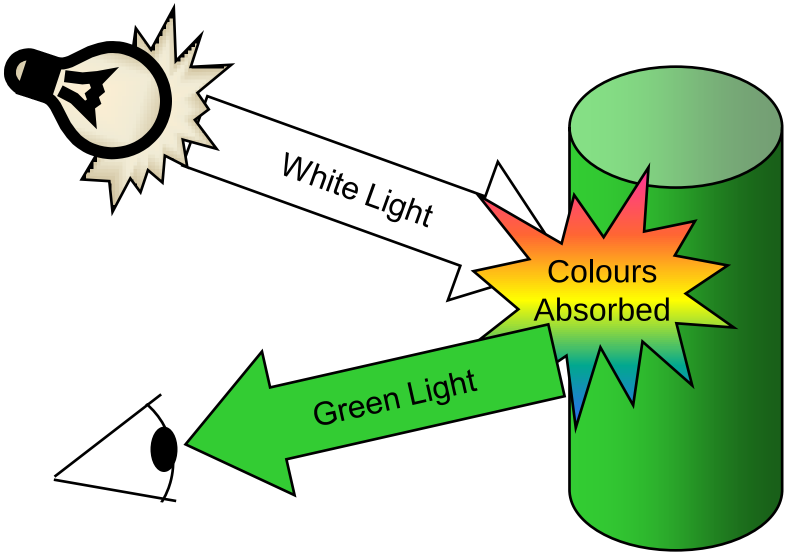
In 1666 Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging beam is split into a spectrum of colours



Colour Fundamentals (cont…)

The colours that humans and most animals perceive in an object are determined by the nature of the light reflected from the object

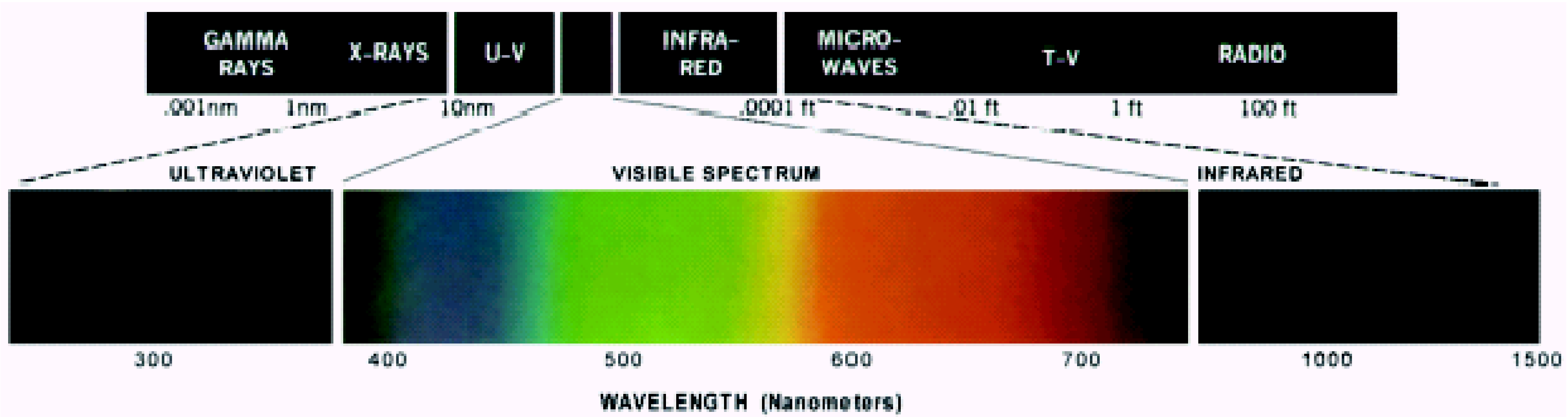
For example, green objects reflect light with wave lengths primarily in the range of 500 – 570 nm while absorbing most of the energy at other wavelengths



Colour Fundamentals (cont…)

Chromatic light spans the electromagnetic spectrum from approximately 400 to 700 nm

As we mentioned before human colour vision is achieved through 6 to 7 million cones in each eye



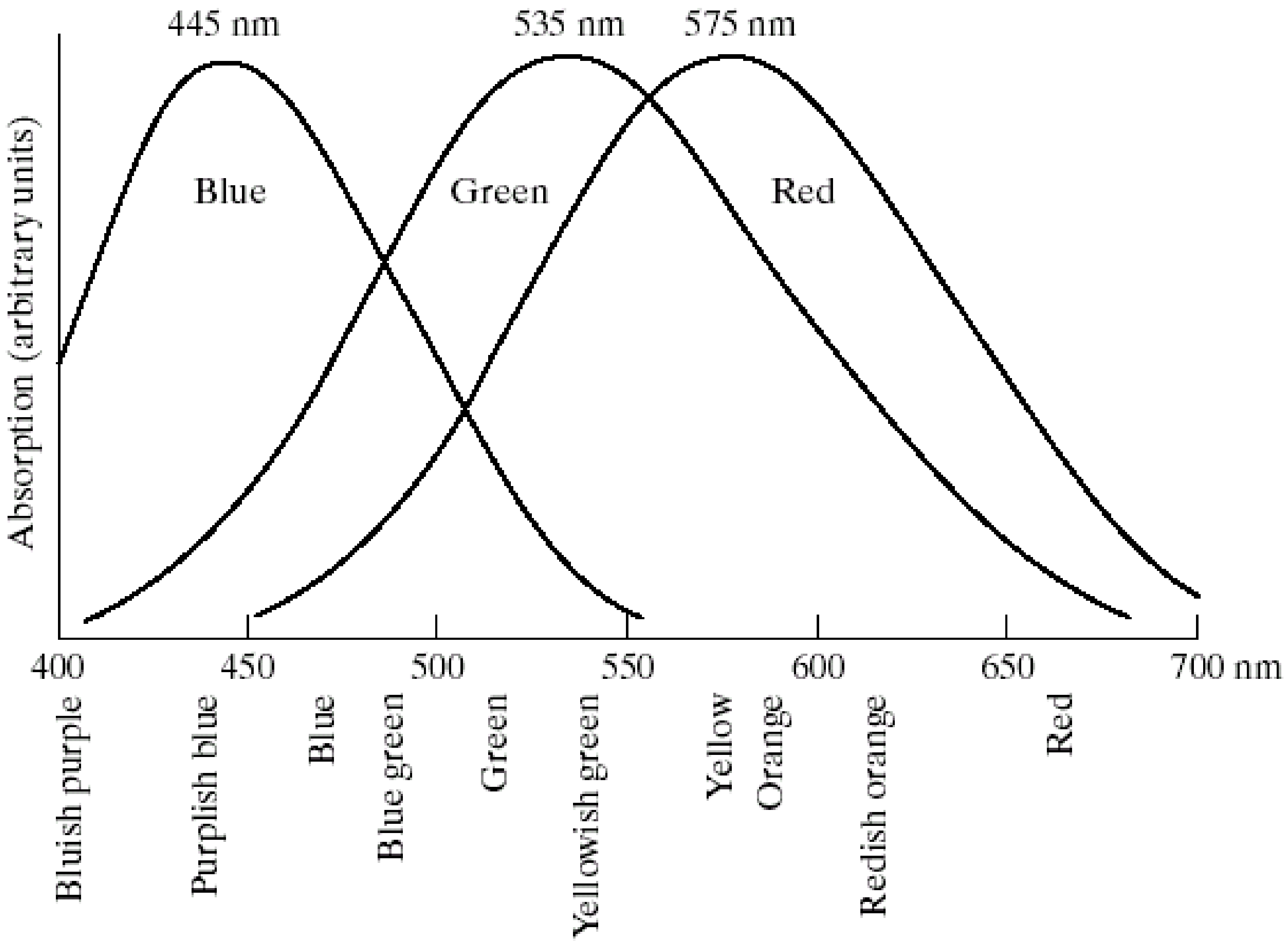
Colour Fundamentals (cont…)

Approximately 66% of these cones are sensitive to red light, 33% to green light and 6% to blue light

Absorption curves for the different cones have been determined experimentally

Strangely these do not match the CIE standards for red (700nm), green (546.1nm) and blue (435.8nm) light as the standards were developed before the experiments!

Colour Fundamentals (cont…)



Colour Fundamentals (cont…)

3 basic qualities are used to describe the quality of a chromatic light source:

- **Radiance:** the total amount of energy that flows from the light source (measured in watts)
- **Luminance:** the amount of energy an observer *perceives* from the light source (measured in lumens)
  - Note we can have high radiance, but low luminance
- **Brightness:** a subjective (practically unmeasurable) notion that embodies the intensity of light

We'll return to these later on

CIE Chromacity Diagram

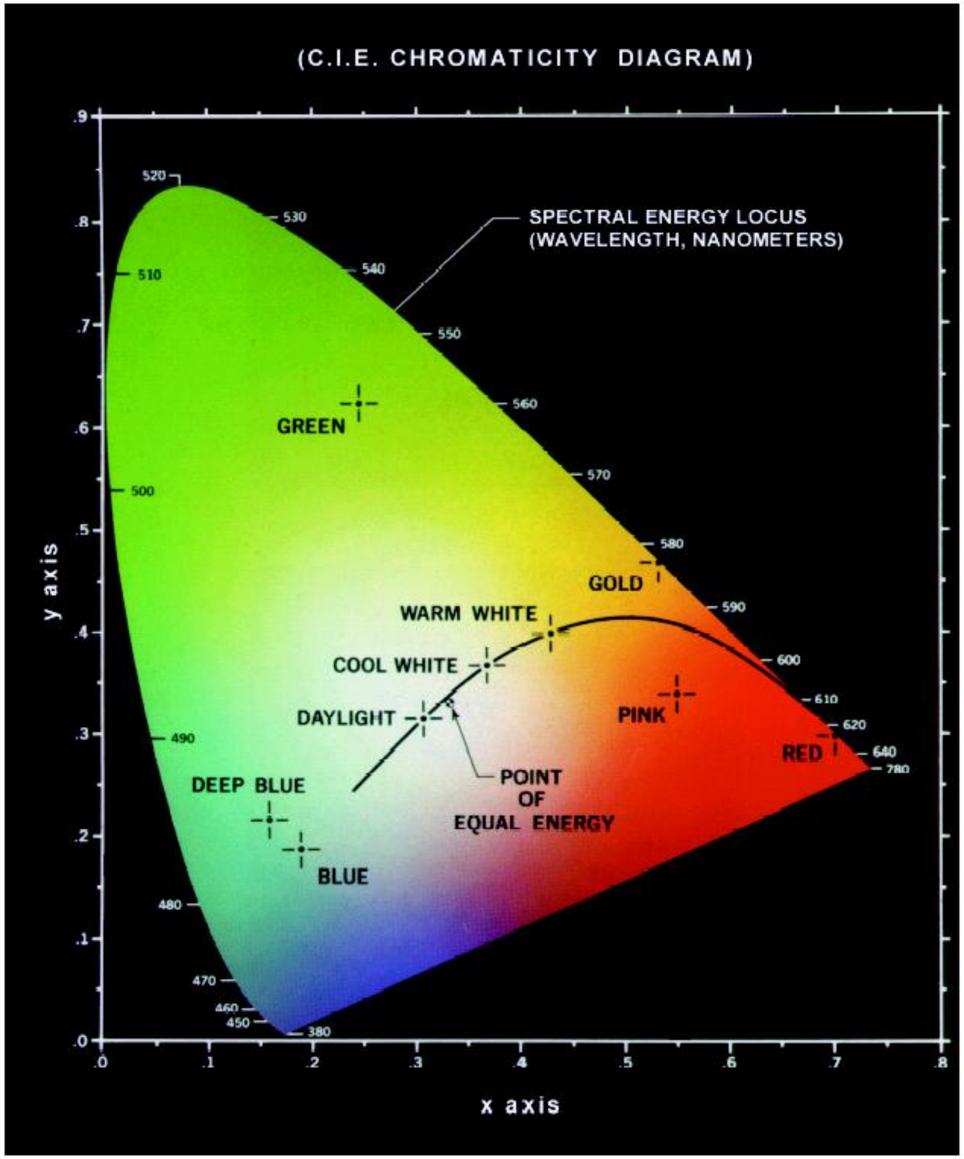
Specifying colours systematically can be achieved using the CIE **chromacity diagram**

On this diagram the x-axis represents the proportion of red and the y-axis represents the proportion of red used

The proportion of blue used in a colour is calculated as:

$$z = 1 - (x + y)$$

CIE Chromacity Diagram (cont…)



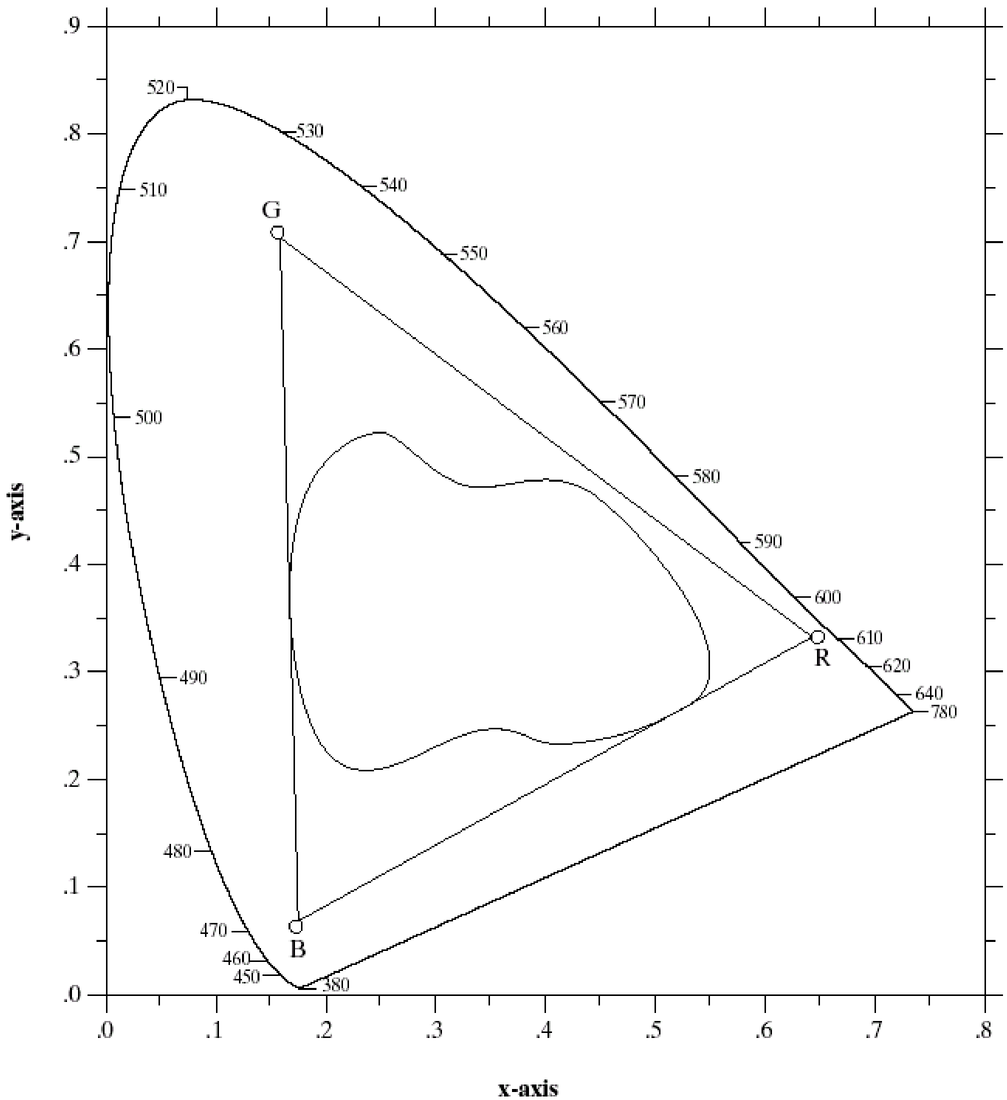
Green: 62% green, 25% red and 13% blue

Red: 32% green, 67% red and 1% blue

CIE Chromacity Diagram (cont…)

- Any colour located on the boundary of the chromacity chart is fully saturated
- The point of equal energy has equal amounts of each colour and is the CIE standard for pure white
- Any straight line joining two points in the diagram defines all of the different colours that can be obtained by combining these two colours additively
- This can be easily extended to three points

CIE Chromacity Diagram (cont…)



- This means the entire colour range cannot be displayed based on any three colours
- The triangle shows the typical colour gamut produced by RGB monitors
- The strange shape is the gamut achieved by high quality colour printers

Colour Models

From the previous discussion it should be obvious that there are different ways to model colour

We will consider two very popular models used in colour image processing:

– RGB (**R**ed **G**reen **B**lue)

– HIS (**H**ue **S**aturation **I**ntensity)

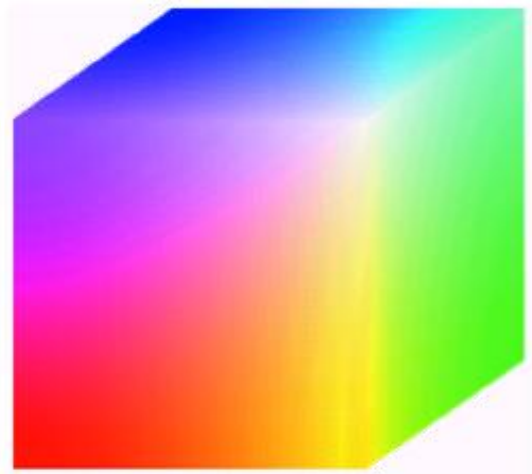
RGB

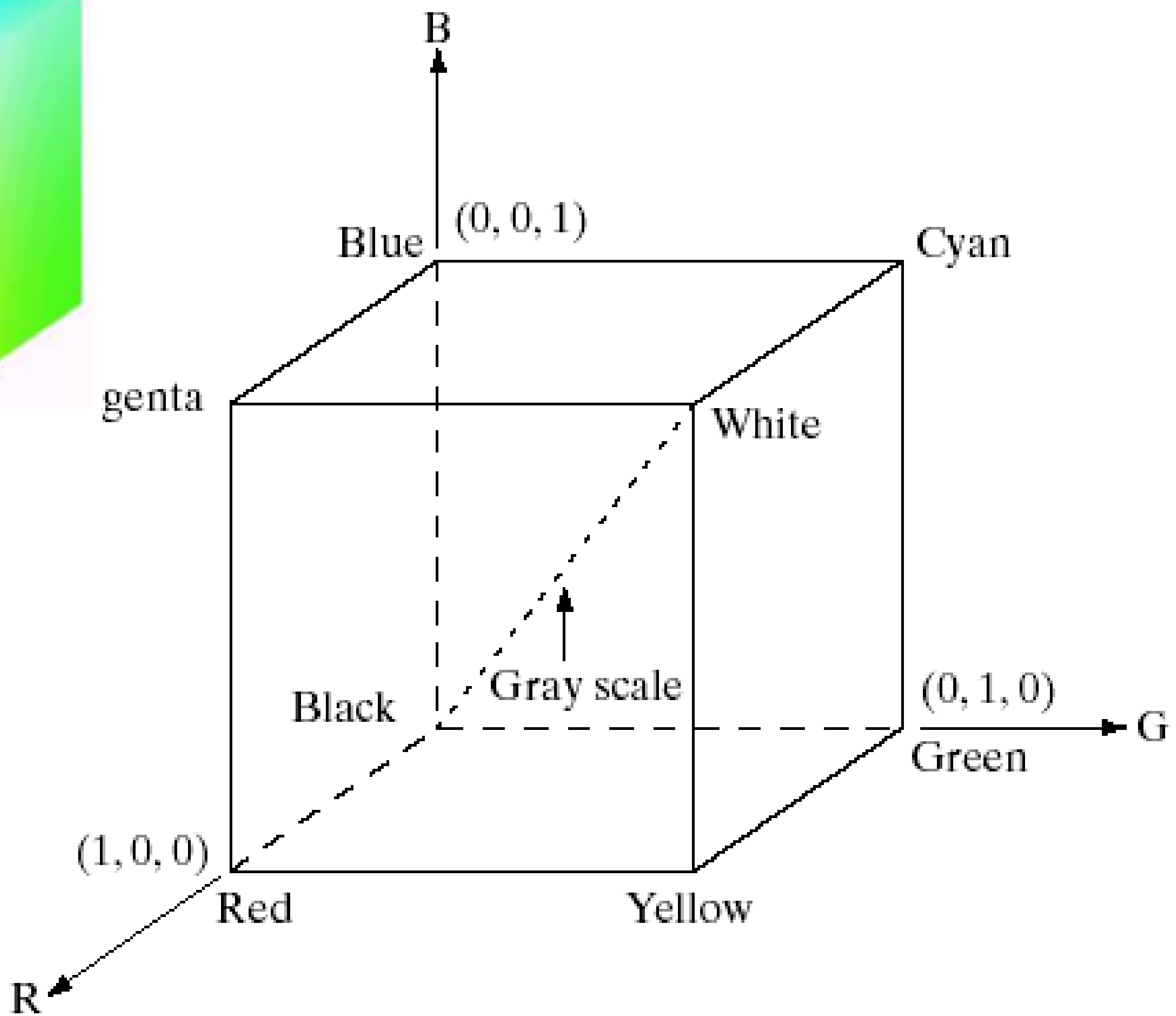
In the RGB model each colour appears in its primary spectral components of red, green and blue

The model is based on a Cartesian coordinate system

- RGB values are at 3 corners
- Cyan magenta and yellow are at three other corners
- Black is at the origin
- White is the corner furthest from the origin
- Different colours are points on or inside the cube represented by RGB vectors

RGB (cont…)





B
Blue
(0, 0, 1)
Cyan
genta
White
Gray scale
Black
(0, 1, 0)
G
Green
(1, 0, 0)
Red
Yellow
R

RGB (cont…)

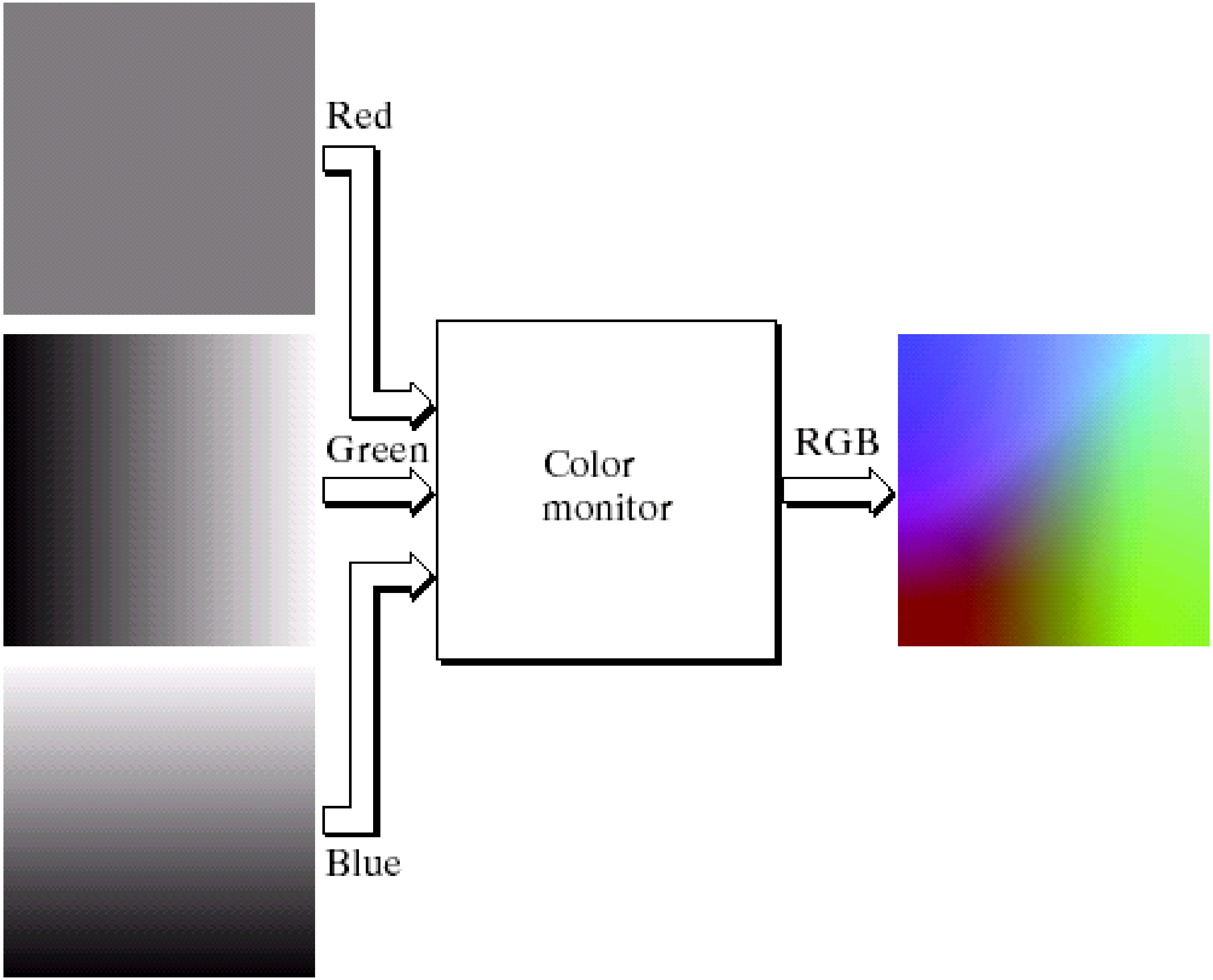
Images represented in the RGB colour model consist of three component images – one for each primary colour

When fed into a monitor these images are combined to create a composite colour image

The number of bits used to represent each pixel is referred to as the colour depth

A 24-bit image is often referred to as a full-colour image as it allows $\left(2^8\right)^3 = 16{,}777{,}216$ colours

RGB (cont…)



The HSI Colour Model

RGB is useful for hardware implementations and is serendipitously related to the way in which the human visual system works

However, RGB is not a particularly intuitive way in which to describe colours

Rather when people describe colours they tend to use **hue**, **saturation** and **brightness**

RGB is great for colour generation, but HSI is great for colour description

The HSI Colour Model (cont…)

The HSI model uses three measures to describe colours:

– **Hue:** A colour attribute that describes a pure colour (pure yellow, orange or red)

– **Saturation:** Gives a measure of how much a pure colour is diluted with white light

– **Intensity:** Brightness is nearly impossible to measure because it is so subjective. Instead we use intensity. Intensity is the same achromatic notion that we have seen in grey level images

HSI, Intensity & RGB

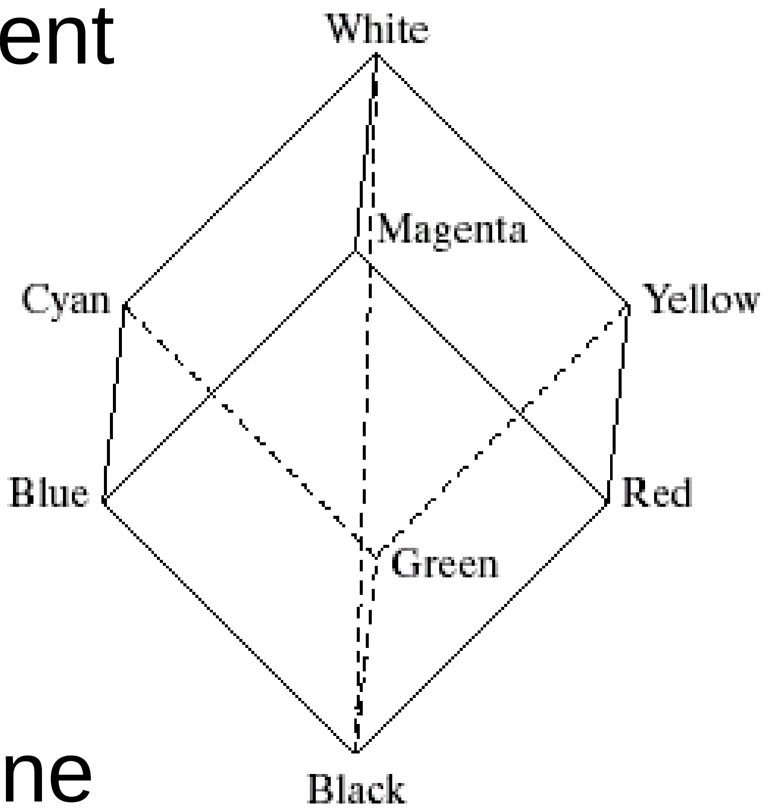
Intensity can be extracted from RGB images – which is not surprising if we stop to think about it

Remember the diagonal on the RGB colour cube that we saw previously ran from black to white

Now consider if we stand this cube on the black vertex and position the white vertex directly above it

HSI, Intensity & RGB (cont…)

Now the intensity component of any colour can be determined by passing a plane *perpendicular* to the intenisty axis and containing the colour point



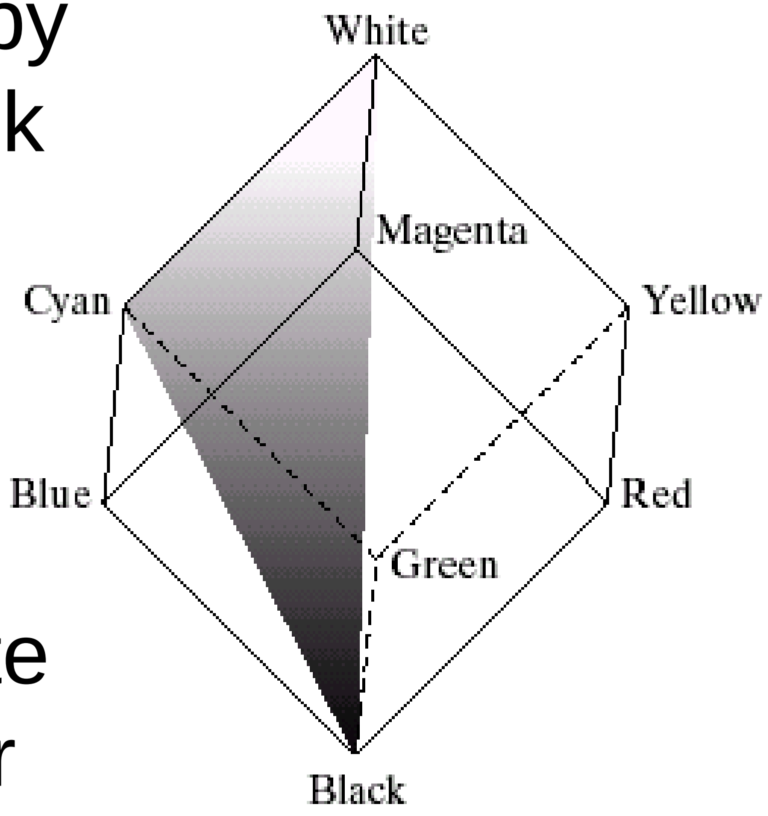
The intersection of the plane with the intensity axis gives us the intensity component of the colour

HSI, Hue & RGB

In a similar way we can extract the hue from the RGB colour cube

Consider a plane defined by the three points cyan, black and white

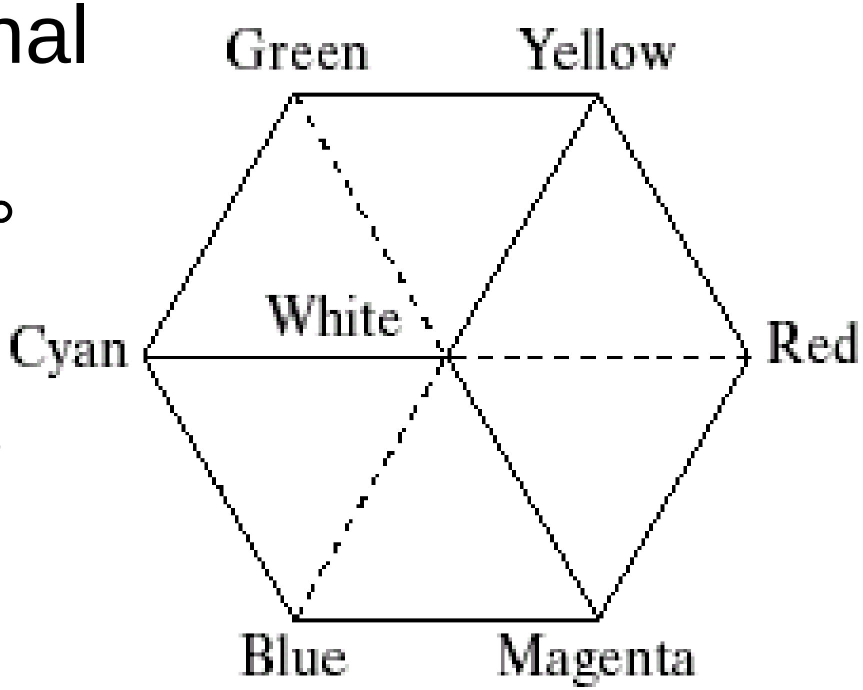
All points contained in this plane must have the same hue (cyan) as black and white cannot contribute hue information to a colour



The HSI Colour Model

Consider if we look straight down at the RGB cube as it was arranged previously

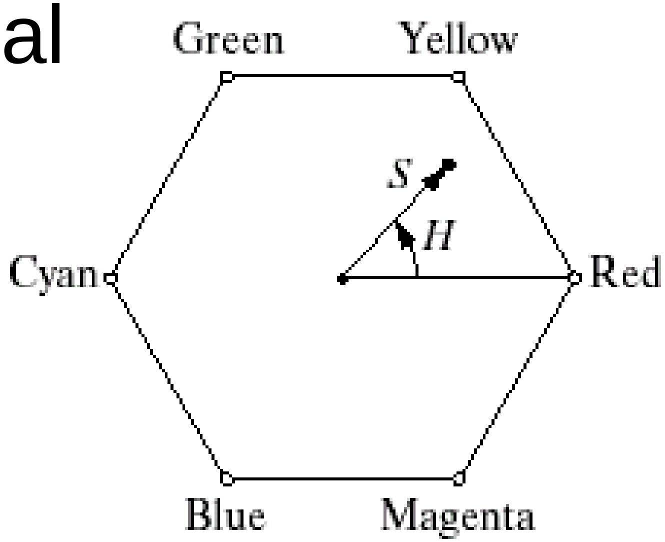
We would see a hexagonal shape with each primary colour separated by 120° and secondary colours at 60° from the primaries



So the HSI model is composed of a vertical intensity axis and the locus of colour points that lie on planes perpendicular to that axis

The HSI Colour Model (cont…)

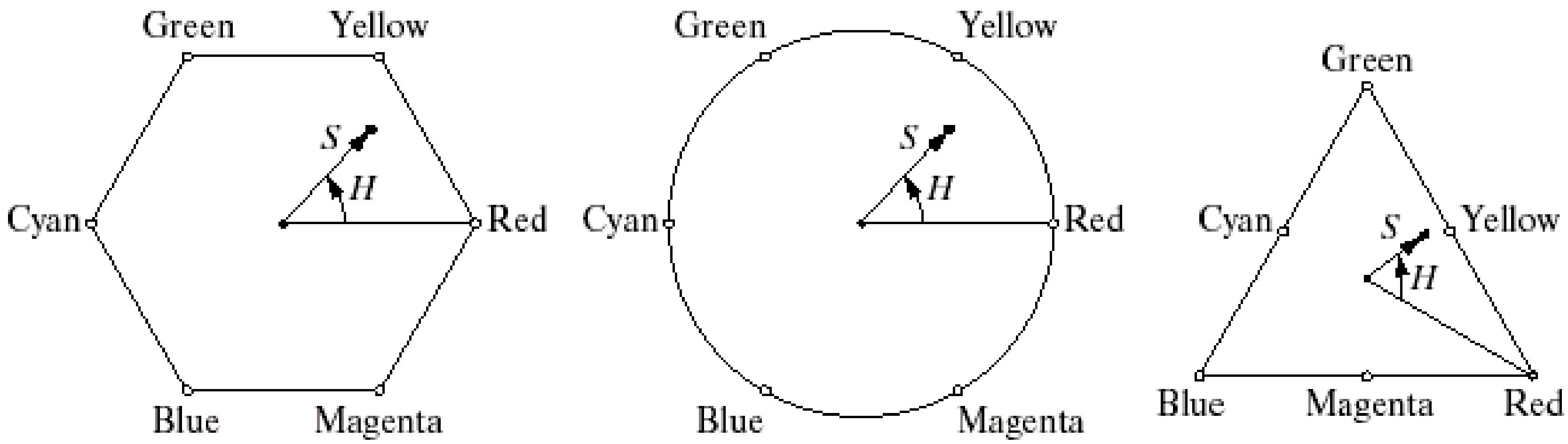
To the right we see a hexagonal shape and an arbitrary colour point



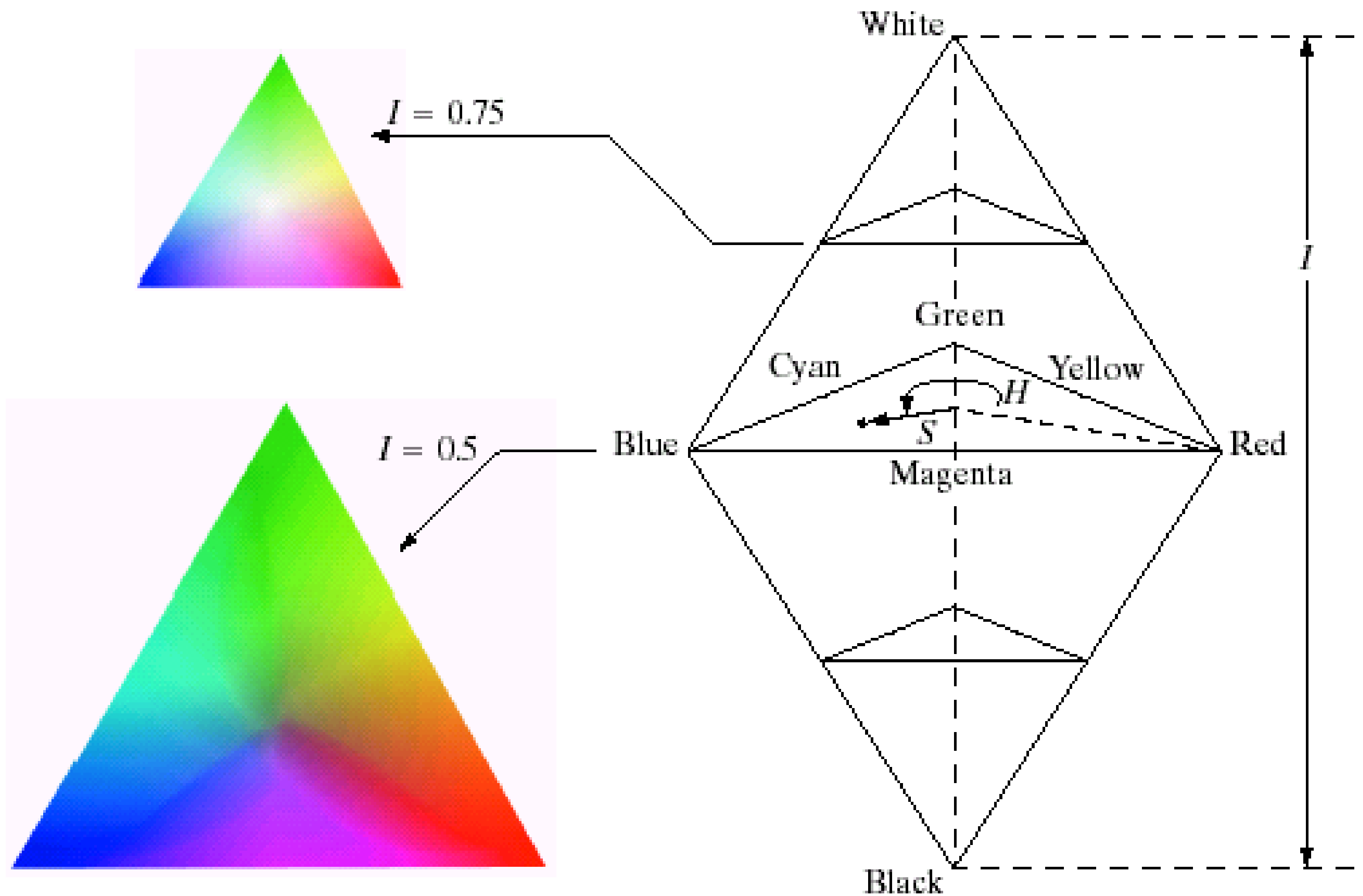
- The hue is determined by an angle from a reference point, usually red
- The saturation is the distance from the origin to the point
- The intensity is determined by how far up the vertical intenisty axis this hexagonal plane sits (not apparent from this diagram

The HSI Colour Model (cont…)

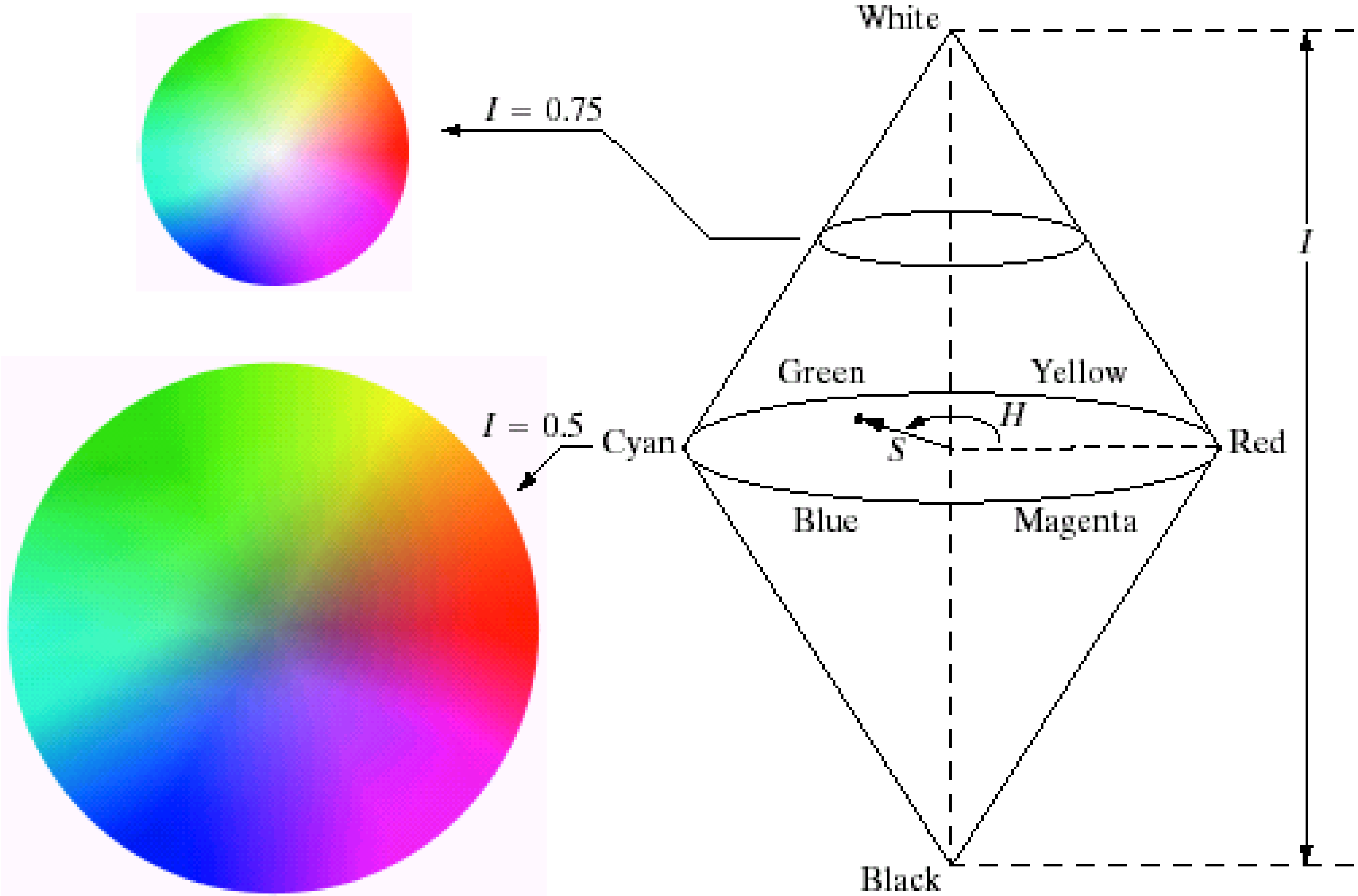
Because the only important things are the angle and the length of the saturation vector this plane is also often represented as a circle or a triangle



HSI Model Examples



HSI Model Examples



Converting From RGB To HSI

Given a colour as R, G, and B its H, S, and I values are calculated as follows:

$$H = \begin{cases} \theta & if\, B \le G \\ 360 - \theta & if\, B > G \end{cases}$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{\frac{1}{2}}} \right\}$$

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right]$$

$$I = \tfrac{1}{3}(R+G+B)$$

Converting From HSI To RGB

Given a colour as H, S, and I it's R, G, and B values are calculated as follows:

– RG sector (*0 <= H < 120°*)

$$R = I\left[1 + \frac{S\cos H}{\cos(60 - H)}\right] \qquad G = 3I - (R + B) \qquad B = I(1 - S)$$

– GB sector (*120° <= H < 240°*)

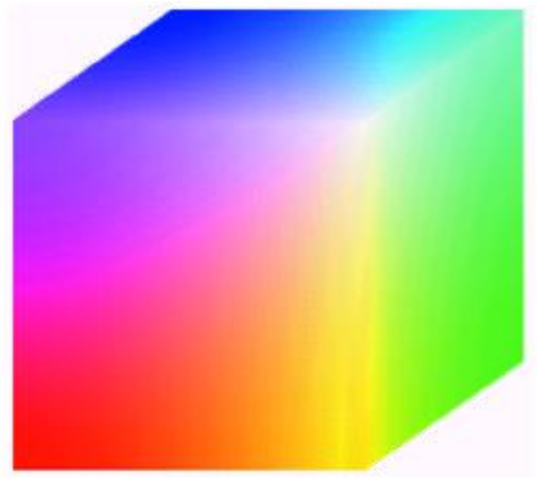
$$R = I(1 - S) \qquad G = I\left[1 + \frac{S\cos(H - 120)}{\cos(H - 60)}\right] \qquad B = 3I - (R + G)$$

Converting From HSI To RGB (cont…)

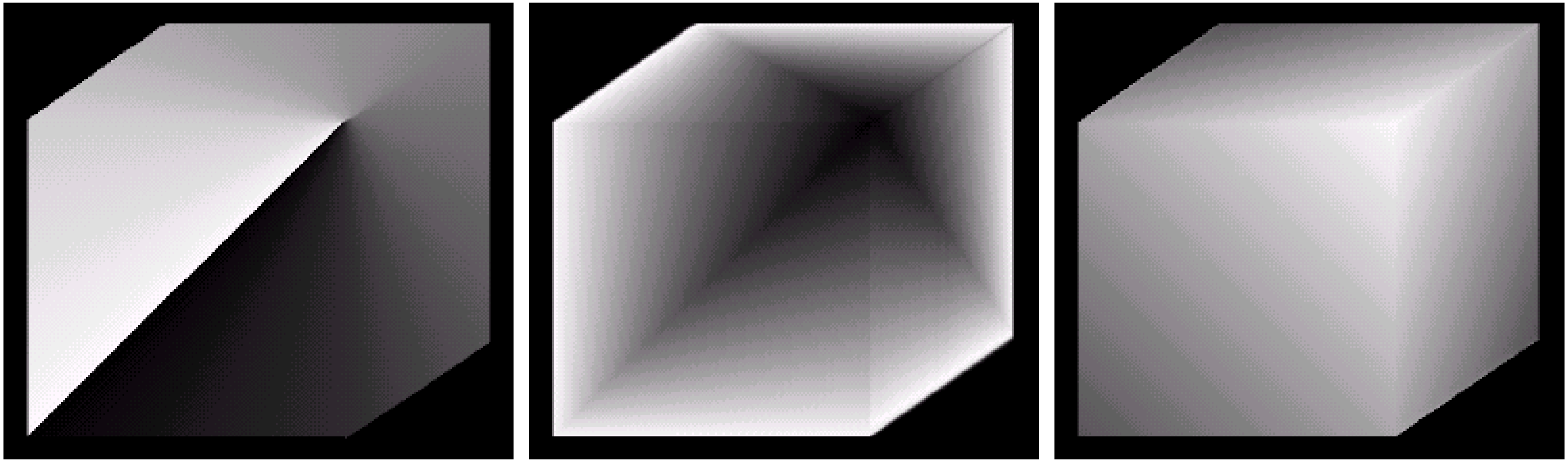
– BR sector ($240° <= H <= 360°$)

$$R = 3I - (G + B) \quad G = I(1 - S) \quad B = I\left[1 + \frac{S\cos(H - 240)}{\cos(H - 180)}\right]$$

HSI & RGB



RGB Colour Cube

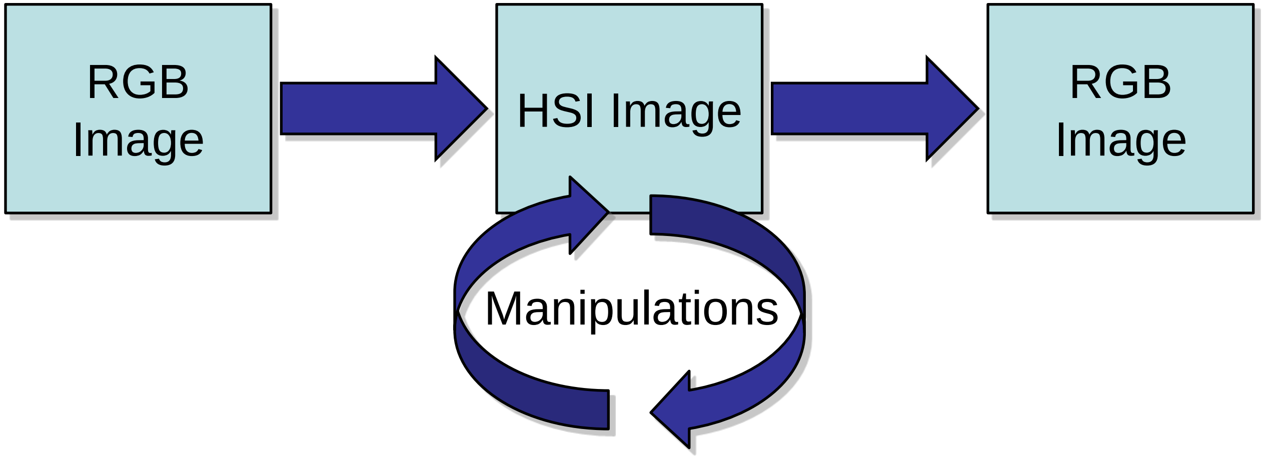


H, S, and I Components of RGB Colour Cube

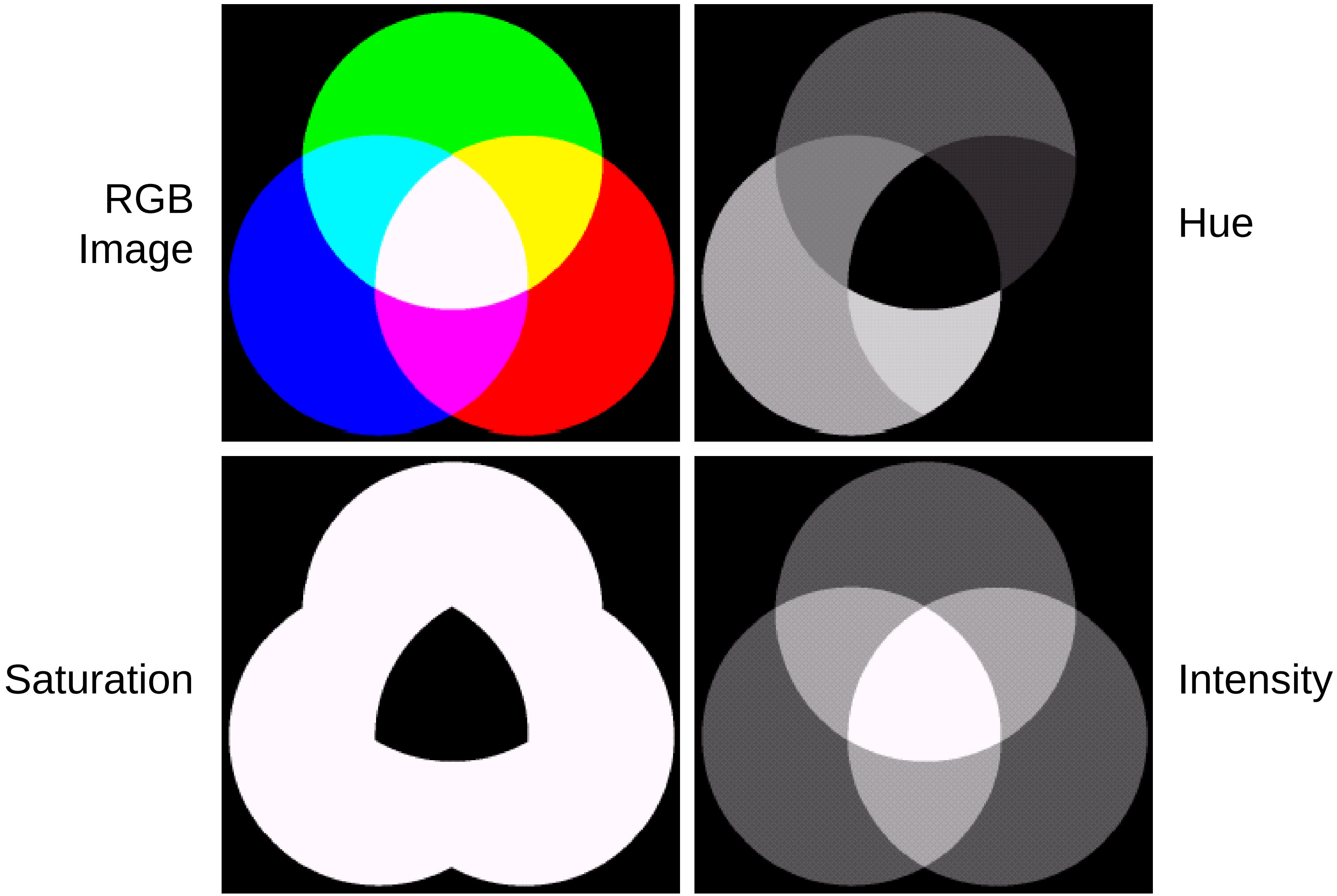
Manipulating Images In The HSI Model

In order to manipulate an image under the HIS model we:

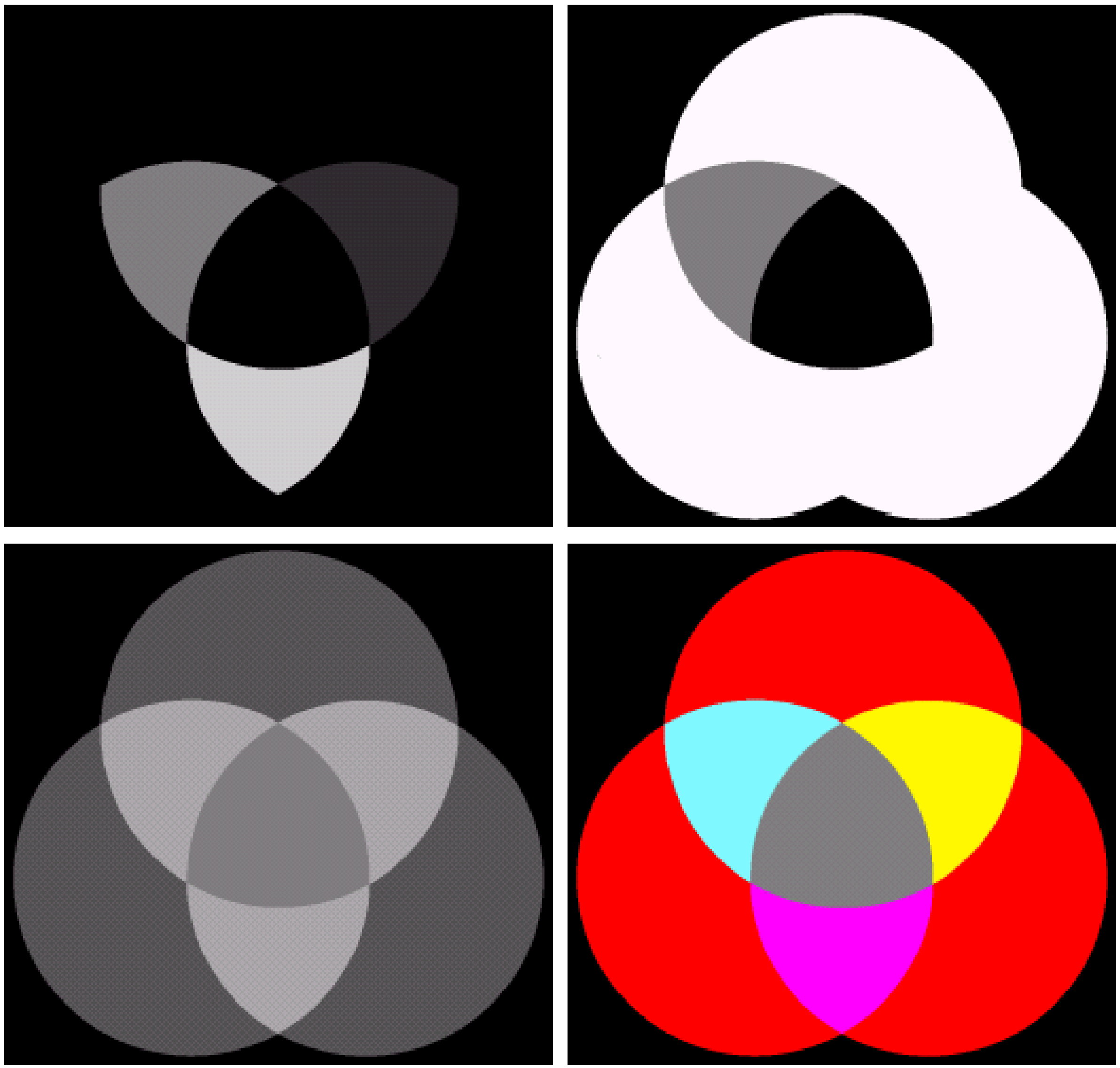
- First convert it from RGB to HIS
- Perform our manipulations under HSI
- Finally convert the image back from HSI to RGB



RGB -> HSI -> RGB



RGB -> HSI -> RGB (cont…)



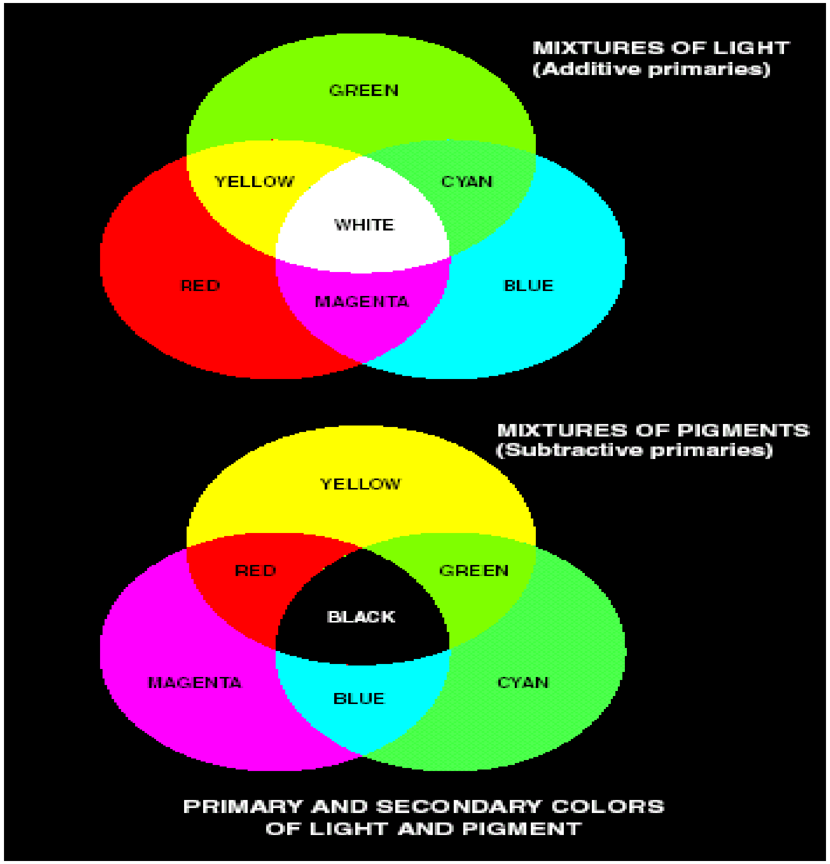
Hue

Saturation

Intensity

RGB Image

Chapter 6
Color Image Processing



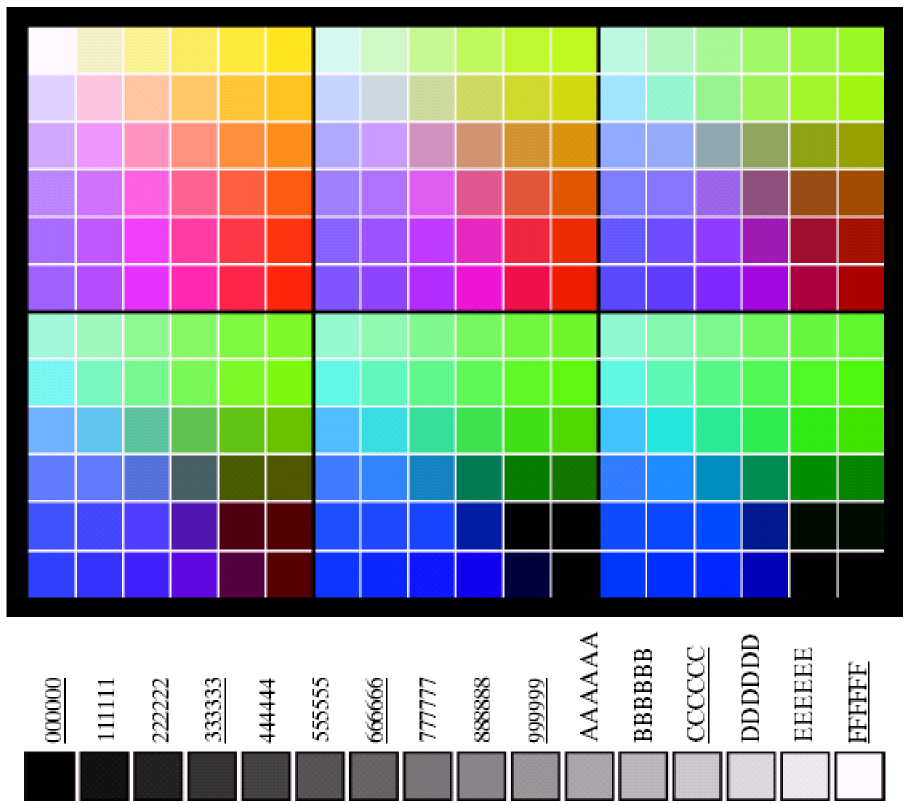
a
b

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

Chapter 6
Color Image Processing

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

TABLE 6.1 Valid values of each RGB component in a safe color.



a
b

FIGURE 6.10 (a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

Chapter 6
Color Image Processing

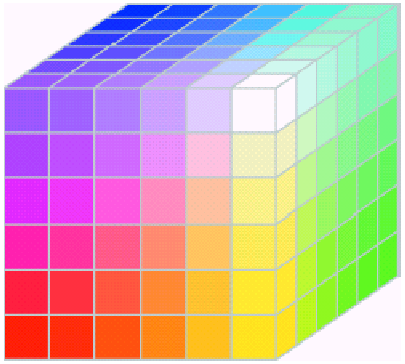


FIGURE 6.11 The RGB safe-color cube.