CHAPTER 1

INTRODUCTION

DIGITAL IMAGE PROCESSING

- Topics of digital image processing and analysis.

- Digital image formation.

- Digital image representation.

- Elementary digital image processing operations.

DIGITAL IMAGE PROCESSING

- Digital image display.
- Fundamentals of color image processing.
- Noise generators for digital image processing.

Introduction

Human vision is one of the most important and complex **perception mechanisms**.

It provides information needed for :

Simple tasks such as:

- *object recognition*

Complex tasks such as :

- *planning*,
- *decision making*,
- *scientific research*,
- *development of human intelligence*

Introduction

Digital Image processing concerns the transformation of an image to a digital format and its processing by digital computers.

Both the input and output of digital image processing system are digital images.

Digital image analysis is related to the description and recognition of the digital image content.

Its input is a digital image and its output is a symbolic image description.

Introduction

Digital image processing and Computer vision techniques have three distinct classes:

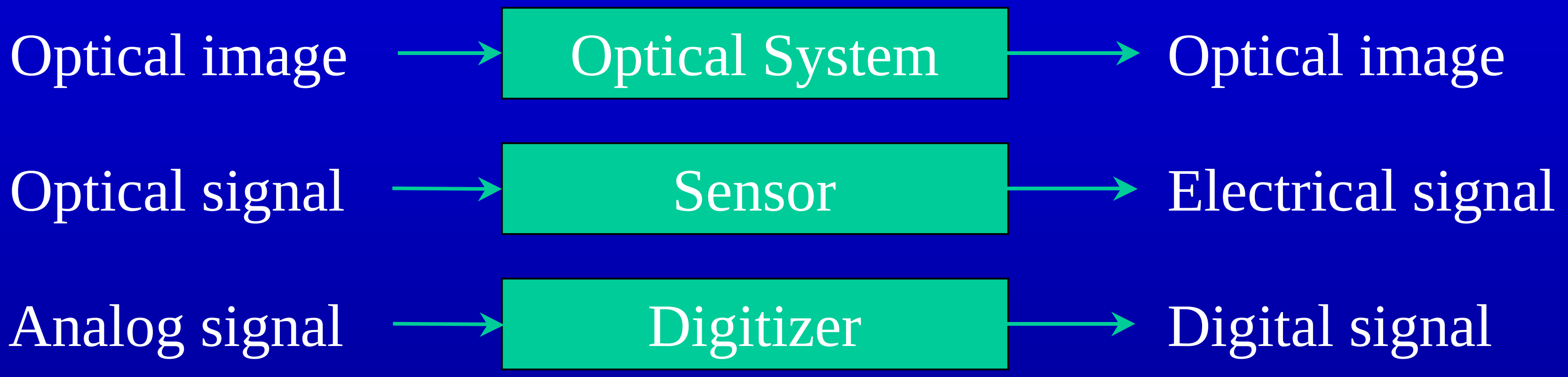
Low-level vision algorithms are essentially digital image processing algorithms: their input and output are digital images.

Intermediate-level vision algorithms have digital images as input and low level symbolic representations of image features as output (e.g. representations of the object contours).

High-level vision algorithms are symbolic representations for both input and output. They are closely related to artificial intelligence and to pattern recognition. They try to simulate the high levels of human visual perception (image understanding).

Topics of digital image processing and analysis from an algorithmic point of view

- Digital image formation is the first step in any digital image processing application**.**
- The Digital image formation system **consists** basically of **an optical system, the sensor and the digitizer**.



Topics of digital image processing and analysis

- **Digital image restoration** techniques concern the reduction of the deformations and degradations introduced during digital image formation.
- **Digital image enhancement** techniques concern the improvement of the quality of the digital image
    - contrast enhancement
    - digital image sharpening
    - noise reduction
    - digital image pseudocoloring
    - digital image halftoning

Topics of digital image processing and analysis

• **Digital image frequency content** plays an important role in digital noise filtering, digital image restoration and digital image compression. Digital image transforms are used to obtain the digital image frequency content.

• **Digital image coding and compression** take advantage of the information redundancy existing in the image in order to reduce its information content and to compress it. Therefore, a good compromise between fidelity and compression ratio must be found.

Topics of digital image processing and analysis

• **Object boundary detection.** This is performed by using edge and line detection techniques. The lines or edges detected are followed subsequently and a list of the boundary coordinates is created.

• **The dual problem of edge detection is region segmentation.** Region segmentation techniques can be grouped in three classes:

- **Local techniques** employ the local properties within an image neighborhood.
- **Global techniques** segment the image on the basis of global information (e.g.global texture properties).
- **Split and merge** techniques employ both pixel proximity and region homogeneity in order to obtain good segmentation results.

Topics of digital image processing and analysis

- **Object recognition** is a very important task in digital image analysis. Shape description models are extensively used to attain this goal. Shape description and representation schemes have been thoroughly studied in the past two decades.
- Computer vision / computer graphics relations: *computer vision concerns the creation of object models from object pictures, whereas computer graphics concern creating digital pictures from symbolic models.*
- Object description schemes can be divided into two classes: **external** and **internal representations**.
  - **External representations** employ the object boundaries and their features.
  - **Internal representations** use region descriptions and features related to the region occupied by an object.

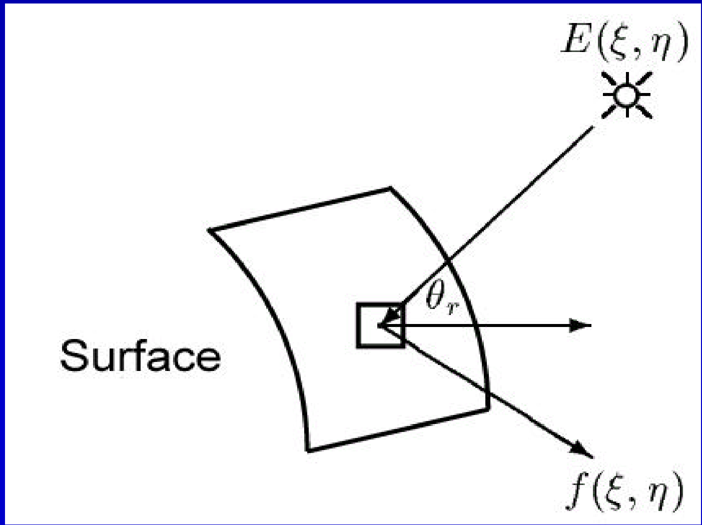
Digital image formation

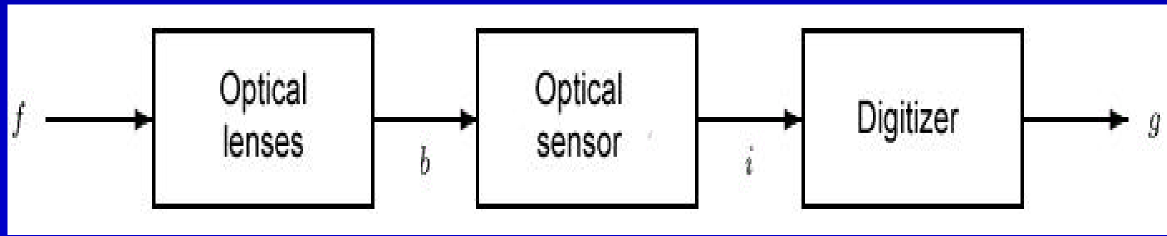
An image is the optical representation of an object illuminated by a radiating source. The following elements are used in an image formation process:

- object,
- radiating source,
- image formation system.

For simplicity, we shall district our description to the case of the visible light reflected on an object.

Digital image formation





Description of reflected light

Digital image formation system

Figure 1: Digital image formation system

Digital image formation

•The optical subsystem **H** can be modeled as a linear shift invariant system having a two-dimensional impulse response $h(x,y)$.

$$f(\hat{\imath},n) \longrightarrow \boxed{\mathbf{H}} \longrightarrow b(x,y)$$

Figure 2: Optical subsystem model

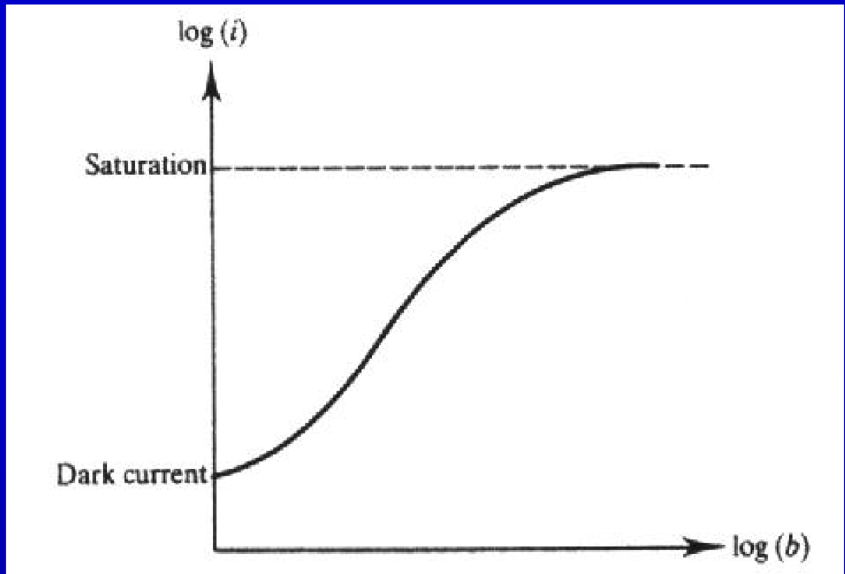
•Since both signals $f(\hat{\imath},n)$, $b(x,y)$ represent optical intensities, they must take non-negative values:

$$f(x,y) \geq 0 \quad , \quad b(x,y) \geq 0$$

Digital image formation

• The input-output relation of the optical subsystem is described by a **2-d convolution:**

$$b(x, y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x, n)\, h(x - x, y - n)\, dx\, dn$$



b: input luminance

i: output current

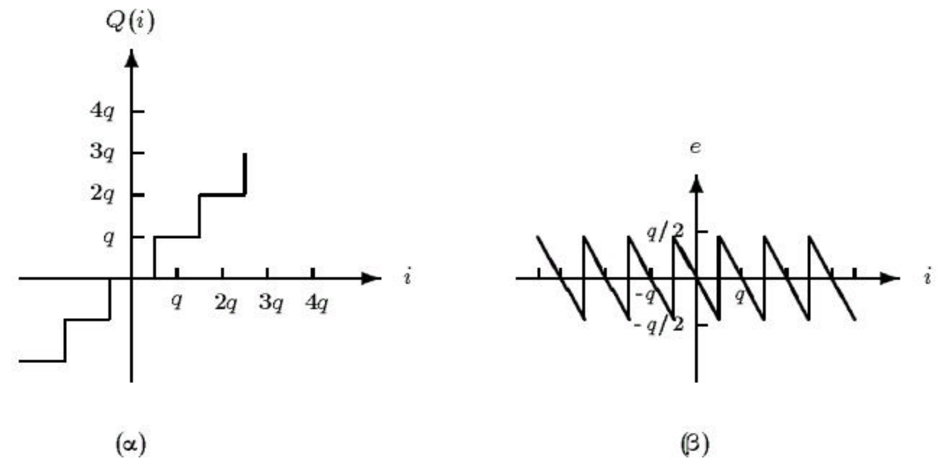
Figure 3: The characteristic curve of the vidicon camera

Digital image formation

• Sampling and digitization are performed by an A/D converter (in a frame grabber). It transforms the analog image $i(x,y)$ to a digital image $i(n_1,n_2)$, $n_1=1,...N$, $n_2=1,...,M$:

$$i(n_1, n_2) = i(n_1T_1, n_2T_2)$$

Quantization : The A/D converter performs quantization of the sampled image as well. If q is the quantization step, the quantized image is allowed to have illumination at the levels kq, $k=0,1,2,...$



$$q = \frac{1}{2^b}$$

Quantization step

Figure 4: (a) Input output curve of quantizer (b) Quantization error

Digital image formation

- **Grayscale** images are quantized at 256 levels and require 1 byte (8 bits) for the representation of each pixel.
- **Binary** images have only two quantization levels: 0,1. They are represented with 1 bit per pixel.

Digital image formation

Figure 5: A digital image quantized at
(a) 256 levels, (b) 64 levels,
(c) 8 levels, (d) 2 levels

Digital image formation

- Image quantization introduces an error term, $e(n_1,n_2)$, equal to:

$$e(n_1,n_2) = i(n_1,n_2) - Q[i(n_1,n_2)]$$

where $Q[...]$ is the quantization function.

- Éf P_i, P_e are the power of the image and error signals respectively, the signal to noise ratio **(SNR)** for the quantizer is given by:

$$SNR = 10\log_{10}\left(\frac{P_i}{P_e}\right) = 10\log_{10} P_i + 10.79 + 6.02b$$

Digital image representation

- The digital image can be conveniently represented by an $N \times M$ matrix **i** of the form:

$$\mathbf{i} = \begin{bmatrix} i(1,1) & i(1,2) & \ldots & i(1,M) \\ i(2,1) & i(2,2) & \ldots & i(2,M) \\ \vdots & \vdots & \ldots & \vdots \\ i(N,1) & i(N,2) & \ldots & i(N,M) \end{bmatrix}$$

- The matrix elements (image pixels) are integers in the range [0,...,255] for 8 bit images. Therefore, they can be represented as unsigned characters in the C language.

Digital image representation

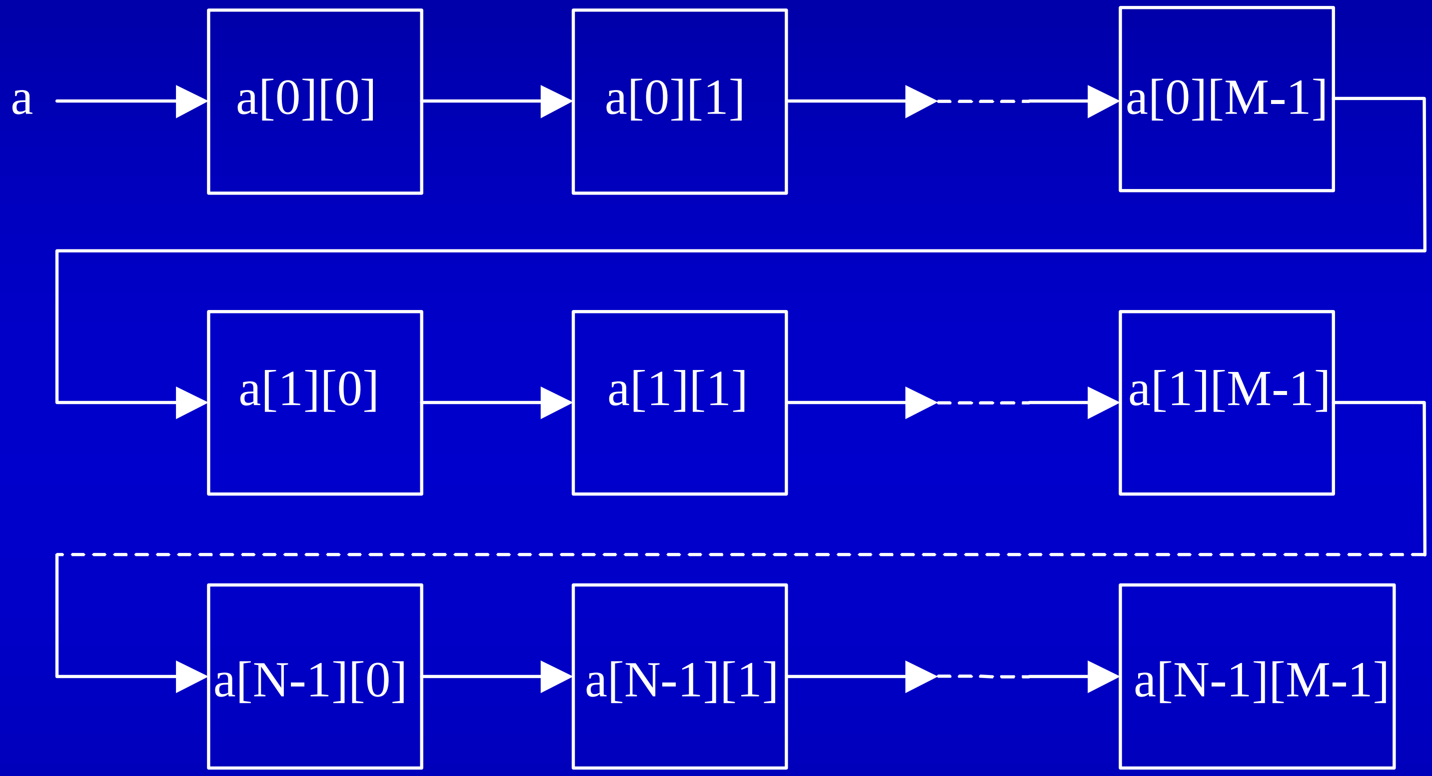


Figure 6: Storage scheme for a two-dimensional array of fixed size

Digital image representation

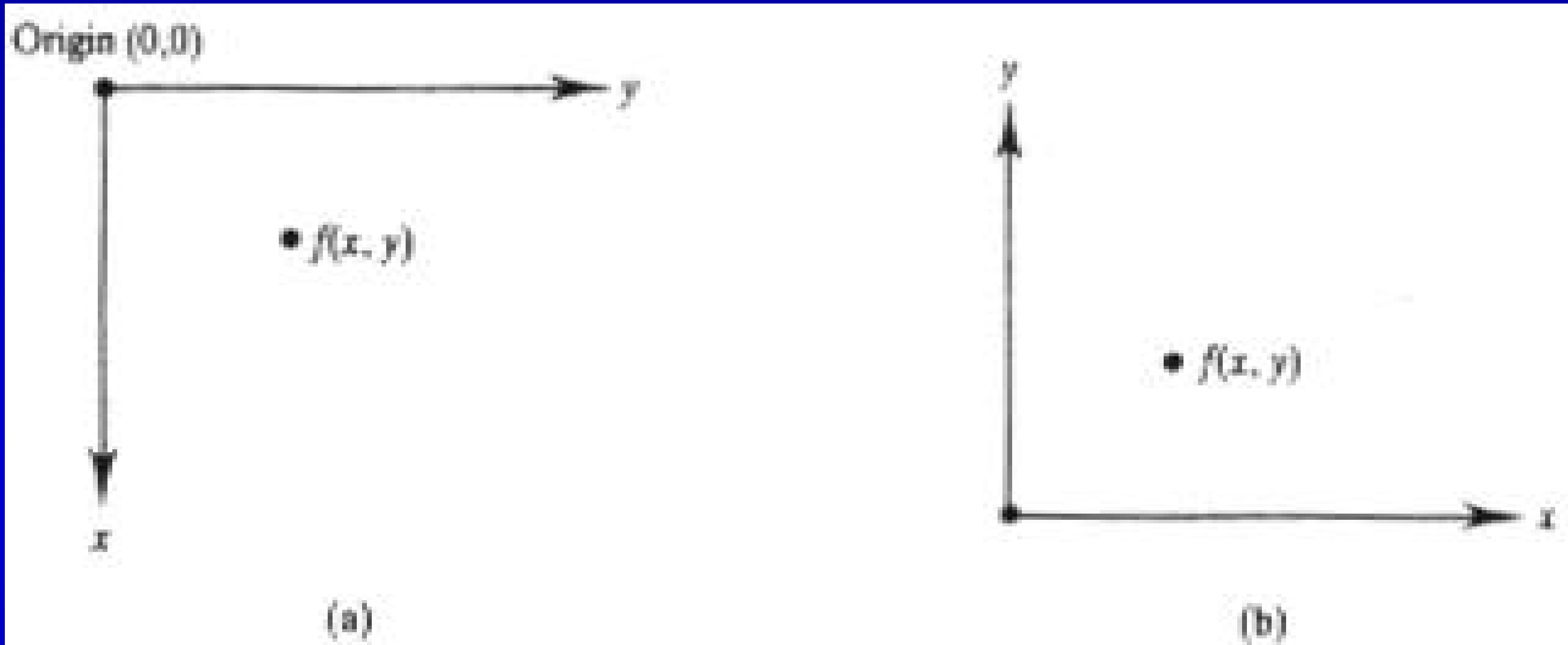


Figure 7: (a) Spatial coordinates used in the digital image representation (b) coordinates used in computer graphics

Elementary digital image processing operations

- Émage addition, subtraction:

$$c[i][j] = a[i][j] \pm b[i][j]$$

- Ìultiplication of an image by a constant:

$$b[i][j] = c \cdot a[i][j]$$

- Point nonlinear transformations of the form:

$$b[i][j] = h(a[i][j])$$

Elementary digital image processing operations

clipping:

$$b[i][j] = \begin{cases} c\max & if \quad a[i][j] > c\max \\ a[i][j] & if \quad c\min \le a[i][j] \le c\max \\ c\min & if \quad a[i][j] < c\max \end{cases}$$

thresholding:

$$b[i][j] = \begin{cases} a_1 & if \quad a[i][j] < T \\ a_2 & if \quad a[i][j] \ge T \end{cases}$$

Binary operations

- Elementary **binary operations**:

$$c[i][j] = a[i][j] \,\&\, b[i][j] \qquad (and)$$

$$c[i][j] = a[i][j] \,||\, b[i][j] \qquad (or)$$

$$c[i][j] = a[i][j] \Lambda b[i][j] \qquad (xor)$$

$$b[i][j] = !a[i][j] \qquad (not)$$

Elementary digital image processing operations

- Binary operations have important applications in binary and morphological image processing.

- The **not** operation must not be confused with the **negation** operation:

$$b[i][j] = 255 - a[i][j]$$

that produces the **negative** of an image.

Elementary digital image processing operations

- Another set of elementary digital image processing operations is related to **Geometric transforms**.

Image translation:

$$b[i][j] = a[i+k][j+1]$$

Image rotation: If the image point $a(x,y)$ is rotated by *è* degrees, its new coordinates (x',y') are given by:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos q & -\sin q \\ \sin q & \cos q \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

Elementary digital image processing operations

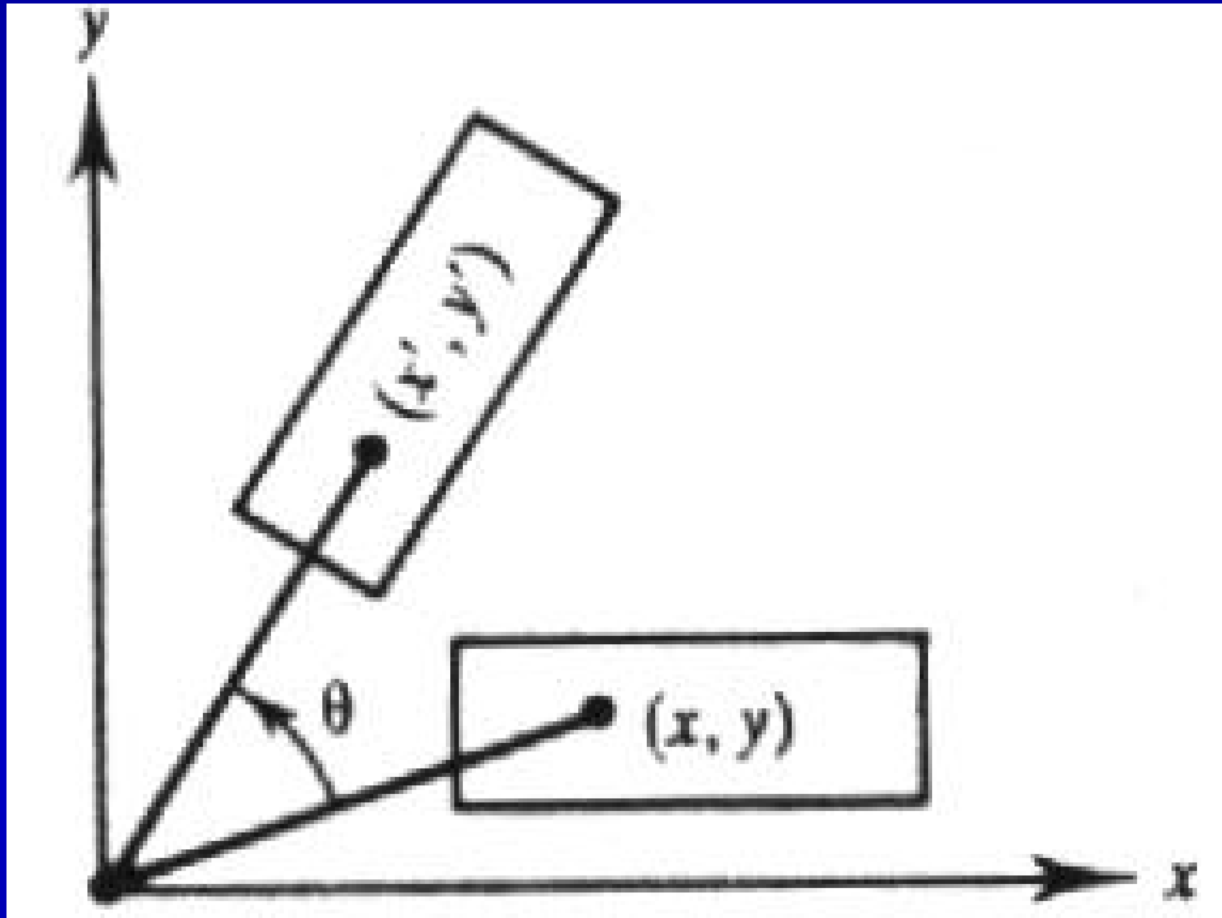


Figure 8: Image rotation

Elementary digital image processing operations

The rotated version $b[x'][y']$ of the image $a[x][y]$ is given by:

$$b[x'][y'] = b[x\cos q - y\sin q][x\sin q + y\cos q] = a[x][y]$$

Scaling is another basic geometrical transformation. It is described by the equation:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & 0 \\ 0 & b \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

Image scaling or zooming is given by:

$$b[k][l] = b[a \cdot i][b \cdot j] = a[i][j]$$

Elementary digital image processing operations

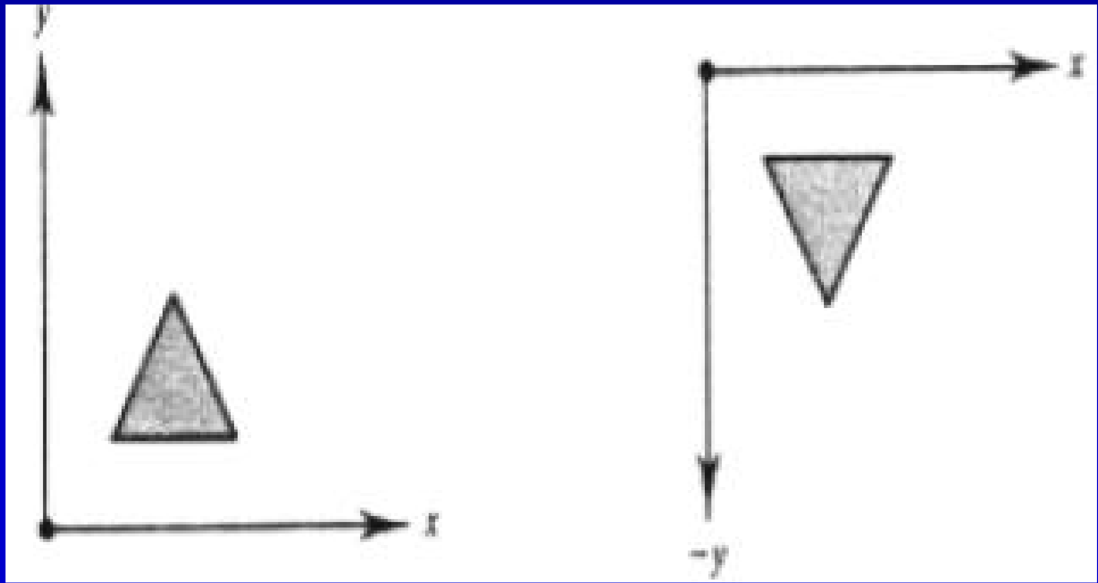
Shear along the horizontal axis is given by:

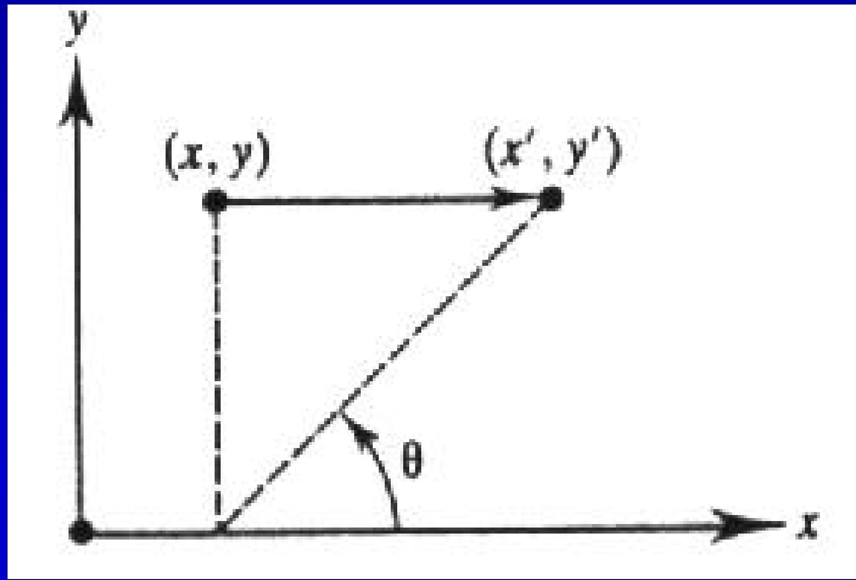
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & \cos q \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

The shear transform of an image is given by:

$$b[x'][y'] = b[x + y\cos q][y] = a[x][y]$$

Elementary digital image processing operations





(a) (b)

Figure 9: (a) Geometrical reflection in the x-axis
(b) Shear along the horizontal axis

Fundamentals of color image processing

- Color representation is based on the theory of T. Young (1802) which states that any color can be produced by mixing three primary colors C_1, C_2, C_3 at appropriate percentages:

$$C = aC_1 + bC_2 + cC_3$$

- This theory is consistent with the fact that the human eye has three different types of cones in the retina.

Fundamentals of color image processing

- The **chromaticities** of a color are defined by the ratios:

$$C_1 = \frac{C_i}{C_1 + C_2 + C_3} \qquad i = 1, 2, 3$$

- It is clear that only two chromaticity coordinates, e.g. c_1, c_2, are independent because:

$$c_1 + c_2 + c_3 = 1$$

- The entire color space is represented by the triplet (c_1,c_2,Y) where Y is given by:

$$Y = C_1 + C_2 + C_3$$

and represents a chrominance plane

Fundamentals of color image processing

•Several color coordinate systems have been proposed in the past. CIE (Commission Internationale de l' Eclairage) has proposed the spectral **primary system *RGB*** corresponding to monochromatic primary sources:

- **R_{CIE} (red 700 nm)**
- **G_{CIE} (green 546.1 nm)**
- **B_{CIE} (blue 435.8 nm)**
- **white color has $R_{CIE}=G_{CIE}=B_{CIE}=1$**

•The CIE spectral primary system ***RGB*** cannot yield all possible reproducible colors. Therefore, CIE has proposed the ***XYZ*** primary system having hypothetical (physically unrealizable) coordinates ***XYZ***.

Fundamentals of color image processing

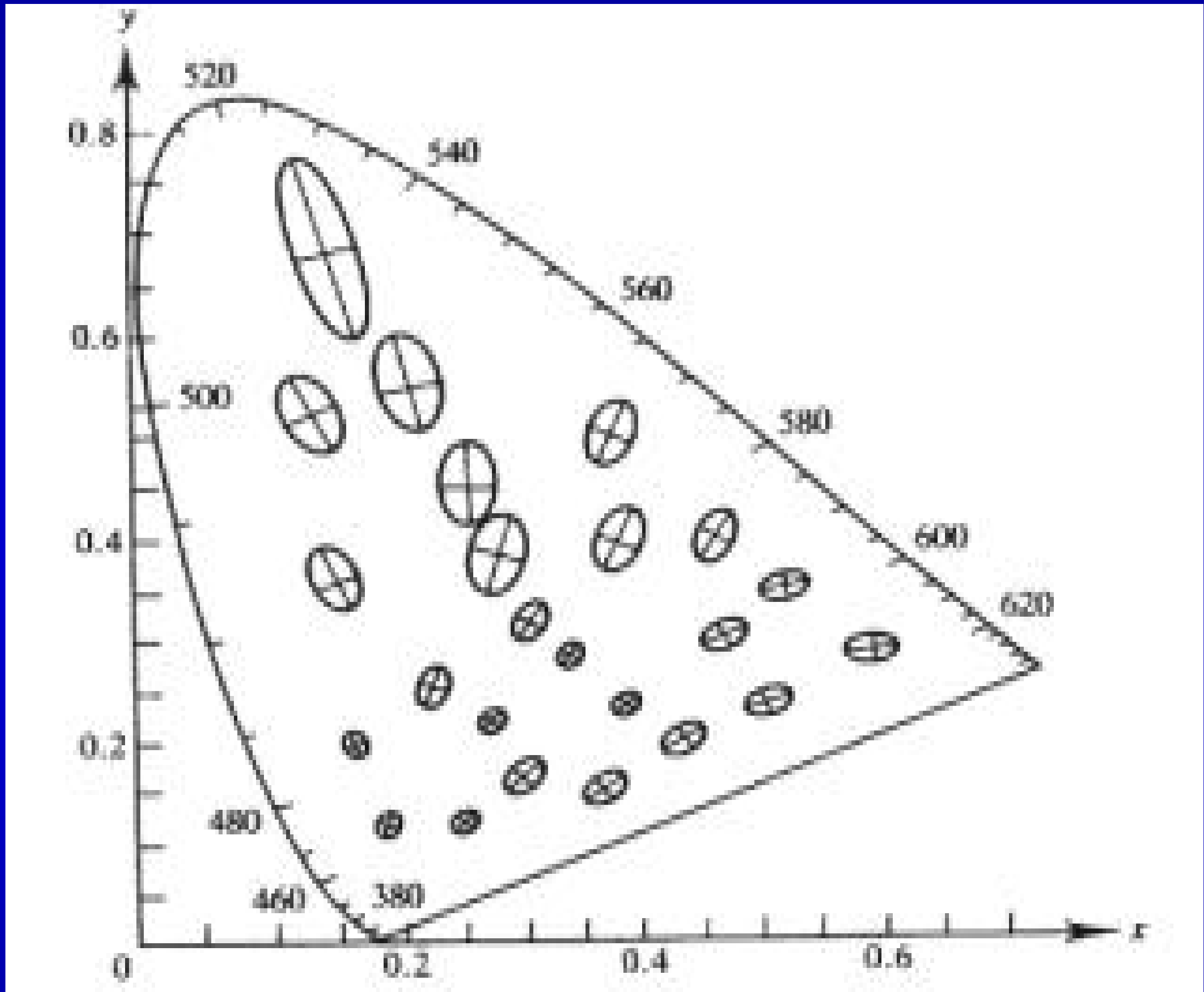


Figure 10: Chromaticity diagram of the *XYZ* system

Fundamentals of color image processing

- The *XYZ* primaries are linearly related to the *RGB* primary system:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.490 & 0.310 & 0.200 \\ 0.177 & 0.183 & 0.011 \\ 0.000 & 0.010 & 0.990 \end{bmatrix} \begin{bmatrix} R_{CIE} \\ G_{CIE} \\ B_{CIE} \end{bmatrix}$$

- The reference white is represented by $X = Y = Z = 1$.
- The chromaticity coordinates:

$$X = \frac{X}{X + Y + Z} \qquad Y = \frac{Y}{X + Y + Z}$$

can be used to produce the chromaticity diagram.

Fundamentals of color image processing

• Problem: color differences cannot be defined in a uniform way on the (x,y) plane.

• Solution: A new uniform chromaticity scale **UCS** system has been proposed. Its coordinates u**,** v**,** Y are given by:

$$u = \frac{4X}{X + 15Y + 3Z} = \frac{4X}{-2X + 12Y + 3}$$

$$v = \frac{4X}{X + 15Y + 3Z} = \frac{4X}{-2X + 12Y + 3}$$

Fundamentals of color image processing

- Color models have also been proposed for convenient image display on specific hardware platforms.

- An RGB color system has been proposed by the National Television Systems Committee (NTSC) for *color image display on CRT monitors.*

- The NTSC transmission system (YIQ) is used for *color image transmission that is compatible with monochrome image transmission.*

- The Cyan Magenta Yellow (CMY) model is *extensively used in printing color images.*

Fundamentals of color image processing

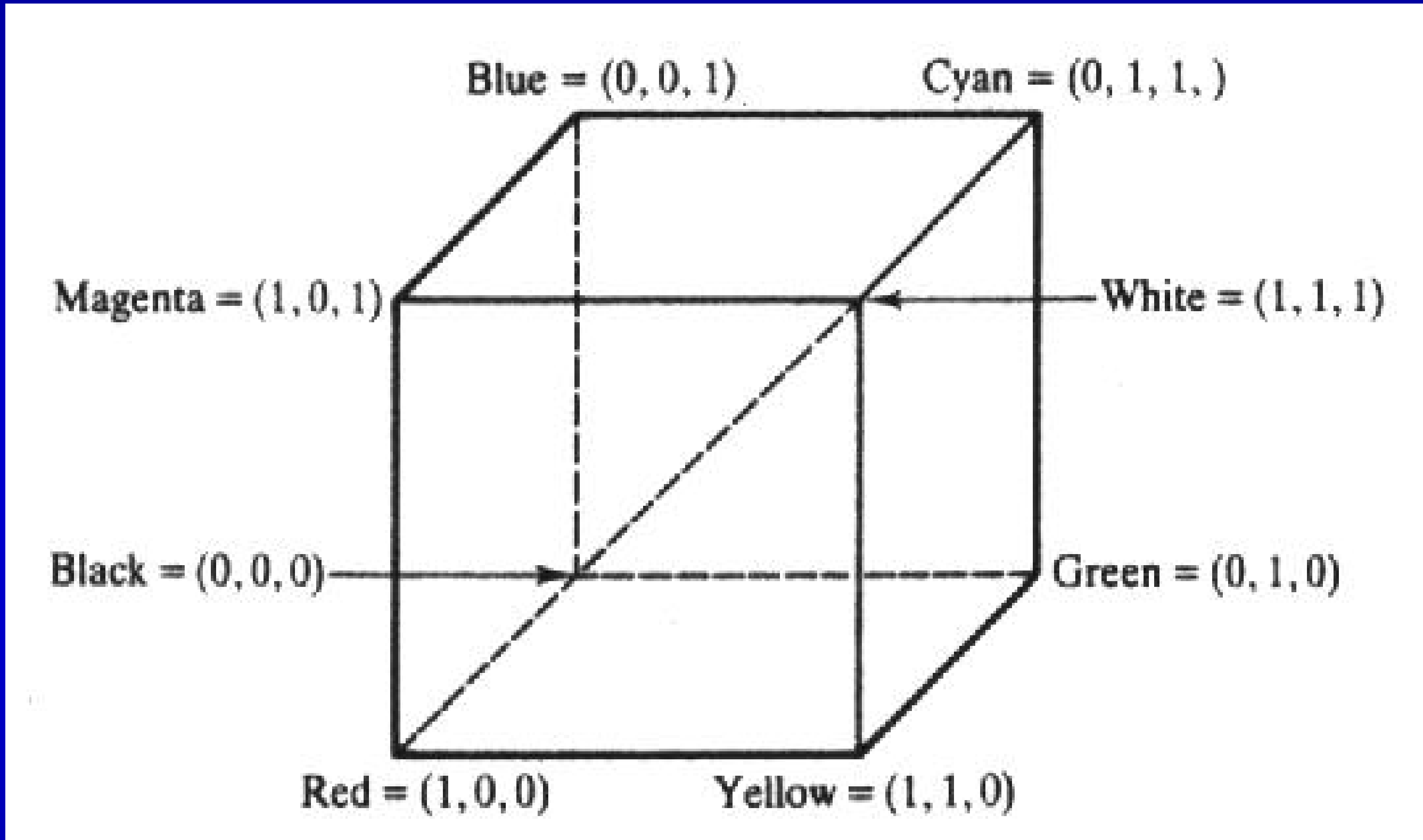


Figure 11: *RGB* color cube

Fundamentals of color image processing

• Cyan, magenta and yellow are complementary colors to red, green and blue respectively.

cyan, magenta, yellow = subtractive primaries

red, green, blue = additive primaries

• In the **CMY** system, the colors are specified by what is subtracted from the white light. The **CMY** coordinates are easily produced from the **RGB** system:

$$C = 1 - R$$
$$M = 1 - G$$
$$Y = 1 - B$$

and vice versa.

Fundamentals of color image processing

• The **CMY** system can be used for color image printing. Because of ink imperfections, this system cannot reproduce black correctly. Therefore the **CMYK** system is used instead:

$$K = \min(C, M, Y)$$
$$C = C - K$$
$$M = M - K$$
$$Y = Y - K$$

The component **K** represents black as a fourth color.

Fundamentals of color image processing

- Color perception usually involves three attributes known as **hue**, **saturation** and **brightness or lightness**.

- **Hue** is used to distinguish colors (e.g.red, yellow,blue) and to determine the **redness** or **greenness** etc. of the light.

- **Saturation** is the measure of the percentage of white light that is added to a pure color. For example, red is a highly saturated color, whereas pink is less saturated.

- **Lightness** or brightness refer to the perceived light intensity.

Fundamentals of color image processing

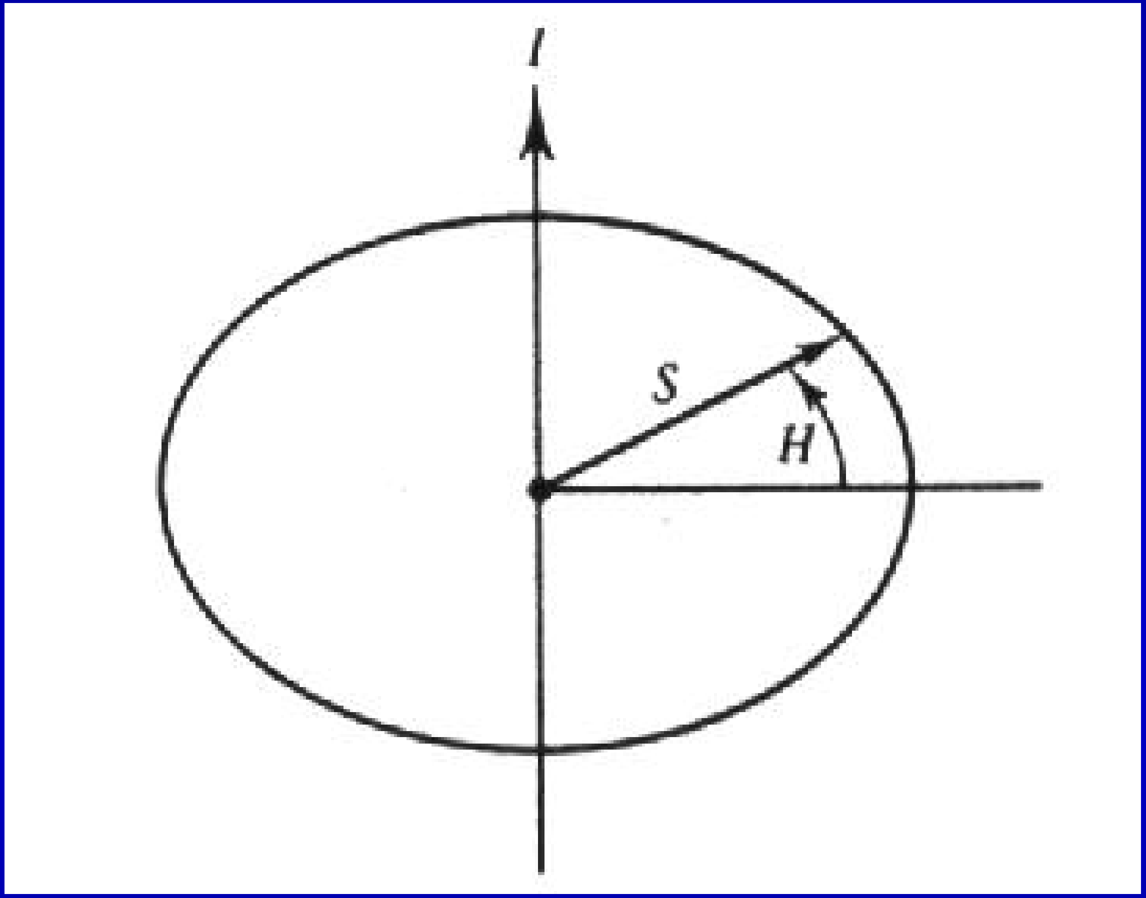


Figure 12: Definitions of hue, saturation and brightness of a color

Fundamentals of color image processing

•Several color models have been developed that represent the color hue, saturation and brightness.

•Such a system is the **HSI** model (hue, saturation, intensity). It is a cylindrical coordinate system, whose axis is the line **R = G = B** of the **RGB** space.

Fundamentals of color image processing

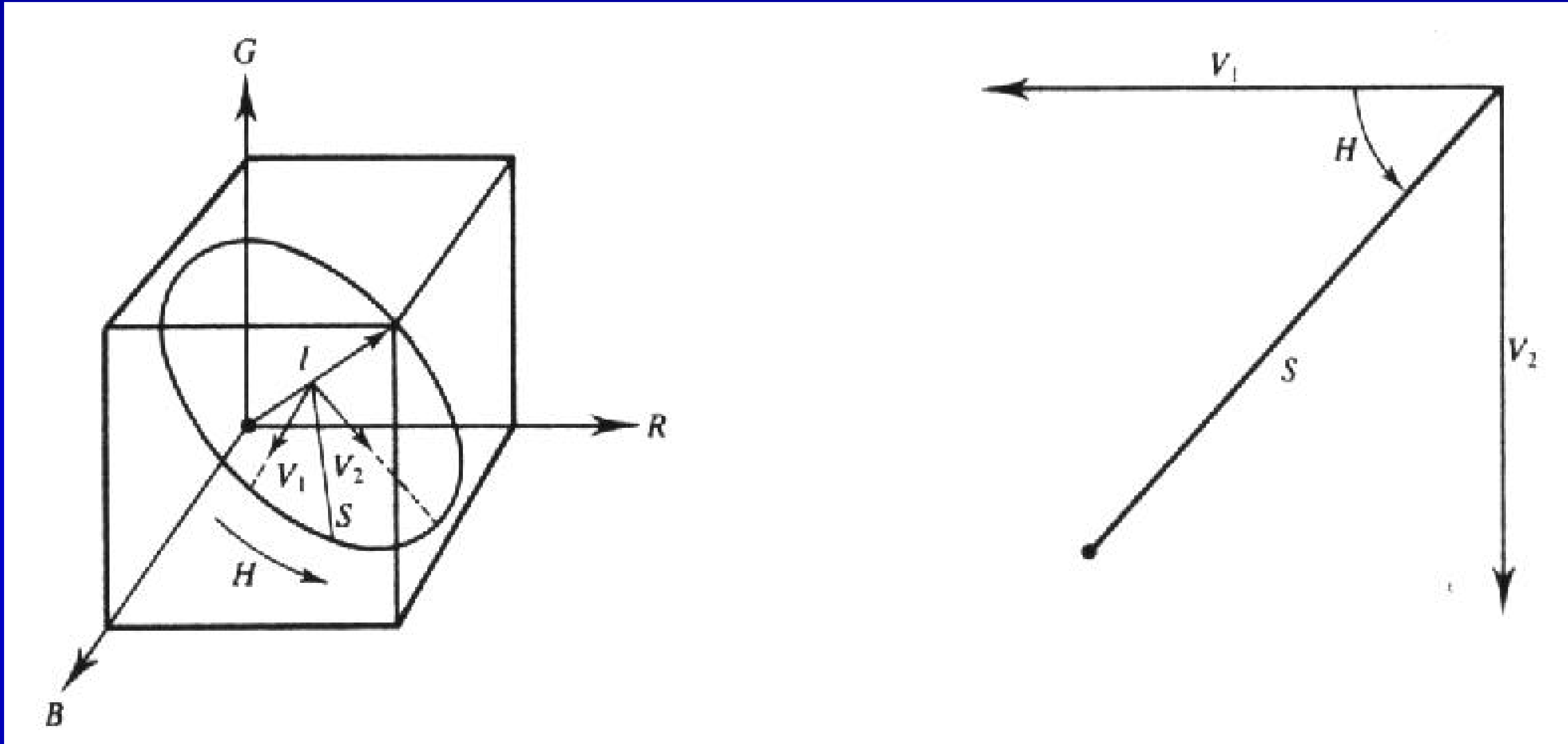


Figure 13: *HSI* color space

- Another color coordinate system based on perceptual color attributes is the **HLS model (hue, lightness, saturation).**

- It is defined in a double hexcone subset of a cylindrical coordinate system.

Fundamentals of color image processing

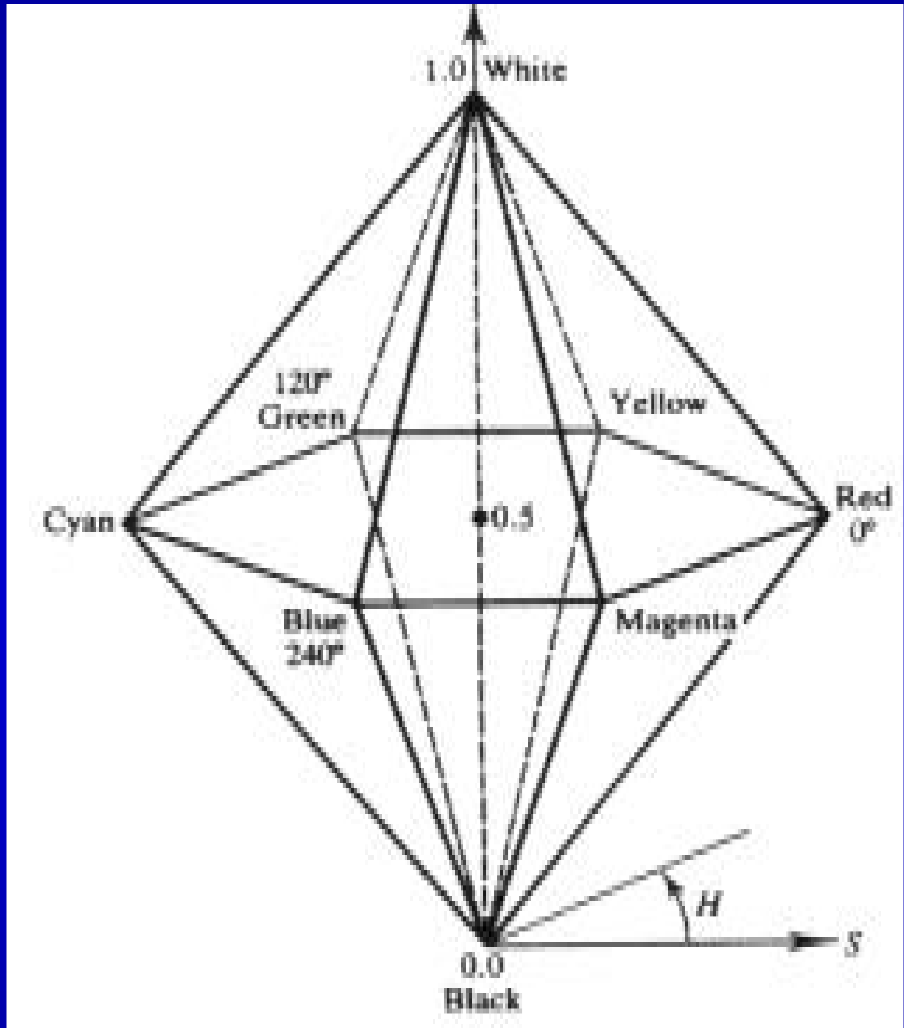


Figure 14: Definition of the **HLS** color space

Noise generators for digital image processing

- Digital images are corrupted by noise either during image acquisition or during image transmission.
- The image acquisition noise is photoelectronic noise or film-grain noise. This noise is signal-dependent.

- The observed image is a nonlinear transform of the original image, corrupted by multiplicative noise:

$$g(x,y) = c(f(x,y))^{-g}\, n(x,y)$$

Noise generators for digital image processing

- Thus, the noisy image acquisition can be described by the equation:

$$g(x,y) = c_2(h(x,y)**f(x,y))^{g} + c_2(h(x,y)*f(x,y))^{g\,1/2}\, n(x,y) + n_t(x,y)$$

f (*x*,*y*): the original image recorded on a film slide

g(*x*,*y*): the image that is observed

h(*x*,*y*): the transfer function of the optical subsystem

n(*x*,*y*): multiplicative noise

n_t(*x*,*y*): additive noise

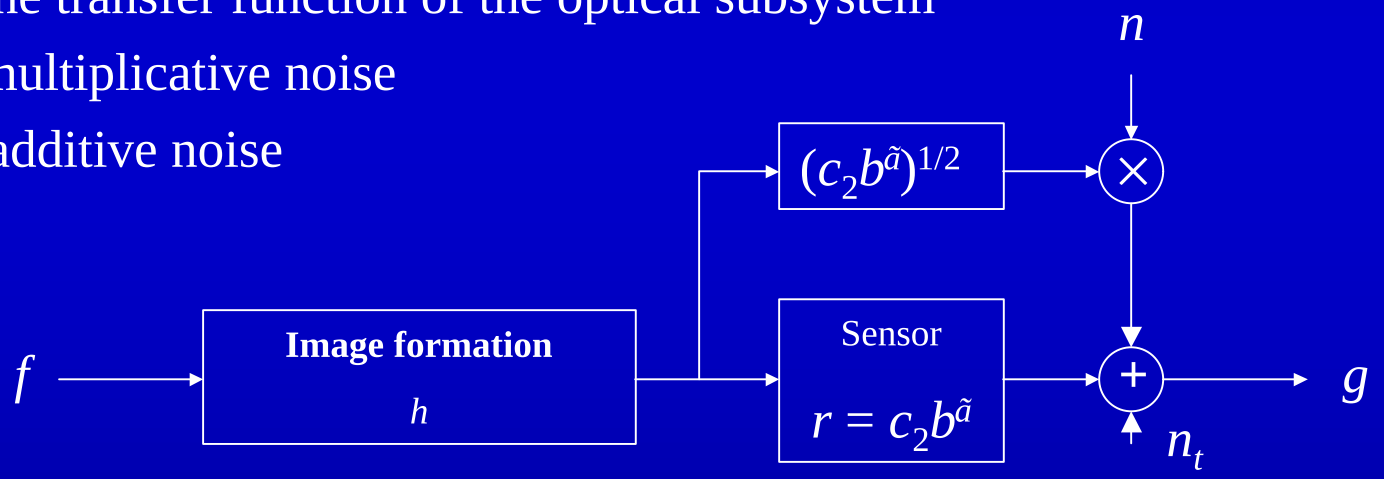


Figure 15: Image formation model

Noise generators for digital image processing

- **salt-pepper noise**. It appears as black and/or white impulses on the image. **It is impulsive noise and its source is either atmospheric or man-made** (e.g. car engines sparkles).

- It can be modeled as follows:

$$g(i,j) = \begin{cases} z(i,j) & \text{with probabilit y } p \\ f(i,j) & \text{with probabilit y } p-1 \end{cases}$$

Noise generators for digital image processing

- Digital images must be corrupted artificially in order to assess the performance of various filtering techniques. Furthermore, artificial noise generation is needed for certain artistic applications (e.g. for the simulation of film-grain noise). Such noise generators that can produce additive noise or multiplicative noise:

$$g(i,j) = f(i,j) + n(i,j)$$
$$g(i,j) = f(i,j)n(i,j)$$

Noise generators for digital image processing

- The following transformation can be used to transform a uniform distribution in [0,1] to a Laplacian distribution:

$$y = \begin{cases} \ln(2x) & 0 \le x \le 1/2 \\ -\ln(2-2x) & 1/2 \le x < 1 \end{cases}$$

- The Laplacian distribution produced by is described by:

$$f_y(y) = \frac{1}{2} e^{-|y|}$$

- The first transformation is used to produce a white additive Laplacian noise generator.

Noise generators for digital image processing

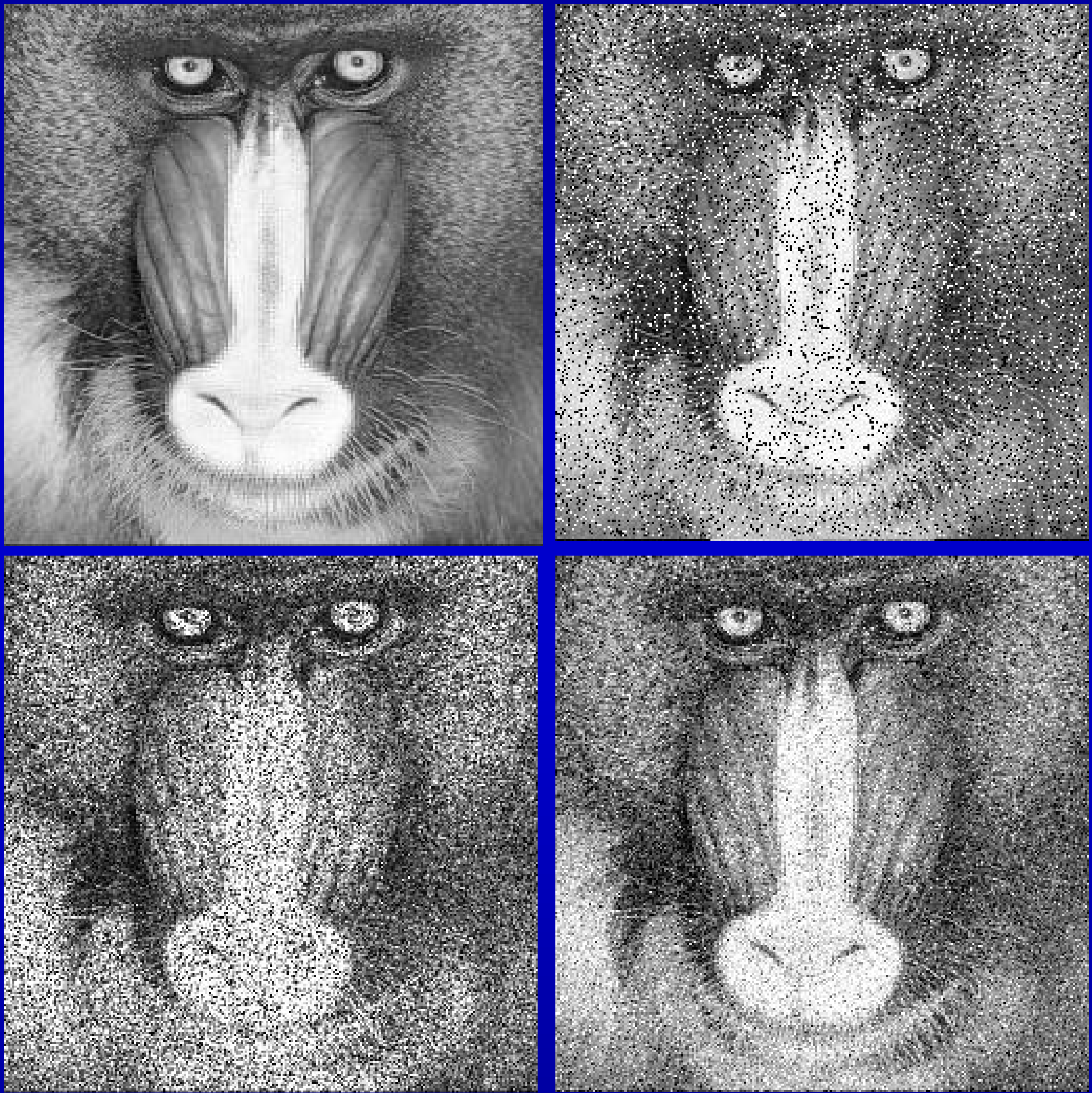


Figure 16:
(a) Original image.
(b) image corrupted by impulsive noise.
(c) image corrupted by multiplicative Gaussian noise.
(d) image corrupted by additive Laplacian noise.