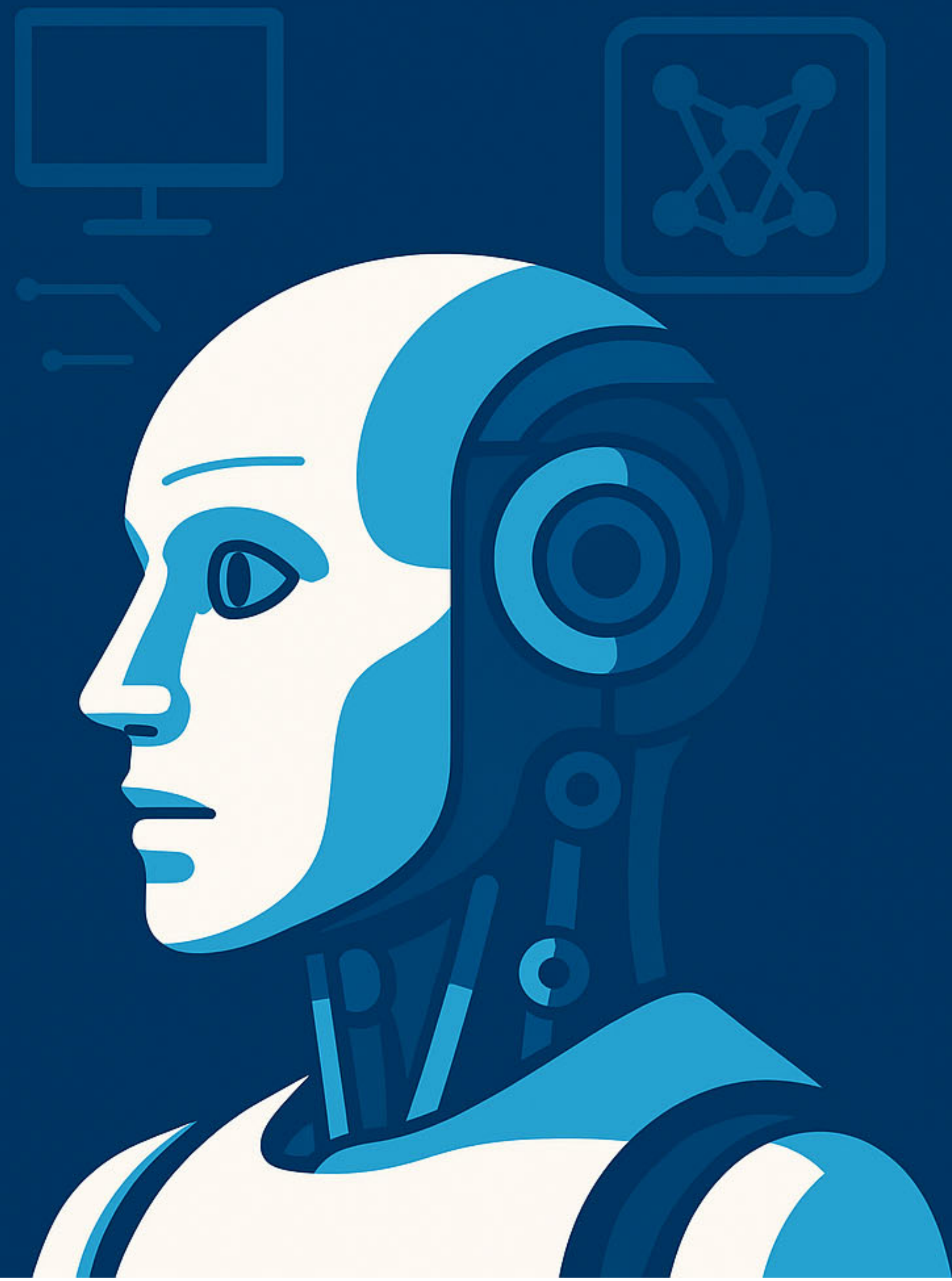
ME5411

ROBOT VISION AND AI



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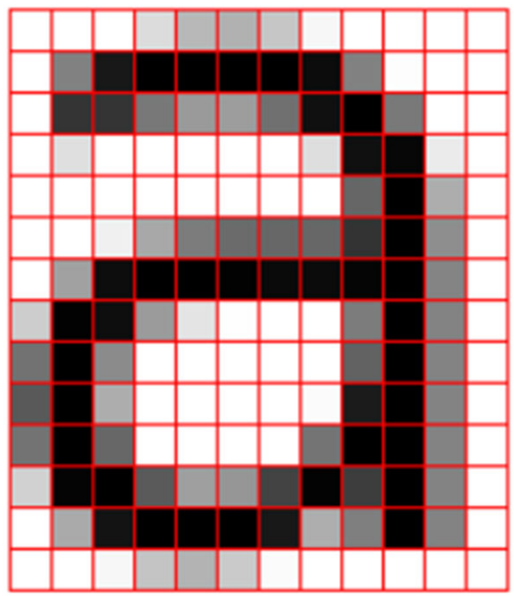
Lecture 1

Digital Image Representation and Properties

Topics

- Image Representation
- Image Sampling and Quantization
- Digital Image Properties
- Digital Color Images



1.0	1.0	1.0	0.9	0.6	0.6	0.6	1.0	1.0	1.0	1.0	1.0
1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	1.0	1.0
1.0	0.2	0.2	0.5	0.6	0.6	0.5	0.0	0.0	0.5	1.0	1.0
1.0	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.0	0.0	0.9	1.0
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0
1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.4	0.0	0.5	1.0
1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0
0.9	0.0	0.0	0.6	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0
0.5	0.0	0.6	1.0	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0
0.5	0.0	0.7	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.5	1.0
0.6	0.0	0.6	1.0	1.0	1.0	1.0	0.5	0.0	0.0	0.5	1.0
0.9	0.1	0.0	0.6	0.7	0.7	0.5	0.0	0.5	0.0	0.5	1.0
1.0	0.7	0.1	0.0	0.0	0.0	0.1	0.9	0.8	0.0	0.5	1.0
1.0	1.0	1.0	0.8	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0

Key takeaways

- Image representation: pixel, brightness, resolution
- Sampling & quantization: spatial density and gray levels
- Image properties: connectivity, distance, histogram
- Thresholding & perception: visual contrast, acuity, illusions
- Color models: RGB, CMY, HSI, YIQ, and color space

Image Representation

- A projection of 3D scene into 2D.

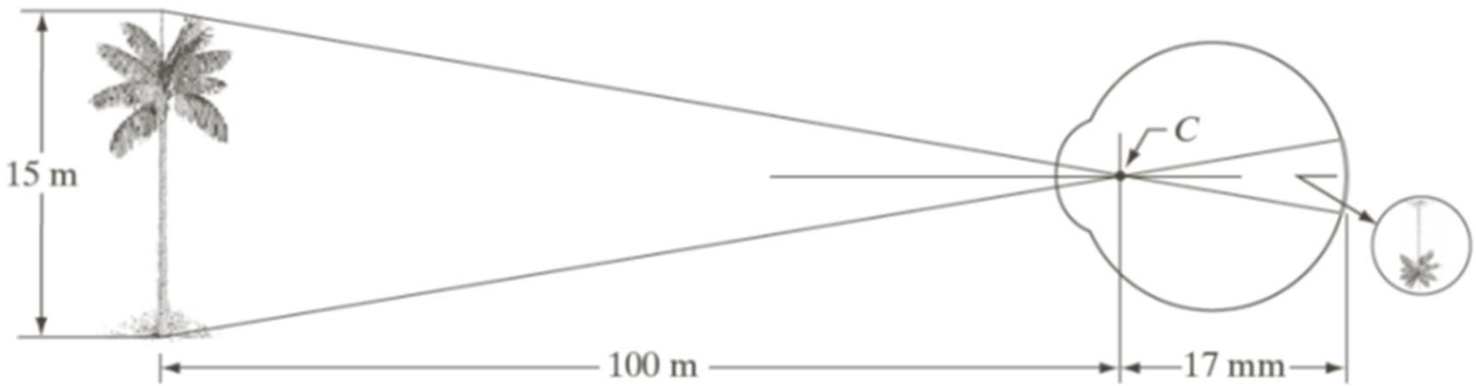


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point C is the optical center of the lens.

(Source: Gonzalez and Woods, 2010)

Image on human retina or captured by a TV camera or senor.

Image Representation

- Continuous Image Function
  - The image is modeled by a continuous function of two variables $f(x, y)$ or three variables $f(x, y, t)$.
    - (x, y) gives the coordinate of a plane. t is the time domain.
  - Image function value f correspond to brightness at an image point.
    - An intensity image is a 2D image bearing information about brightness points.

Image can be considered as a 2D light intensity function, $f(x,y)$, where x and y are spatial coordinates, and f at (x, y) is related to the brightness or color of the image at that point.

Image Representation

- Continuous Image Function
  - The brightness or intensity of the image is determined by
    - Illumination component: the amount of light incident on the viewing scene.
    - Reflection component: the amount of light reflected by the object in the scene.
      - Example values of typical surfaces: black silk (0.01), stainless steel (0.65), silver plate (0.90). Image function value *f* correspond to brightness at an image point.

Image Representation

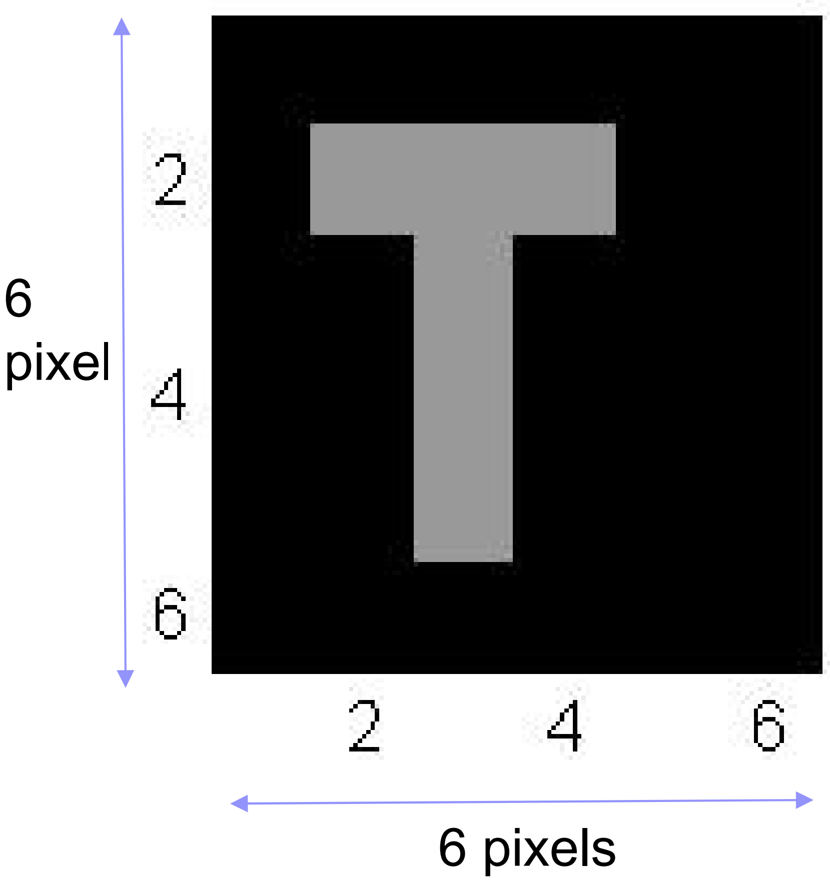
- Image Digitalization
  - An image to be processed by computer must be represented using appropriate discrete data structure.
    - Matrix or 2D array for 2D image
  - Image digitalization is the process of converting an image into a numerical representation through sampling and quantization.
  - Sampling turns the continuous function f(x,y) into a matrix of N rows and M columns.
  - Quantization assigns an integer value to each continuous sample.

Image Representation

- Digital Image
  - A digital image (== raster or bitmapped image) is the representation of a continuous image f(x,y) by a matrix of discrete sample.
  - The function value at each discrete sample is quantized to be represented by a finite number of bits.
  - Each element of the matrix of samples is called pixel (for PICture ELement).

Image Representation

- Digital Image



A digital image is represented by numbers.

0	0	0	0	0	0
0	10	10	10	0	0
0	0	10	0	0	0
0	0	10	0	0	0
0	0	10	0	0	0
0	0	0	0	0	0

A pixel represents brightness at a point.

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 10 & 10 & 10 & 0 & 0 \\ 0 & 0 & 10 & 0 & 0 & 0 \\ 0 & 0 & 10 & 0 & 0 & 0 \\ 0 & 0 & 10 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

A digital image can be represented as a matrix.

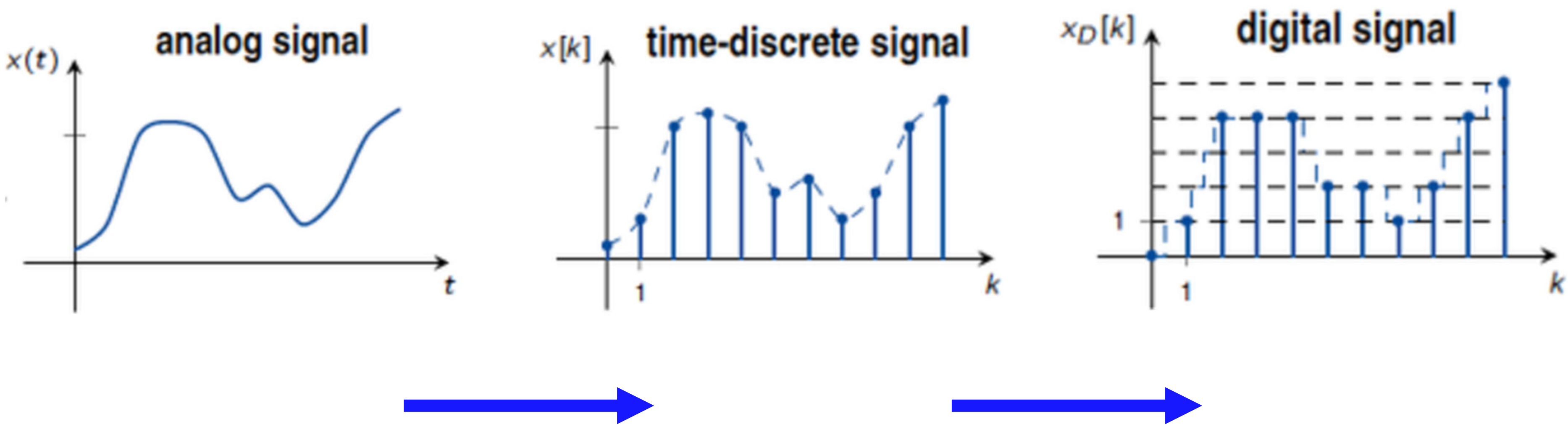
Image Representation

- Pixel
  - Pixel is a point sample of the original image.
  - It is the smallest piece of information in an image - the elemental part of an image.
  - It has a position relative to other pixels in the image.
  - It has a color capability measured in bits.
  - Pixel is often represented using dot or square.

Image Sampling and Quantization

- Digital image processing is the use of computer algorithms to perform image processing on digital images.
- It is a sub field of digital signal processing.
- Image sampling and image quantization are examples of digital image processing.

Image Sampling and Quantization



Sampling

Quantization

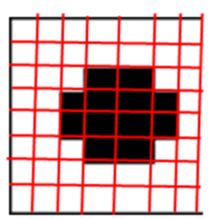
Image Sampling and Quantization

- Sampling

Sampling turns the continuous function f(x,y) into a matrix of N rows and M columns.

- Image sampling – discretion in space
  - SAMPLE does not equal to the original shape

Fewer pixels mean lower spatial resolution. For example, we may reduce the size of a 640 x 480 image to 160 by 120. We will observe blurring when the 160 x 120 image is interpolated back to 640 x 480.



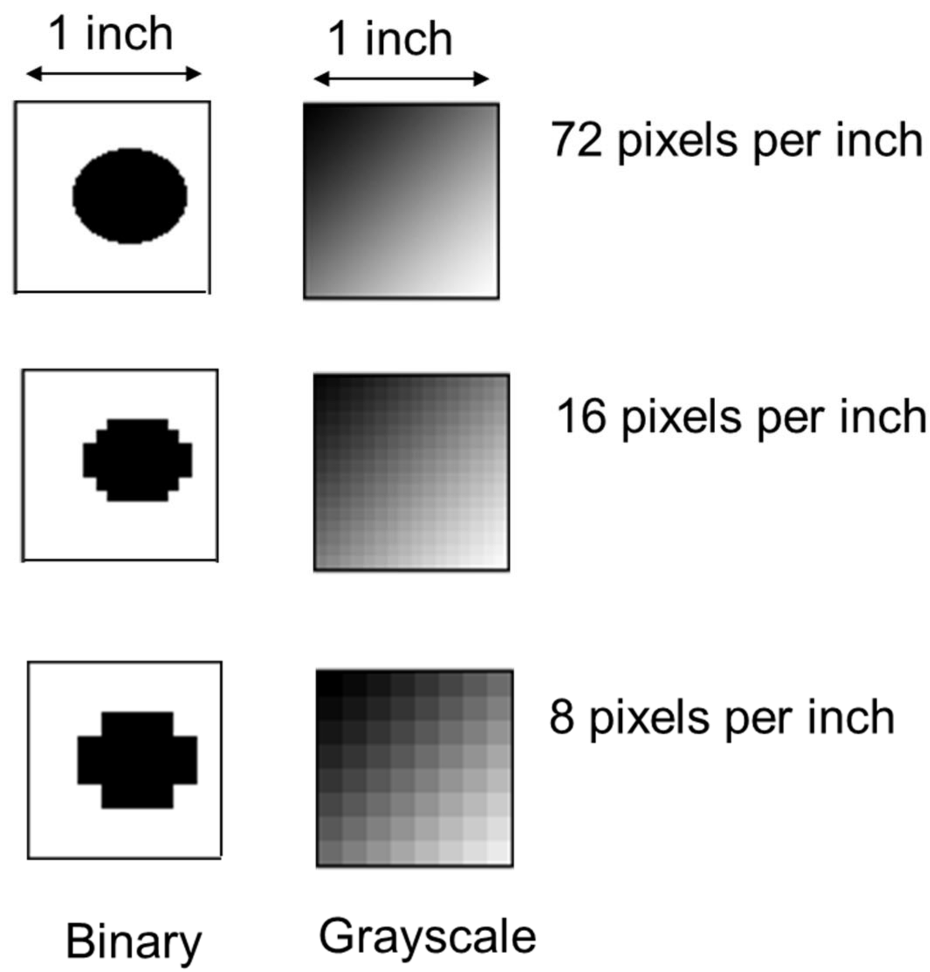
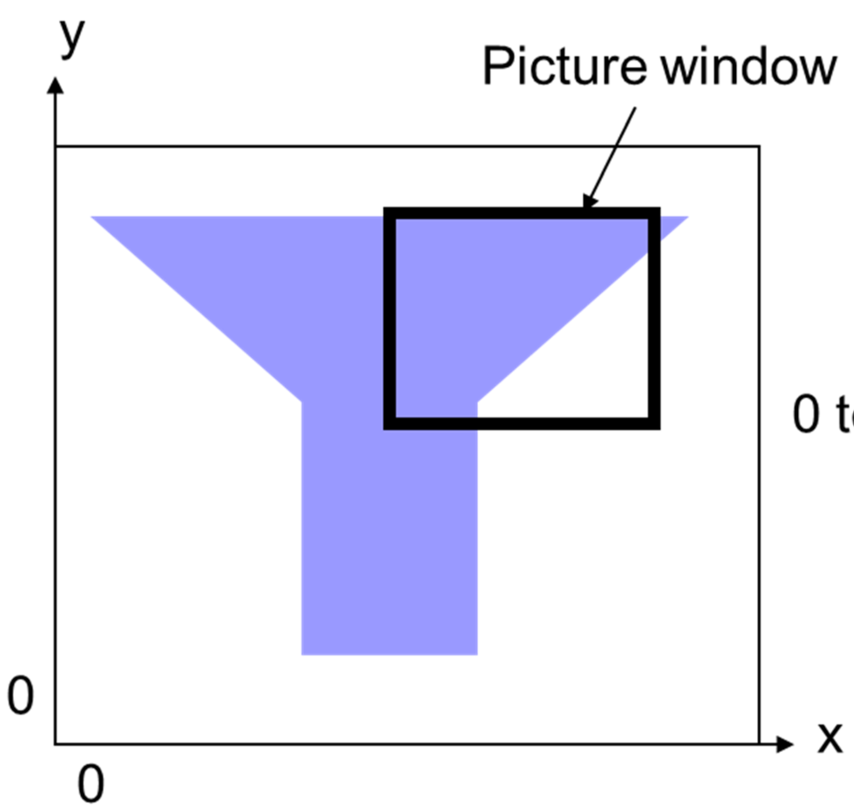


Image Sampling and Quantization

- Picture Space vs Image Space

IMAGE: M x N matrix of pixels $p(i, j)$



Picture space

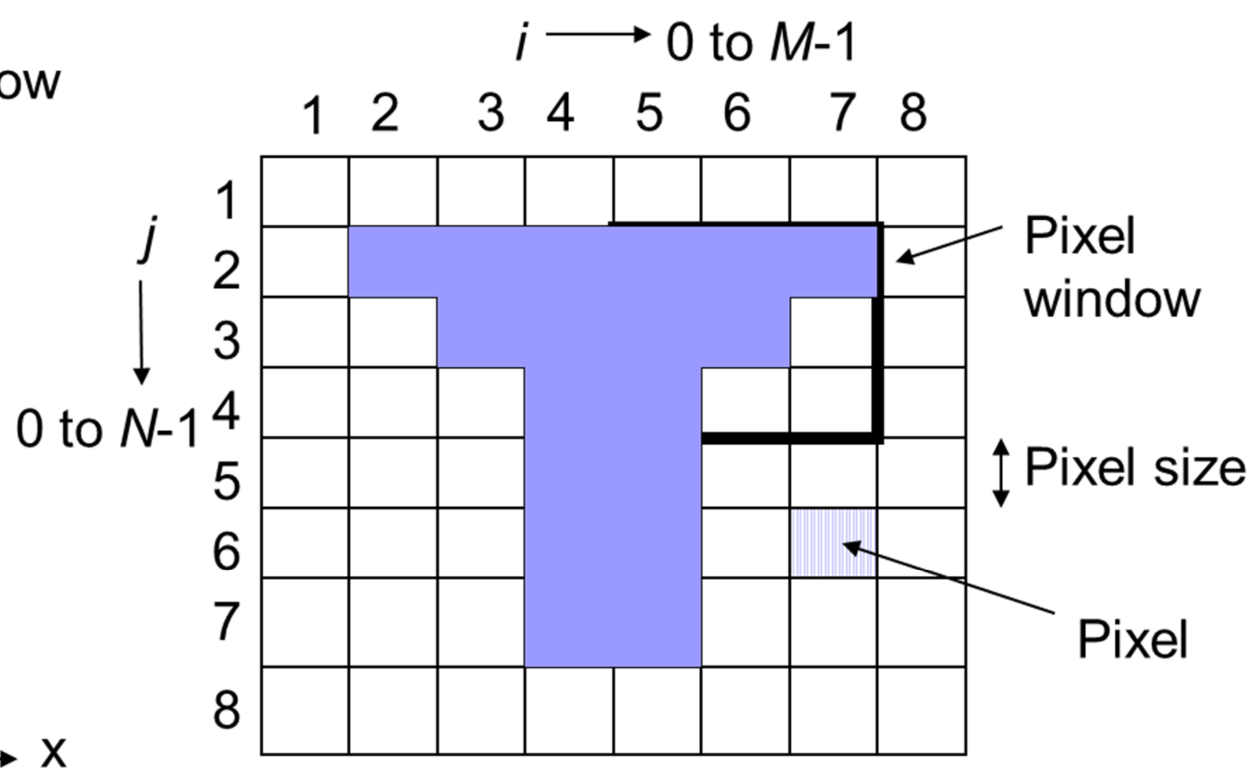


Image space – Pixel matrix

Image Sampling and Quantization

- Image resolution
  - Image resolution is a measure of sampling density.
    - Provides a relationship between pixel dimensions and physical dimensions
  - Pixels per inch (ppi)
    - If the dimension of an image is 1 inch x 1 inch, and *M*= *N* = 8, there are 8/1 = 8 pixels per inch.
    - Pixel size = 1/8 = 0.125 inch
    - Pixels per cm

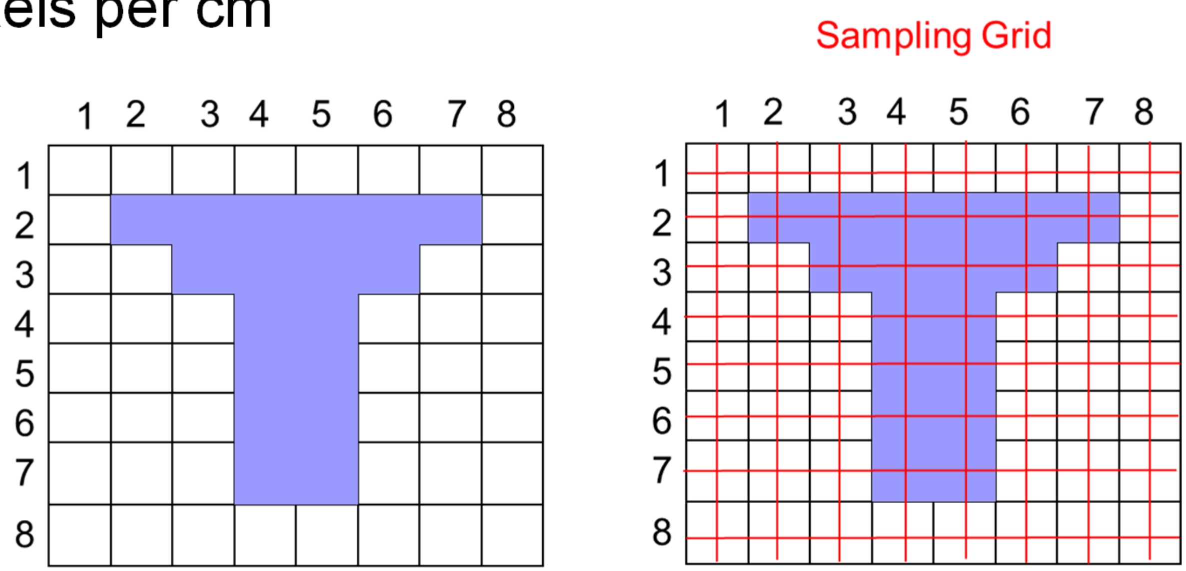
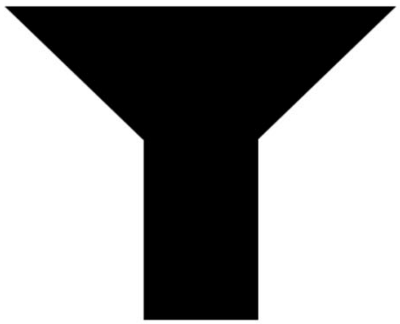
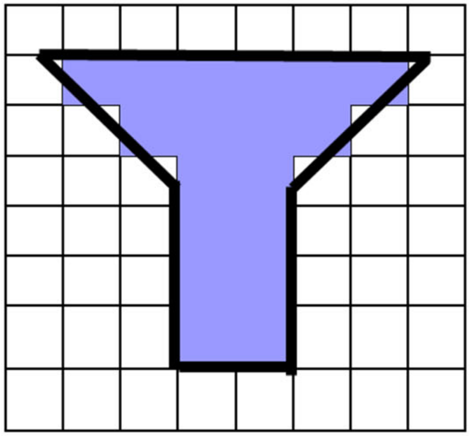


Image Sampling and Quantization

- Pixel size determines the resolution

- Sub-pixel accuracy
  - Many pixels + computational model

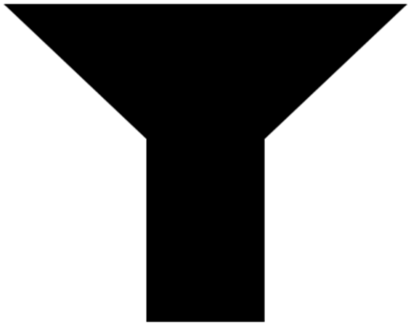
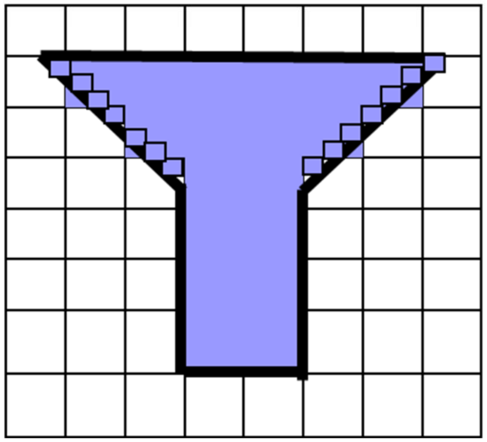



Image Sampling and Quantization

original image

sampled by a factor of 2

sampled by a factor of 4

sampled by a factor of 8

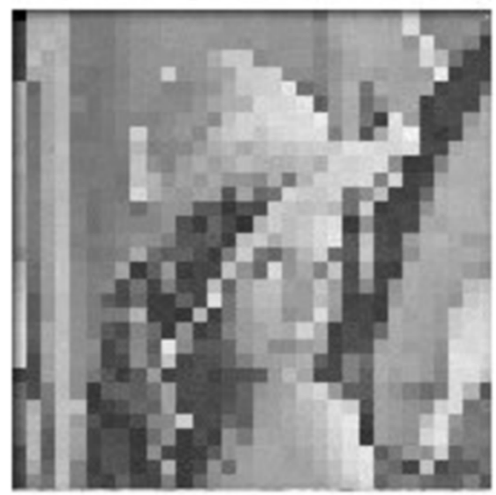
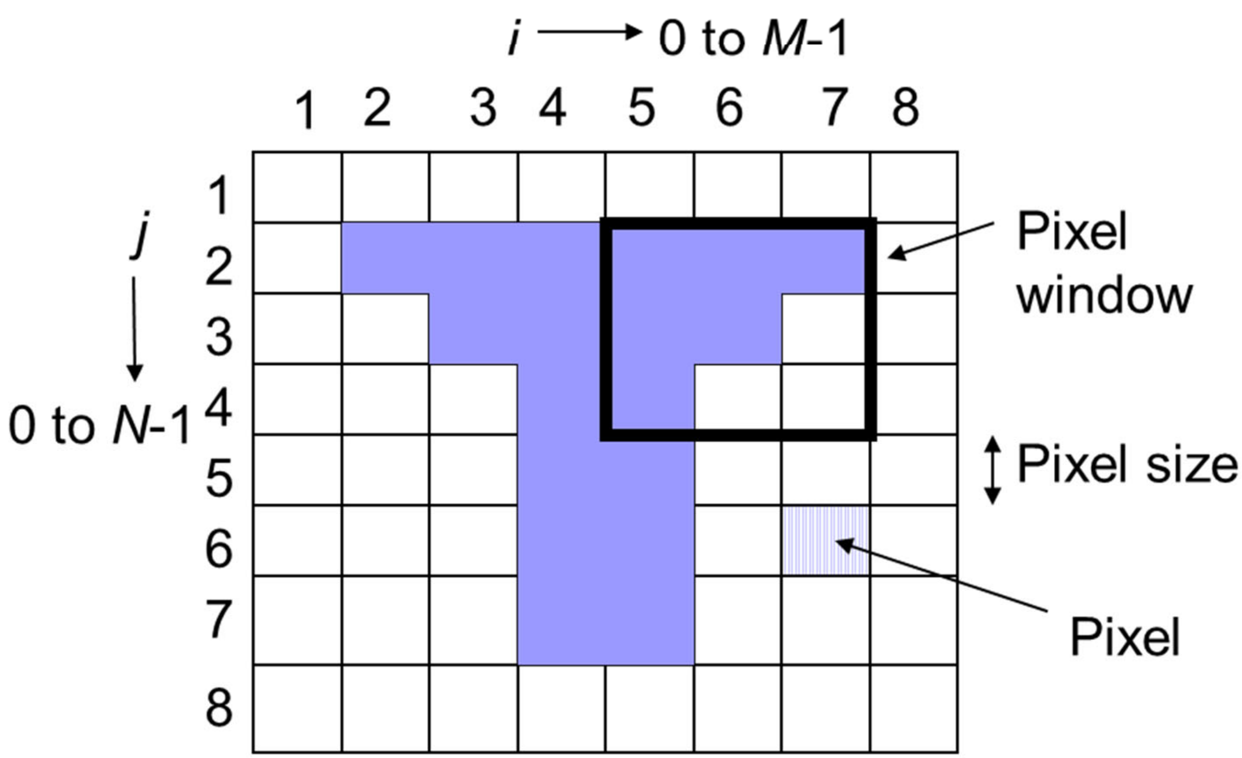


Image Sampling and Quantization

- Raster dimension

Raster or image dimension (= width x height) is the number of horizontal and vertical samples in the pixel grid.

IMAGE: M x N matrix of pixels $p(i, j)$



The pixel values $p(i, j)$ are sorted into the matrix in "natural" order, with i (or x) corresponding to the column and j (or y) to the row index.

This results in $p(i, j) = p_{ji}$ where p_{ji} denotes an individual element in common matrix notation.

Image Sampling and Quantization

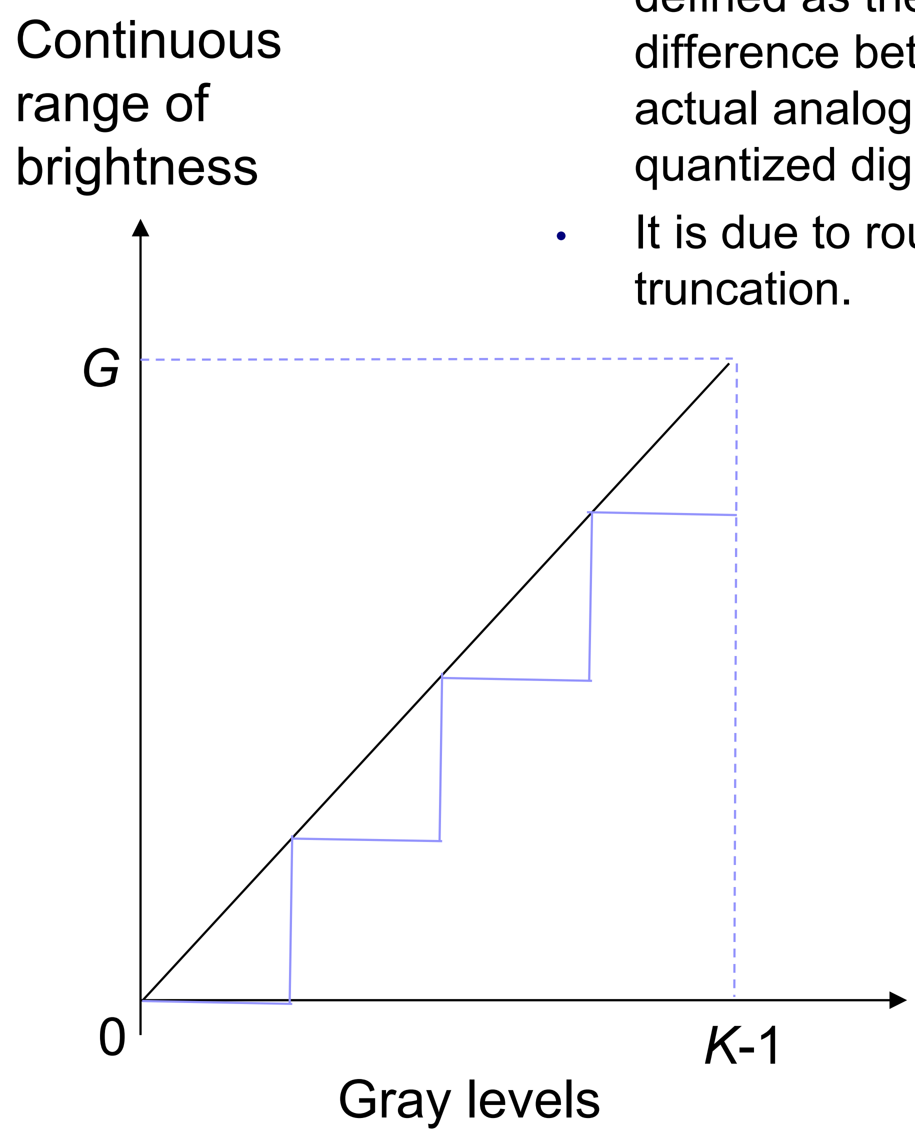
- Raster dimension
  - Number of pixels in an image (== raster dimension)
    - Video Graphics Array (VGA) display = 640 by 480 display;
      - M = 640 pixels, N = 480 pixels. 640 x 480 = 307,200 pixels or 0.3 megapixels
    - SVGA: 800 x 600 == 0.4 megapixels
    - XGA: 1024 x 768 == 0.8 megapixels
    - 1080i HDTV: 1920 x 1080 == 2.1 megapixels; 16:9 aspect ratio
      - High resolution digital TV format
    - 2K: 2048 x 1536 == 3.1 megapixels; 4:3 aspect ratio
      - Used for digital effects in feature films
    - Common CCD camera: at least 512 x 256 pixels = 131,072 pixels
    - Digital SLR camera: at least 4 million pixels

Image Sampling and Quantization

- Raster dimension
  - Scaling (or resampling): the process to create an image with different dimensions from that of the source image.
  - Scaling image down (or decimation): the process of reducing the raster dimension.
    - Averaging the values of source pixels contributing to each output pixel
  - Scaling image up: the process of increasing the image size to create sample points between the original sample samples in the source raster.
    - Interpolation – using the values in the sample grid to guess the values of the unknown pixels

Image Sampling and Quantization

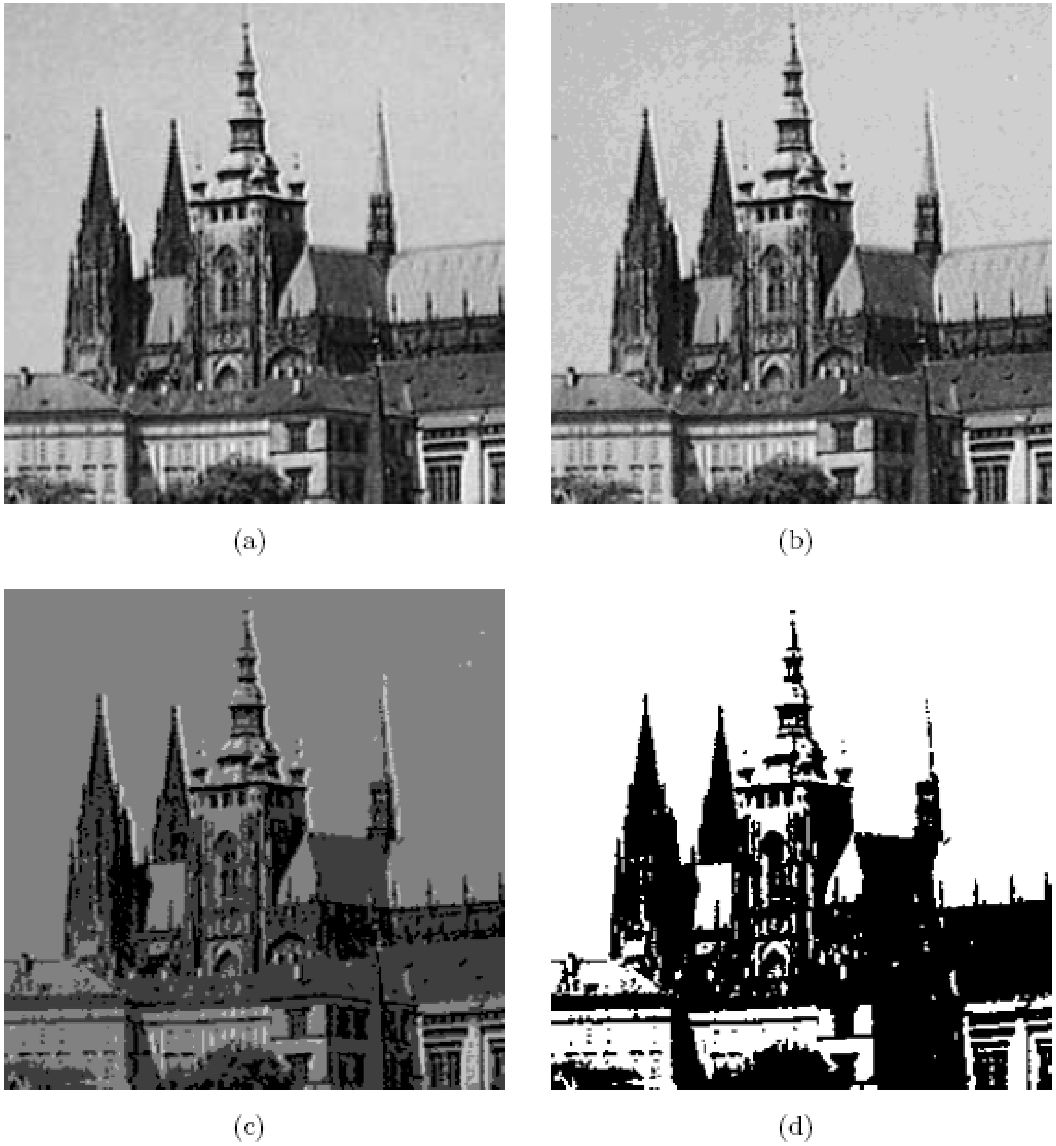
- Quantization
  - Quantizes the continuous range of brightness or intensity to *K* gray levels.
  - $K = 2^n$ where *n* is known as the color capability or color depth or bit depth.
  - *n* is the number of bits used to indicate the color of a single pixel.



- Quantization error is defined as the difference between actual analog value and quantized digital value.
- It is due to rounding or truncation.

Image Sampling and Quantization

- Quantization
  - Image quantization = discretion in light intensity
  - Brightness level = gray level in monochrome image



(Source: Sonka, Hlavac and Boyle, 2008)

Figure 2.3: Brightness levels. (a) 64. (b) 16. (c) 4. (d) 2.

Image Sampling and Quantization

- Color Depth
  - Maximum number of data a pixel can store
  - Monochrome: $p(i,j) = 0, 1, 2, \ldots, K\text{-}1$
  - Binary: $p(i,j) = 0, 1$
    - 0: black (current off – no light), 1: white (current on – maximum illumination).
    - Color capability = 1 bit of data
  - Grayscale: $p(i,j) = 0, 1, \ldots, 255$
    - 0: black, 1..254: gray, 255: white
    - Color capability = 8 bits of data

Image Sampling and Quantization

- Color Depth
  - Color: p(*i,j*) = [*R*(*i,j*) *G*(*i,j*) *B*(*i,j*)]
    - RGB/8: *R*(i,j) = 0..255, *G*(i,j) = 0..255, *B*(i,j) = 0..255. 8 bit of data per color channel.

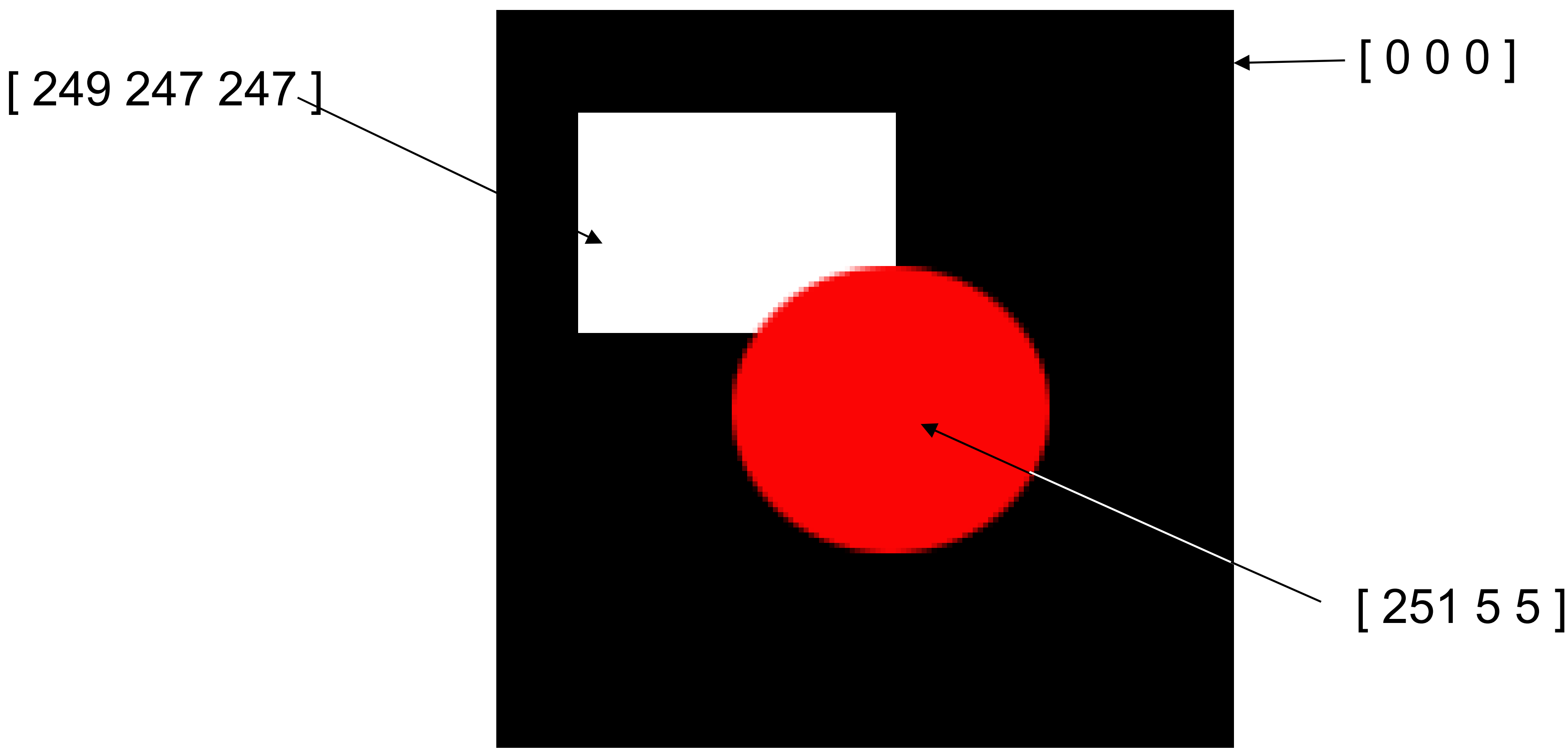


Image Sampling and Quantization

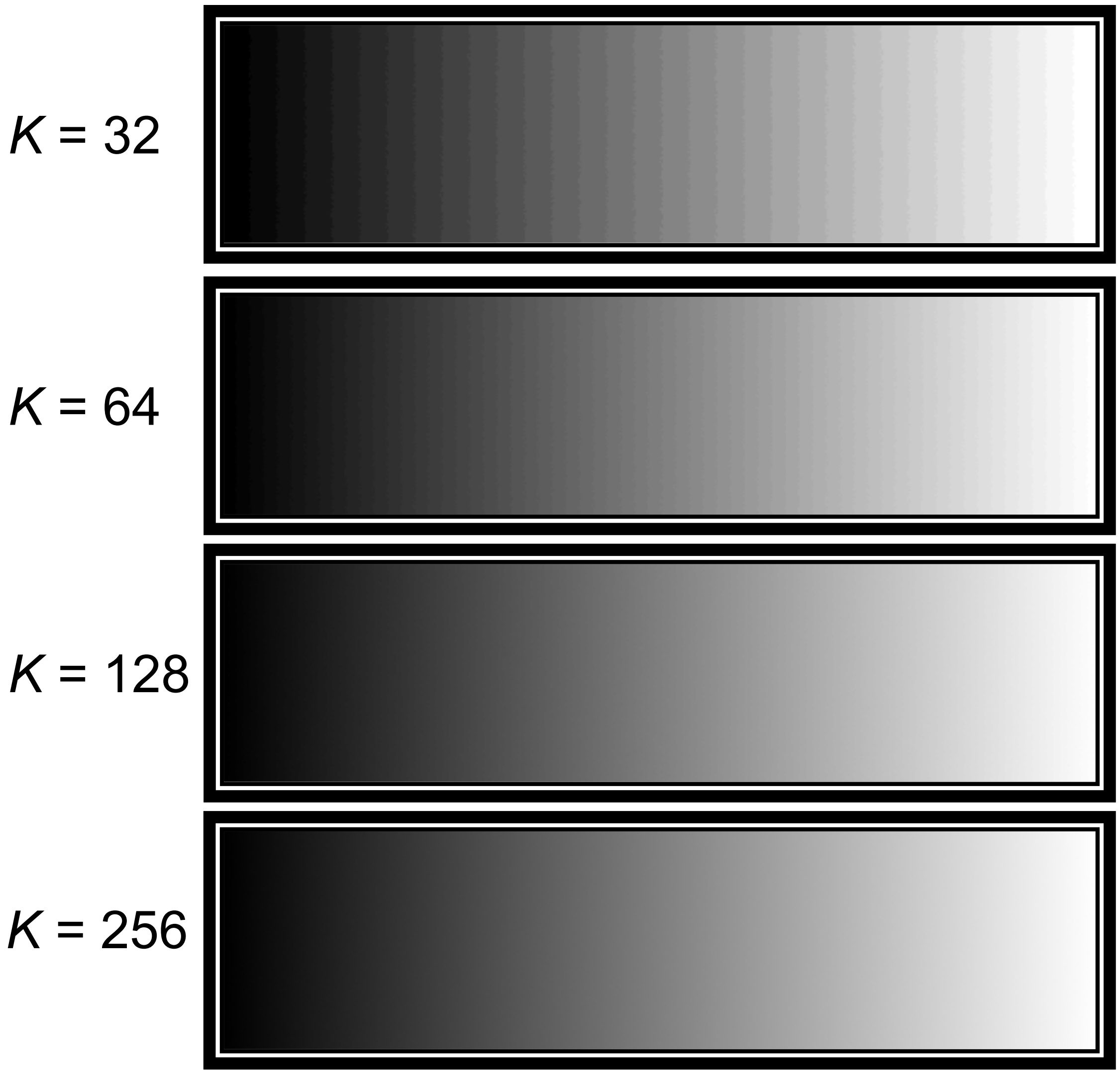
- Color Depth
  - Indexed Color
    - Color capability = 8 bits per pixel, maximum number of values = 256. Each value is an index number corresponds to explicit color value in the file’s look-up table.
    - The look-up table (color look-up table or colormap) is stored at the header of the image file. Color look-up table can be a hardware device built into an imaging system.

Image Sampling and Quantization

- Color Depth
  - Indexed Color
    - A colormap is defined as a list of colors, each indexed by an integer pixel value. Each entry in a colormap is called a color cell. A color cell represents a color usually defined by a set of three numeric values, representing intensities of red, green and blue respectively.
    - Advantages: save memory/storage space and/or transmission time.
    - The finer the sampling (i.e., the larger M and N) and quantization (i.e., the larger K), the better the approximation of the continuous image function f(x,y) achieved.
    - The number of quantization levels (brightness or gray levels) should be high enough for human perception of fine shading details in the image.

Image Sampling and Quantization

- Color Depth



How many gray levels are required for human visual perception?

A human is able to recognize about 60 gray levels at most.

A digital image is usually quantized to 256 gray levels.

Digital Image Properties

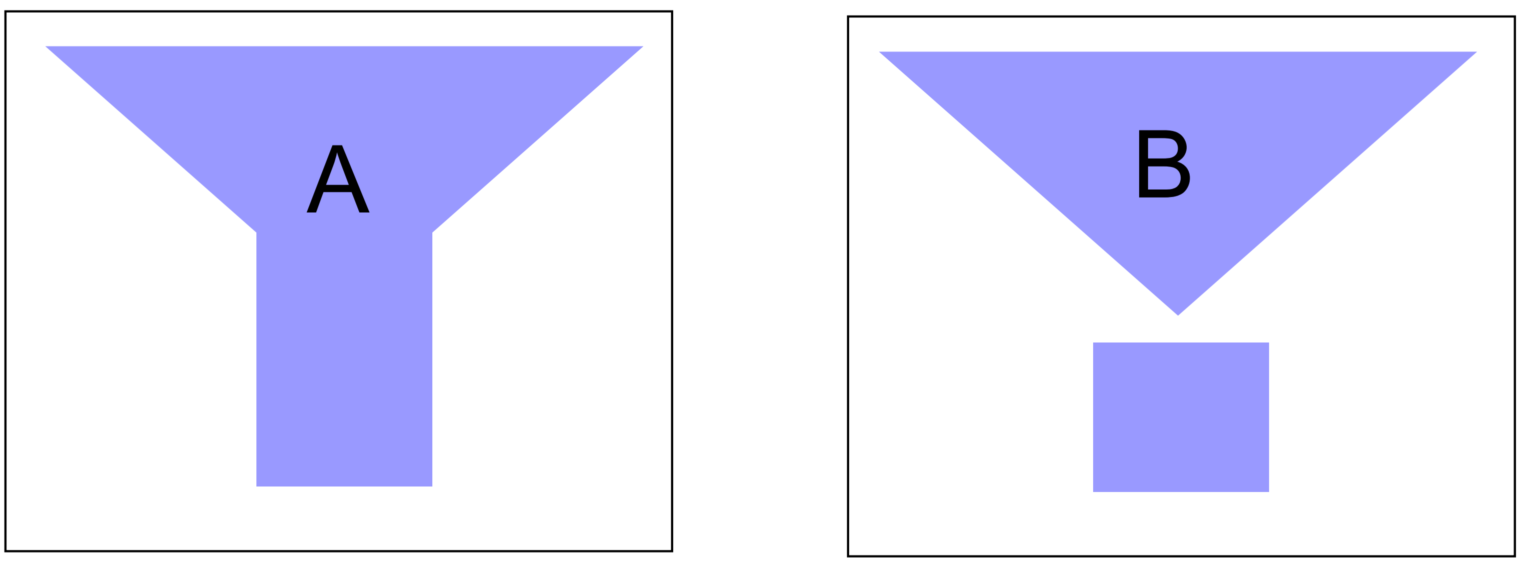
- Metric and topological properties
- Histogram
- Visual perception

Digital Image Properties

- Metric and Topological Properties
  - A set is a collection of distinct objects.
  - A metric space is a set where a notion of metric (or distance) between elements of the set is defined.
  - A topological space is a mathematical structure that allows the formal definition of connectivity, convergence and continuity. (How parts are interrelated or arranged, and spatial relations unaffected by change of shape or size)

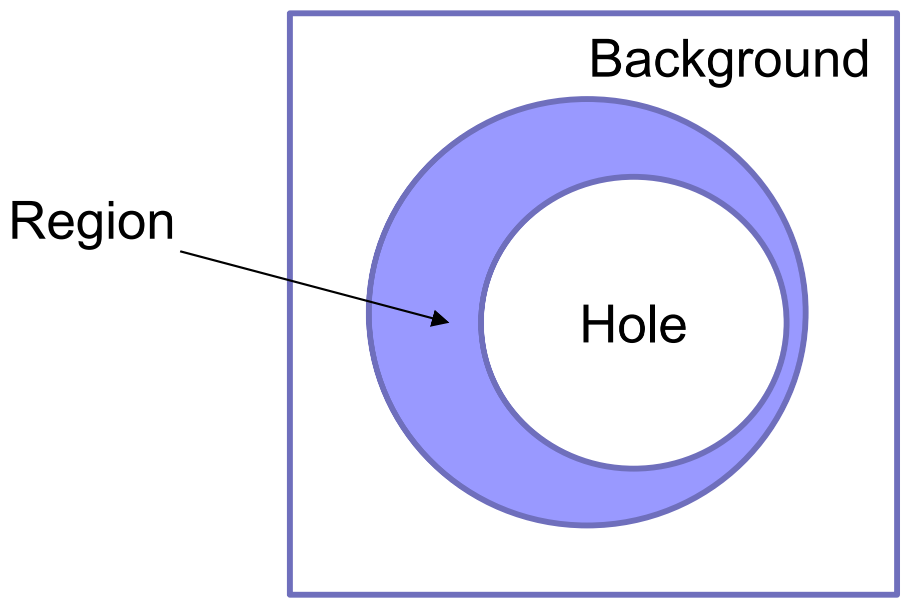
Digital Image Properties

- Connectivity
  - A connected space is a topological space which cannot be represented as the disjoint union of two or more nonempty open subsets.



Digital Image Properties

- Connectivity
  - To provide shape information
  - To establish objects' components and boundaries



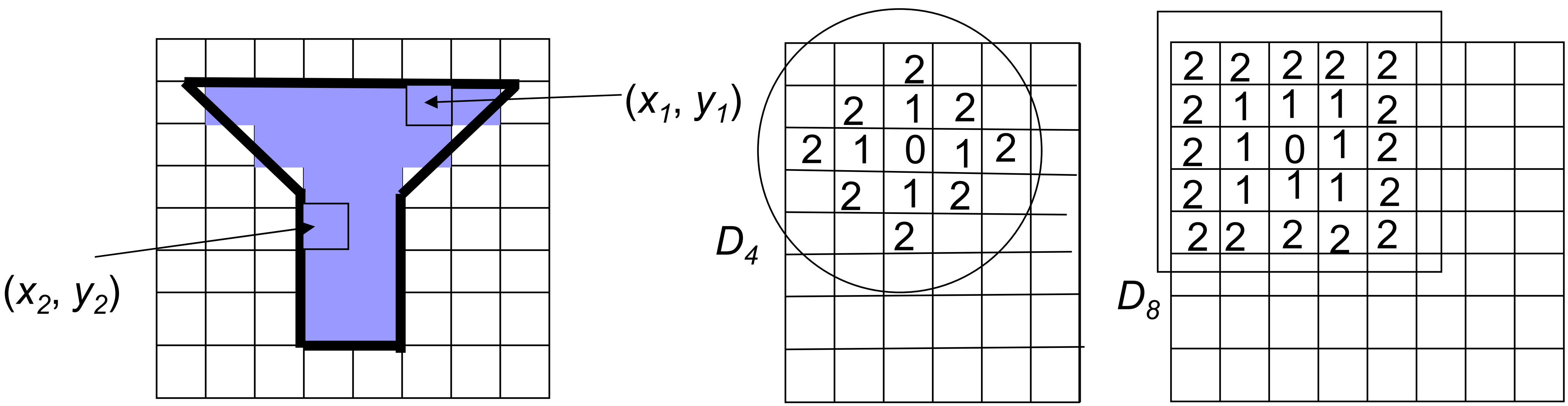
Digital Image Properties

- Connectivity
  - Distance to examine connectivity

$$\text{Euclidean}: D_E = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

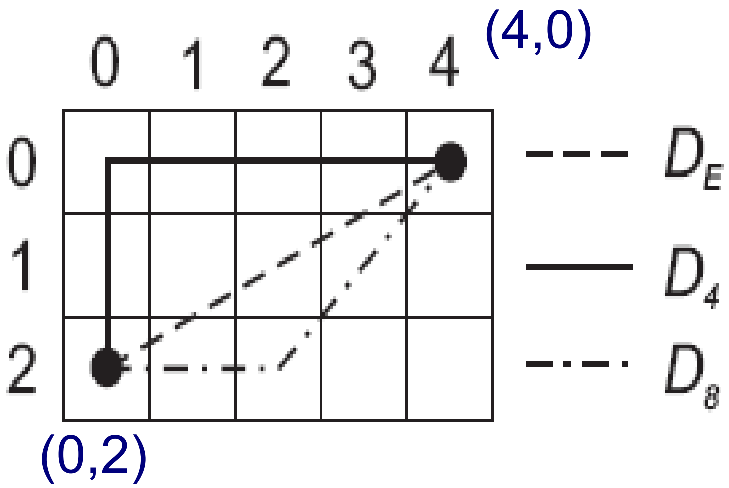
$$\text{City block}: D_4 = |x_2 - x_1| + |y_2 - y_1|$$

$$\text{Chess board}: D_8 = \max(|x_2 - x_1|, |y_2 - y_1|)$$



Digital Image Properties

- Connectivity
  - Distance to examine connectivity



- What is the distance between (4,0) and (0,2)?

Figure 2.4: Distance metrics D_e, D_4, and D_8.

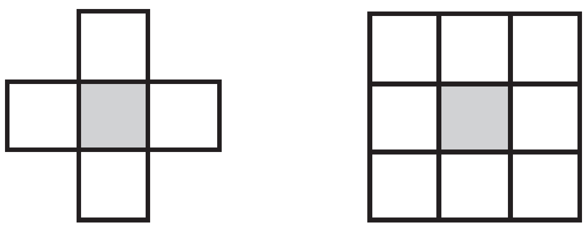
(Source: Sonka, Hlavac and Boyle, 2008)

D_E = sqrt((4-0)^2 + (0-2)^2) = sqrt(20)
D_4 = |4-0| + |0-2| = 6
D_8 = max(|4-0| , |0-2|) = 4

Digital Image Properties

- Typical Connectivity
  - 4-neighborhood (or 4-connectivity)
  - 8-neighborhood (or 8-connectivity)

- *p* and *q* are contiguous if there is a path between them (connected).
- A region is a connected set (each pair of pixels is contiguous).



(a) 4-neighborhood (b) 8-neighborhood

(Source: Sonka, Hlavac and Boyle, 2008)

Figure 2.5: Neighborhood of the representative pixel (gray filled pixel in the middle).

2 pixels *p* and *q* form a region are 4-connected if *q* is in the set containing the 4-neighbours of *p*. $D_4(p, q) = 1$

Digital Image Properties

- Typical Connectivity

0 – all off, no light, black; background
1 – all on, light, white; object

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

Figure 2.8: Input binary image. Gray pixels correspond to objects and ~~white~~ pixels to background.

5	4	4	3	2	1	0	1
4	3	3	2	1	0	1	2
3	2	2	2	1	0	1	2
2	1	1	2	1	0	1	2
1	0	0	1	2	1	0	1
1	0	1	2	3	2	1	0
1	0	1	2	3	3	2	1
1	0	1	2	3	4	3	2

Figure 2.9: Result of the distance transform when the distance D_4 is considered in calculations.

(Source: Sonka, Hlavac and Boyle, 2008)

Digital Image Properties

- Histogram
  - The brightness histogram H(*z*) of an image provides the frequency of the brightness value *z* in the image.
  - The histogram of an image with *L* gray-level is represent by a 1D array with *L* elements.

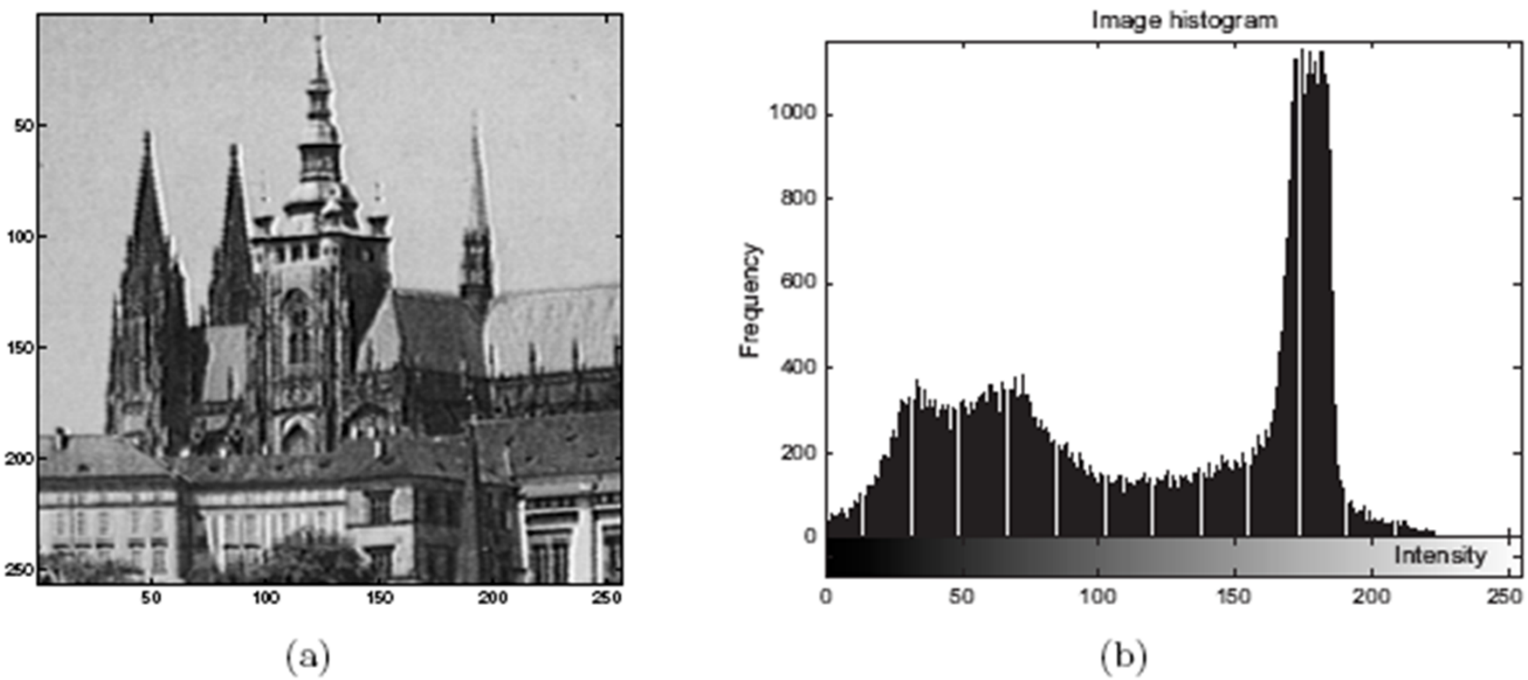


Figure 2.16: Original image (a) and its brightness histogram (b).

(Source: Sonka, Hlavac and Boyle, 2008)

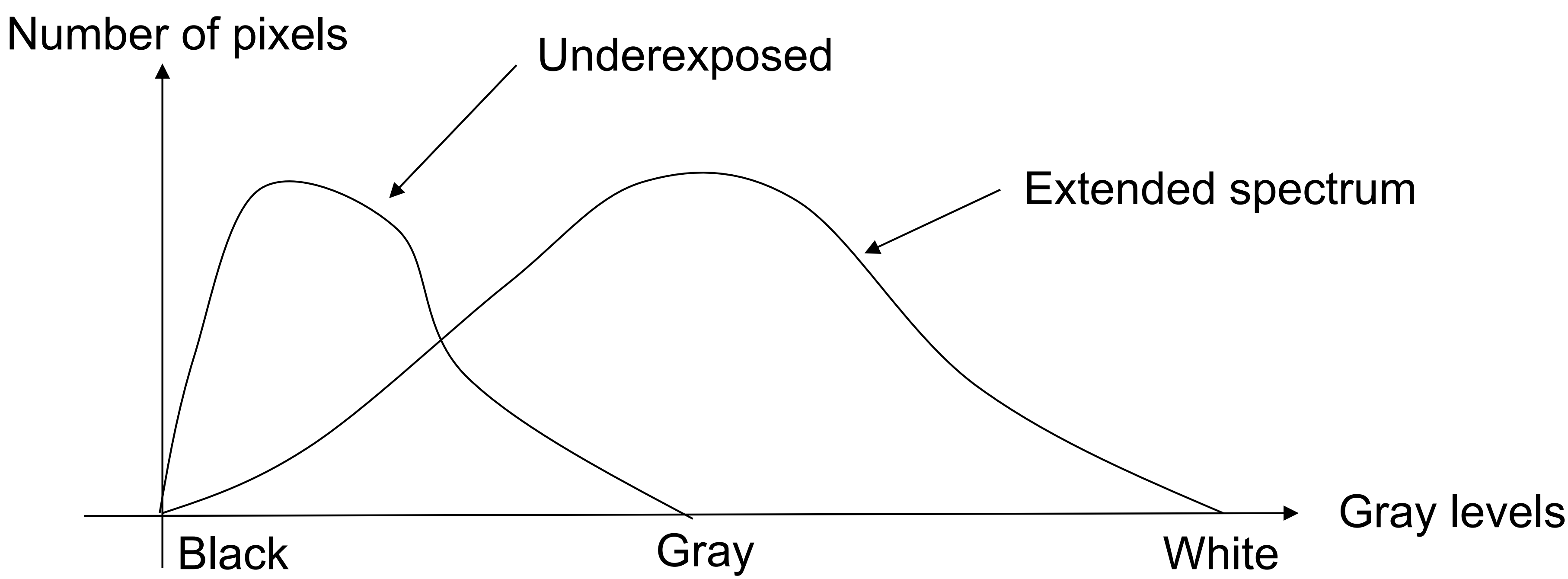
Digital Image Properties

- Histogram
  - Can be achieved by simply counting the number of pixels for each gray level.

  - https://www.mathworks.com/help/matlab/ref/matlab.graphics.chart.primitive.histogram.html

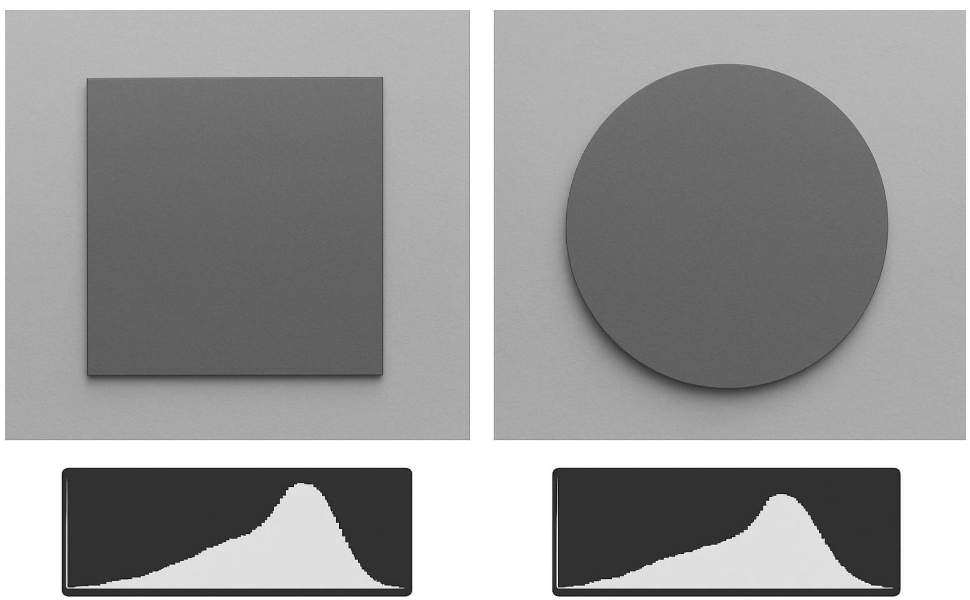
Digital Image Properties

- Histogram
  - It can detect image with contrast problems, underexposed (too dark) and overexposed (too light).



Digital Image Properties

- Histogram
  - More than one images can have the same histogram.
  - It can be used to remove background using thresholding.
  - Invariant to typical image transformation such as rotation.
  - It does not relate to object's shape information.



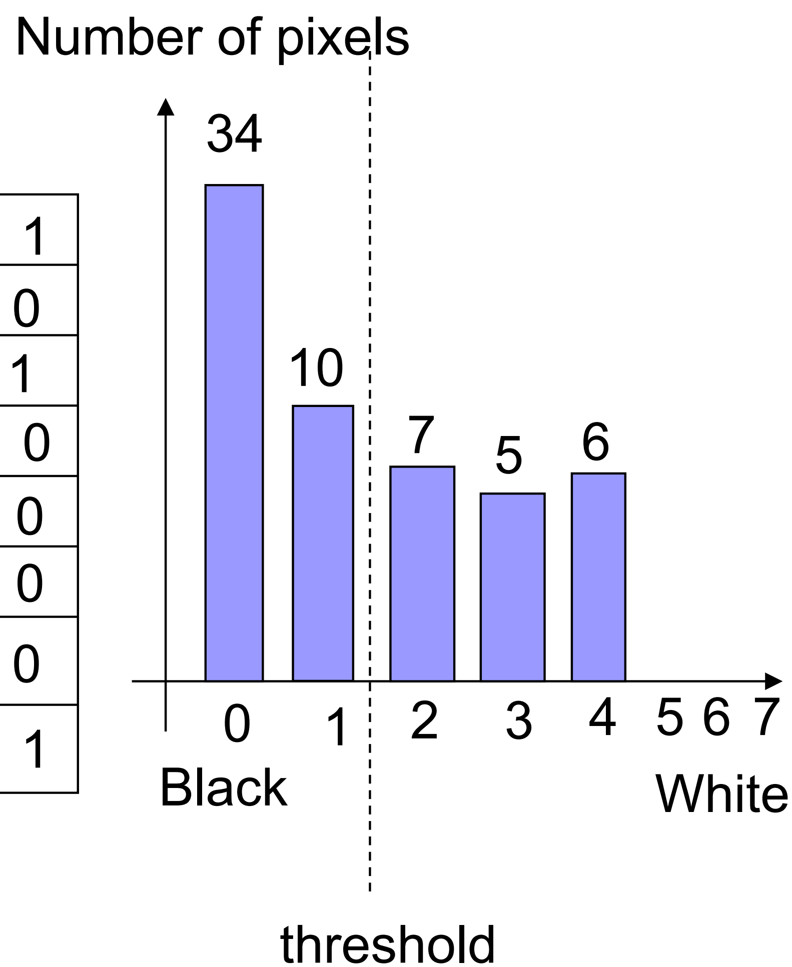
Digital Image Properties

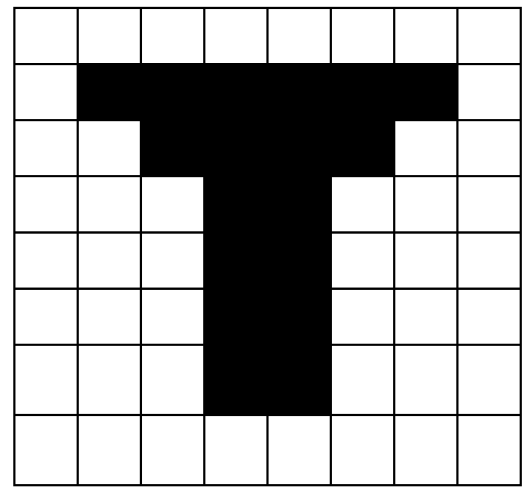
- Thresholding
  - Thresholding is the simplest method of image processing.
  - A binary image is created from a grayscale image by marking individual pixels in an image as “object” pixels if their value is greater than some threshold value (assuming the object is lighter than background) and “background” pixel otherwise.
  - Note that objects in an image are not necessary represented using darker shades.

Digital Image Properties

- Thresholding

1	0	0	0	0	0	0	1
0	2	2	3	3	3	2	0
0	0	2	4	4	2	0	1
0	0	0	4	4	0	0	0
0	1	0	4	4	0	1	0
0	0	0	3	3	0	0	0
1	0	1	2	2	0	1	0
0	0	0	1	1	0	0	1





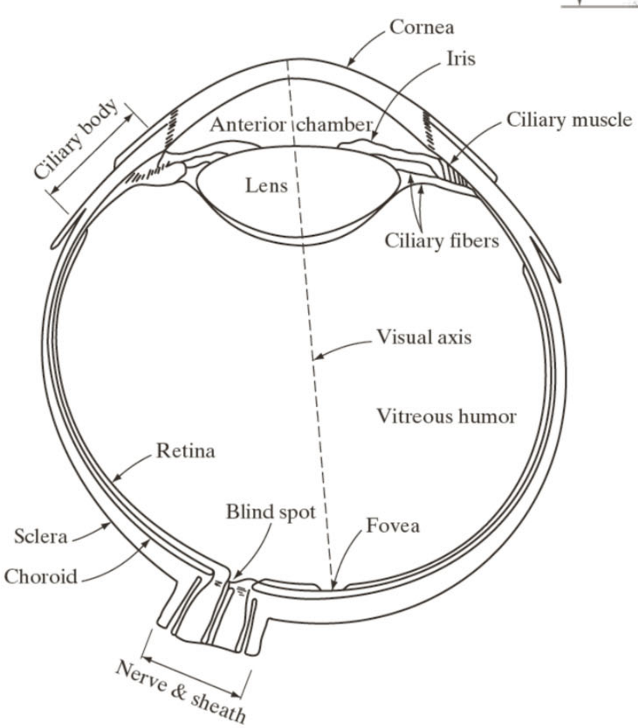
The above is for illustration only. The background is black and the object is white.

Original image → Histogram → Binary image

Digital Image Properties

- Visual Perception

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



(Source: Gonzalez and Woods, 2010)

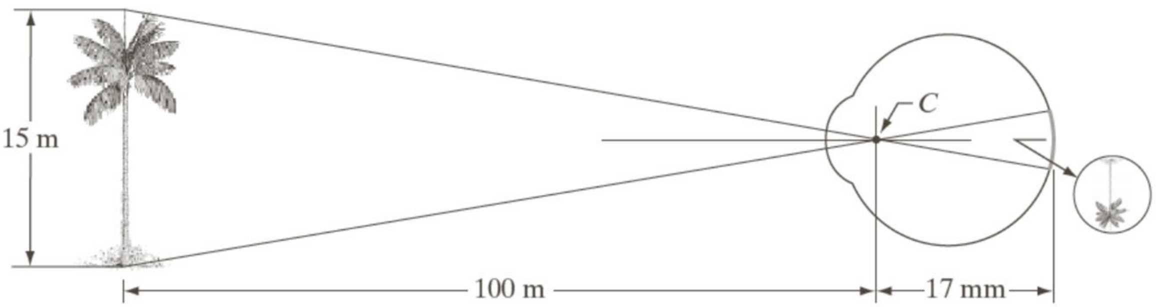
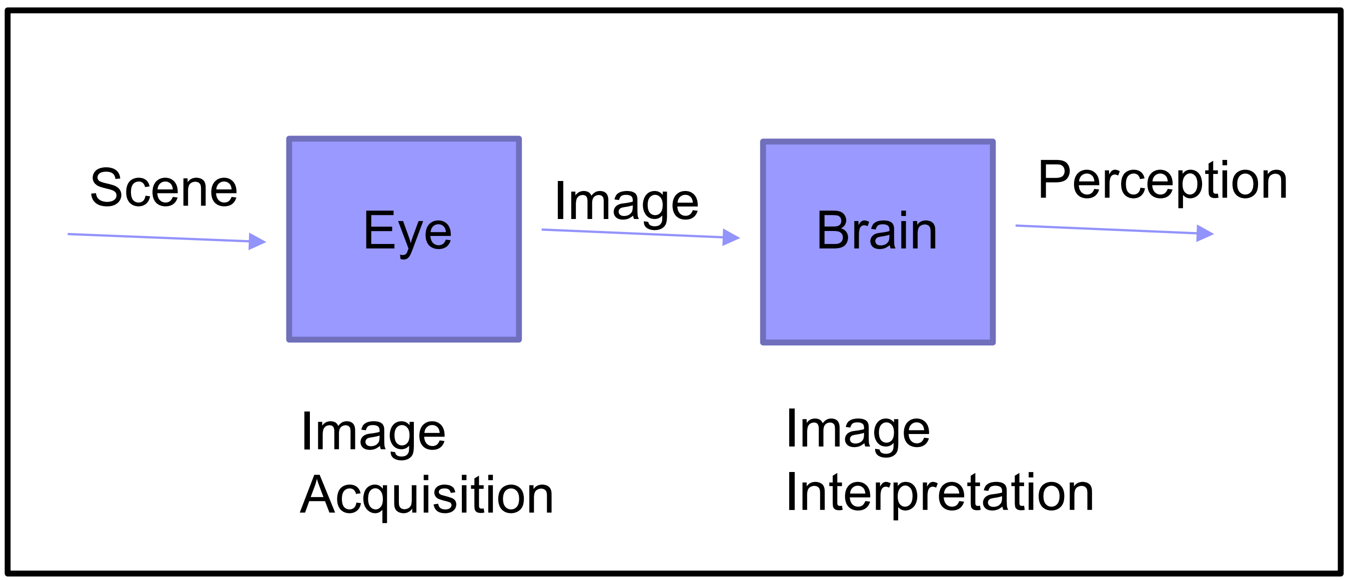


FIGURE 2.3 Graphical representation of the eye looking at a palm tree. Point *C* is the optical center of the lens.

Does our eye see the tree?



Digital Image Properties

- Visual Perception
  - Contrast
    - Contrast is the local change in brightness.
    - The ratio between average brightness of an object and the background.

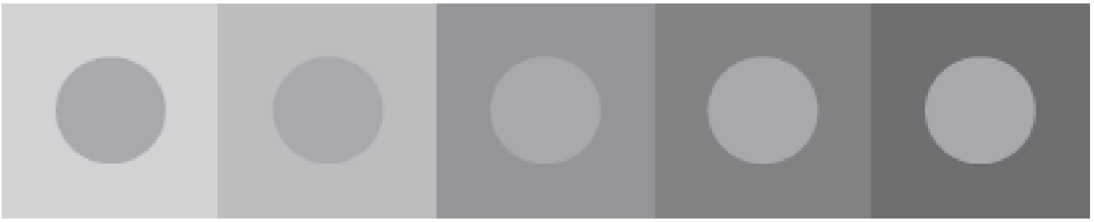
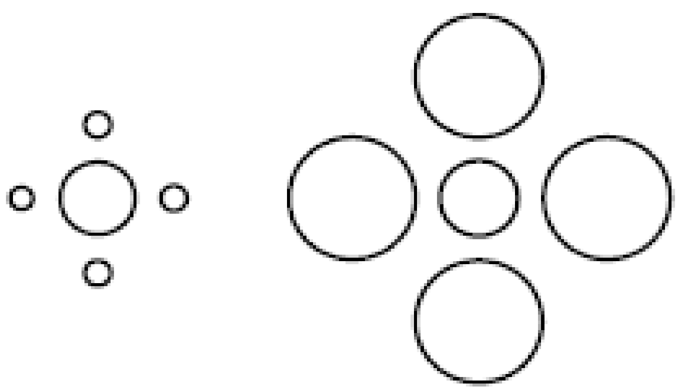


Figure 2.17: Conditional contrast effect. Circles inside squares have the same brightness and are perceived as having different brightness values.

Contrast sensitivity is the ability of our visual system to distinguish objects from the background.

Digital Image Properties

- Visual Perception
  - Acuity
    - The ability to detect details in an image.
    - Acuity defines the resolution ability of human eye (sharpness).



Two inner circles of same diameter appeared to have different diameters.

Figure 2.18: The Ebbinghaus illusion.

Digital Image Properties

- Visual Perception
  - Some visual illusions

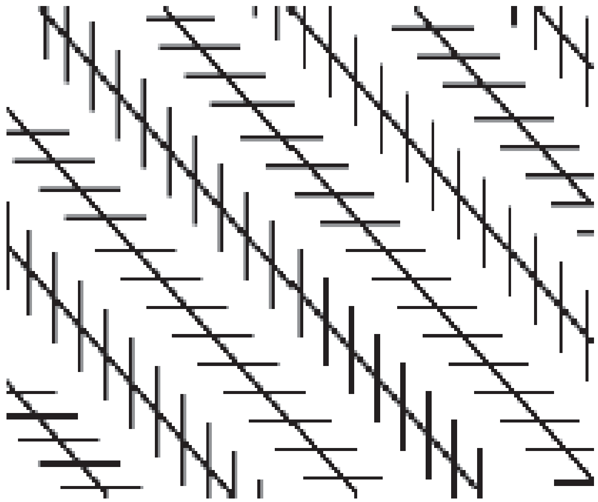


Figure 2.19: Disrupted parallel diagonal lines.

Parallel diagonal line segments are not perceived as parallel.

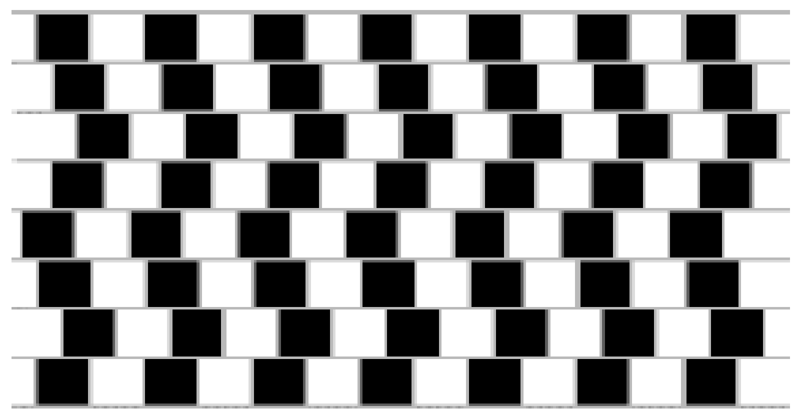


Figure 2.20: Horizontal lines are parallel, although not perceived as such.

Rows of black and white squares are all parallel.

Digital Image Properties

- Visual Perception
  - Perceptual grouping
    - The human visual ability to extract significant image relations from lower-level image features without any knowledge of the image content, and group them to obtain meaningful higher level structure.

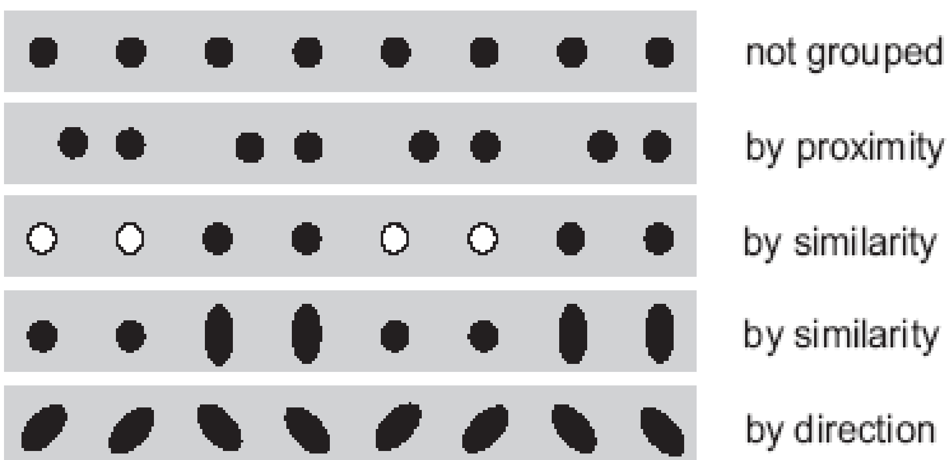


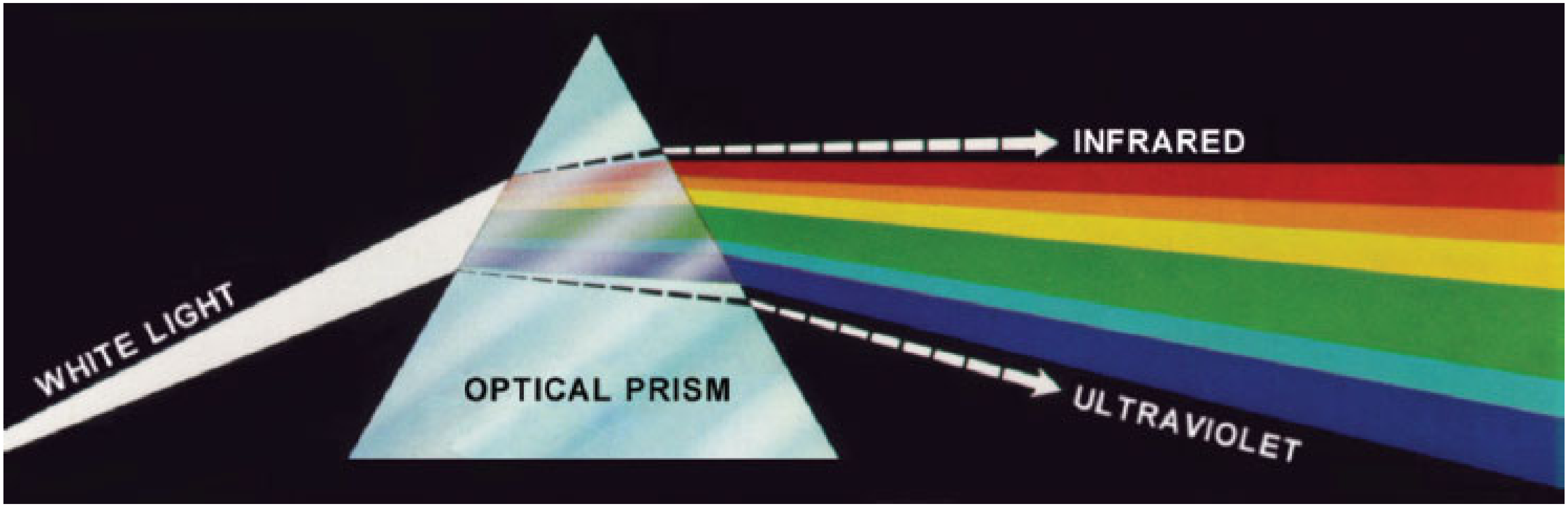
Figure 2.21: Grouping according to properties of elements.

Digital Color Images

- In automated image analysis, color is a powerful descriptor that often simplifies object identification and extraction from a scene.
- In image analysis performed by human, human can discern thousands of color shades and intensities, compared to not more than 60 shades of grey.
- Two major areas: full color (image acquired by color TV camera or color scanner) and pseudo color (a shade of color is assigned to a particular monochrome intensity or range of intensities).

Digital Color Images

- Color Spectrum
  - Sir Issac Newton discovered in 1666 that when a beam of sunlight is passed through a glass prism, consists of a continuous spectrum of colors ranging from violet at one end to red at the other. The color spectrum may be divided into six broad regions violet, blue, green, yellow, orange, and red.

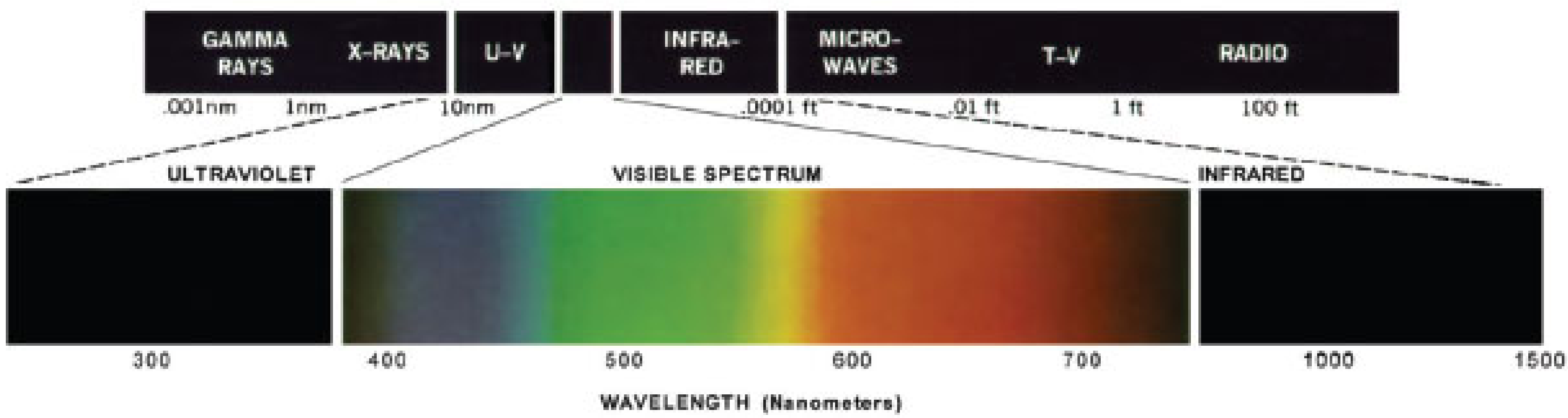


Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lighting Division.)

Source: Digital Image Processing By Gonzalez and Woods, Pearson.

Digital Color Images

- Color Spectrum
  - When view in full color, no color in the spectrum ends abruptly, but rather each color blends smoothly into the next.
  - The colors that human perceives in an object are determined by the nature of the light reflected from the object. A body that reflects light that is relatively balanced in all visible wavelengths appears white to the observer.
  - However, a body that favors reflectance in a limited range of the visible spectrum exhibits some shades of color. For example, green objects reflect light with wavelengths primarily in the 500 to 570 nm range, while absorbing most of the energy at other wavelengths.

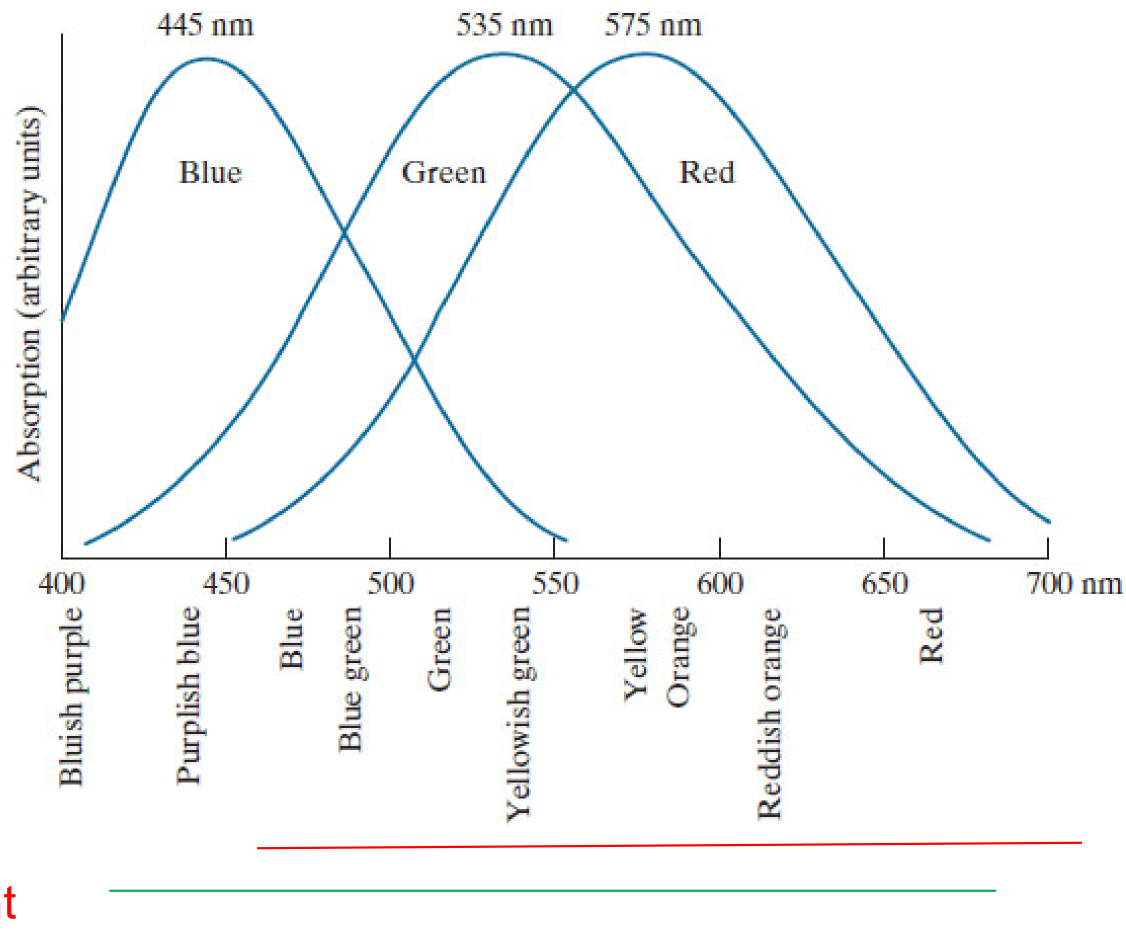


Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lighting Division.)
Source: Digital Image Processing By Gonzalez and Woods, Pearson.

Digital Color Images

- Color Spectrum

Color perception in human eye are done by the 6-7 millions cones in human eye.

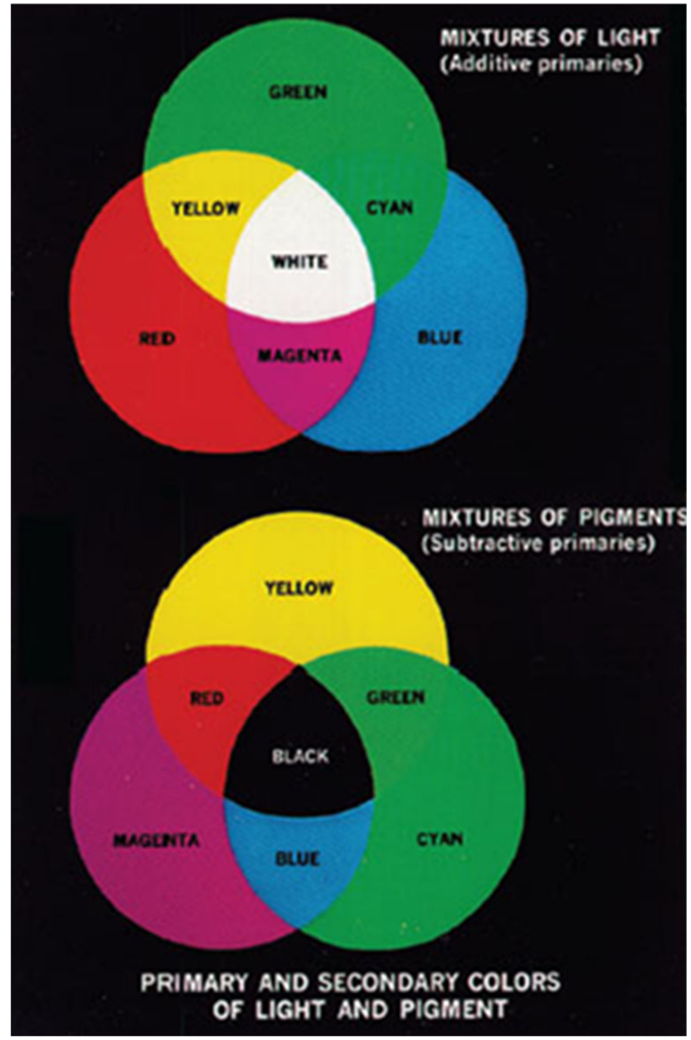


Three categories: red/green/blue light sensitive cones

Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.
Source: Digital Image Processing By Gonzalez and Woods, Pearson.

Digital Color Images

- Primary and Secondary Colors
  - The primary colors can be added to produce the secondary colors of light –
    - Magenta = Red + Blue
    - Cyan = Green + Blue
    - Yellow = Red + Green
  - Mixing the three primaries, or a secondary with its opposite primary color in the right intensities produces the white light.



Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lighting Division.) Source: Digital Image Processing By Gonzalez and Woods, Pearson.

Digital Color Images

- Color Characteristics
  - **Brightness** embodies the chromatic notion of intensity.
  - **Hue** is an attribute associated with the dominant wavelength in a mixture of light waves. Thus hue represents the color as perceived by an observer; when we call an object red, orange or yellow, we are specifying its hue.
  - **Saturation** refers to relative purity or the amount of white light mixed with the hue. The pure spectrum colors are fully saturated. Colors such as pink (red and white) are less saturated, with the degree of saturation being inversely proportional to the amount of white light added.

Digital Color Images

- Color Characteristics
  - **Hue and saturation taken together** are called *chromaticity*, and therefore, a color may be characterized by its brightness and chromaticity. The amounts of red, green and blue needed to form any particular color are called the tristimulus values and are denoted, *X, Y* and *Z*, respectively.

  - A color is then specified by its trichromatic coefficients, defined as:
    - $x = X/(X + Y + Z)$
    - $y = Y/(X + Y + Z)$
    - $z = Z/(X + Y + Z)$
    - $x + y + z = 1$

Digital Color Images

- Chromaticity Diagram
  - It shows color composition as a function of x (red) and y(green). For any value of x and y the corresponding value of z (blue) can be obtained by x + y + z = 1.
  - Example, the point marked green in Plate IV, has approximately 62% green and 25% red content, and hence the composition of blue is approximately 13%.

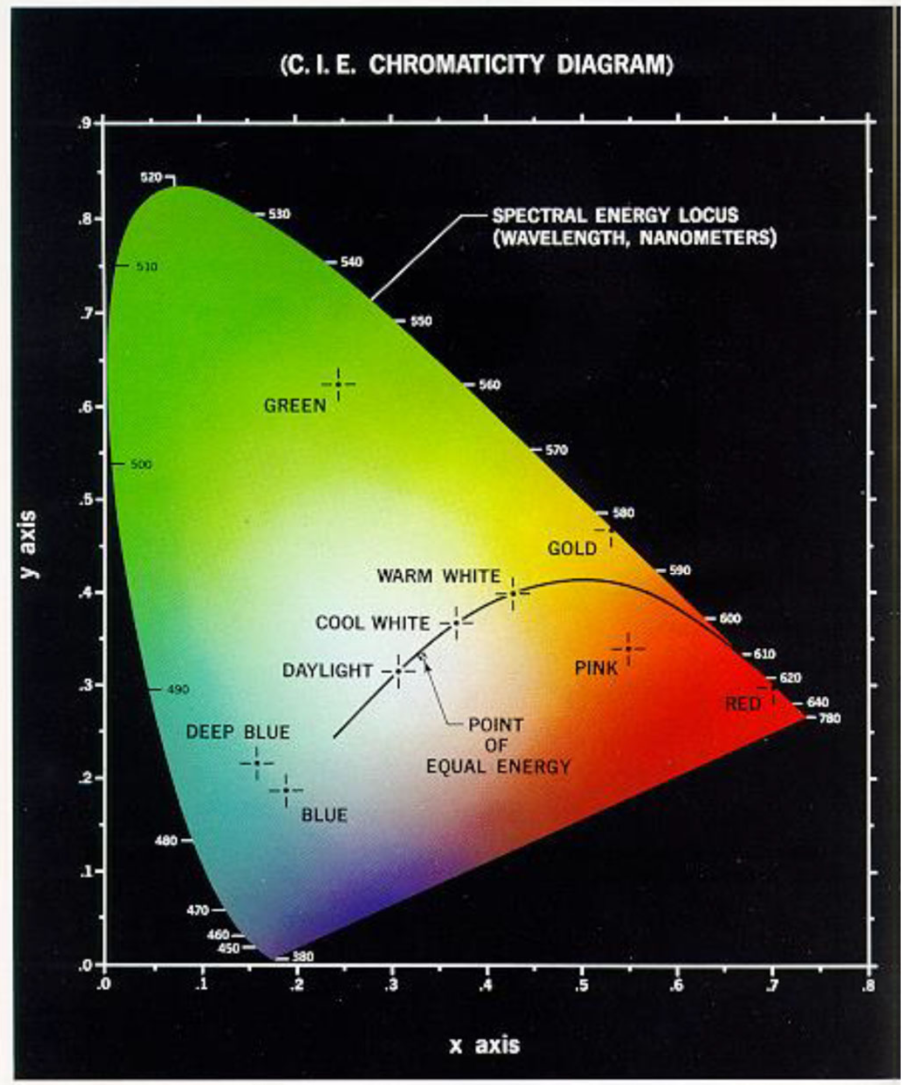


Plate IV. Chromaticity diagram. (Courtesy of General Electric Co., Lamp Business Division.)

Digital Color Images

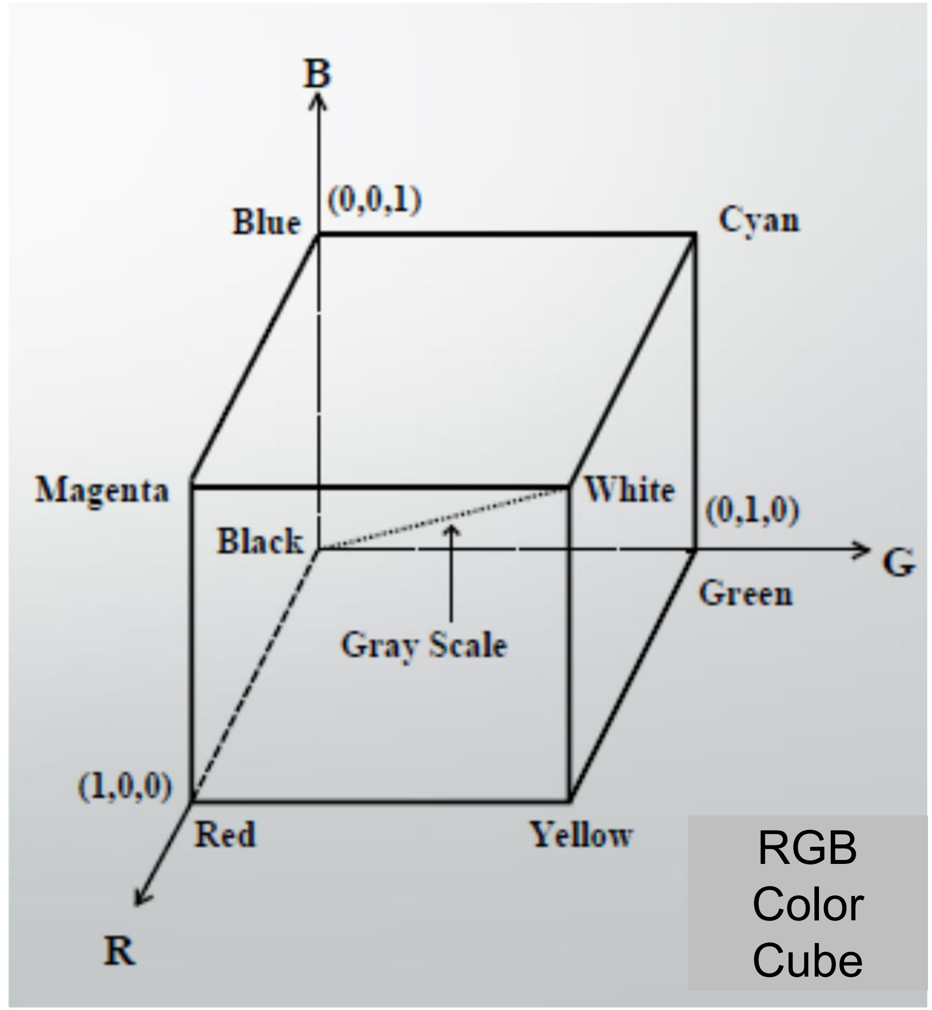
- Color Models
  - A color model is a specification of a 3D coordinate system and a subspace within that system where each color is represented by a single point.
  - Hardware oriented models most commonly used in practice are:
    - RGB (red, green, blue) model for color monitor and broad class of color video cameras.
    - CMY (cyan, magenta, yellow) model for color printers; and
    - YIQ model, which is the standard for color TV broadcast. In this model, Y corresponds to luminance, and I and Q are two chromatic components called inphase and quadrature, respectively.
  - Models frequently used for color image manipulation are the HSI (hue, saturation, intensity) model and the HSV (hue, saturation, value) model.
  - Color models most often used for image processing are the RGB, the CMY, the YIQ and the HSI models.

Color model == color space == color system: standardization of color specification

Digital Color Images

Mainly used in color monitors and video cameras

- RGB Color Models
  - The gray scale extends from black to white along the line joining these two points, and colors are points on or inside the cube, defined by vectors extending from the origin.
  - For convenience, the assumption is that all color values have been normalized so that the cube is a unit cube, i.e., all values of R, G, and B are assumed to be in the range [0,1].
  - Images in the RGB color model consist of three independent image planes, one for each primary color. Most color cameras used for acquiring digital images utilize the RGB format, which alone makes this an important model in image processing.



Points along the main diagonal have grey values from black at the origin to white at point (1,1,1).

Digital Color Images

Mainly used in printing devices

- CMY Color Models
  - Cyan, magenta and yellow are three secondary colors of light, or alternatively, the primary colors of pigments. Cyan subtracts red light from reflected white light which composes of equal amount of red, green and blue light.
  - CMY color model is used in generation of hardcopy output.
  - Most devices that deposit color pigments on paper (examples: color printers and copiers) require CMY data input or perform an RGB to CMY conversion internally.

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

where all color values are normalized to the range of (0,1).

- RGB values can be easily obtained from a set of CMY values.

Digital Color Images

- YIQ Color Models

YIQ color model is used in commercial color TV broadcasting.

- YIQ is a recording of RGB for transmission efficiency and for maintaining compatibility with monochrome TV standards. Y component provides all the video information required by a monochrome television set.
- RGB to YIQ conversion:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

where all color values are normalized to the range of (0,1).

- YIQ model takes advantage of human vision system's greater sensitivity to changes of luminance than to change in hue or saturation. More bandwidth (or bits in the case of digital colors) are used to present Y, and less bandwidth in representing Y and Q.
- Advantage in image processing: luminance (Y) and color information (I and Q) are decoupled. Luminance is proportional to the amount of light received by the eye. The decoupling enables luminance component of an image be processed without affecting its color content.
- Histogram Equalization can be applied to a YIQ color image simply by applying histogram equalization to its Y component without affecting its relative colors.

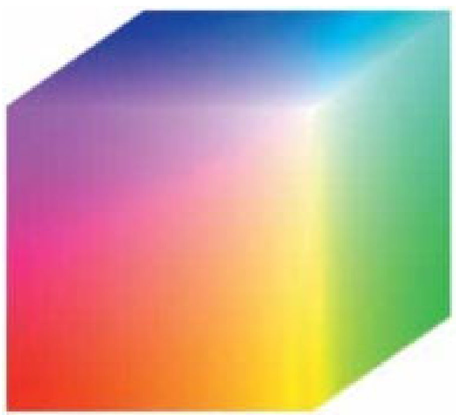
Digital Color Images

Based on the way human describes and interprets color. Helps in separate color and grayscale information in an image.

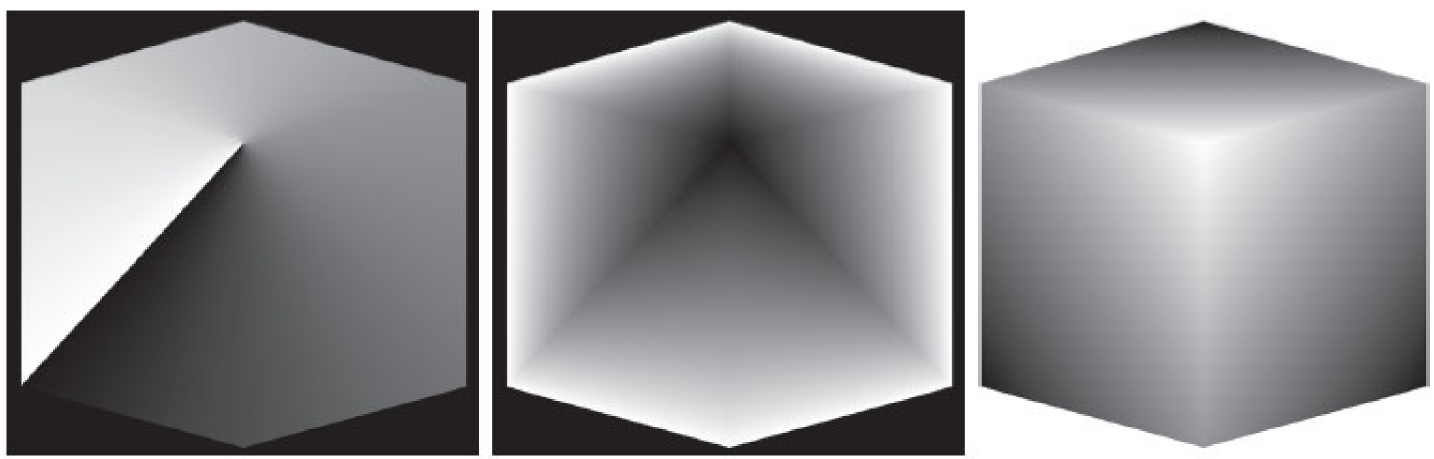
- HSI Color Models
  - Hue is a color attribute that describes a pure color (pure yellow, orange or red), whereas saturation gives a measure of the degree to which a pure color is diluted by white light
  - Two advantages
    - The intensity component I, is decoupled from the color information of the image. (I == amount of light == grayscale)
    - The hue and saturation components are intimately related to the way in which human beings perceived color.
  - An ideal tool for developing image processing algorithm based on some of the color sensing properties of the human visual system.
  - Examples of the usefulness of the HSI model range from the design of imaging systems for automatically determining the ripeness of fruits and vegetables, to systems for matching color samples or inspecting the quality of finished color goods.
  - The conversion formulas to go from RGB to HSI and back are considerably more complicated than in the preceding models.

Digital Color Images

- HSI Color Models



A 24-bit RGB color cube



a b c

HSI components: (a) hue, (b) saturation, and (c) intensity images.

Source: Digital Image Processing By Gonzalez and Woods, Pearson.