Color Model and Pixel Relations

Wahyono, Ph.D.
Department of Computer Science and Electronics
Faculty of Mathematics and Natural Sciences
Universitas Gadjah Mada, Yogyakarta, Indonesia
Email: wahyo@ugm.ac.id

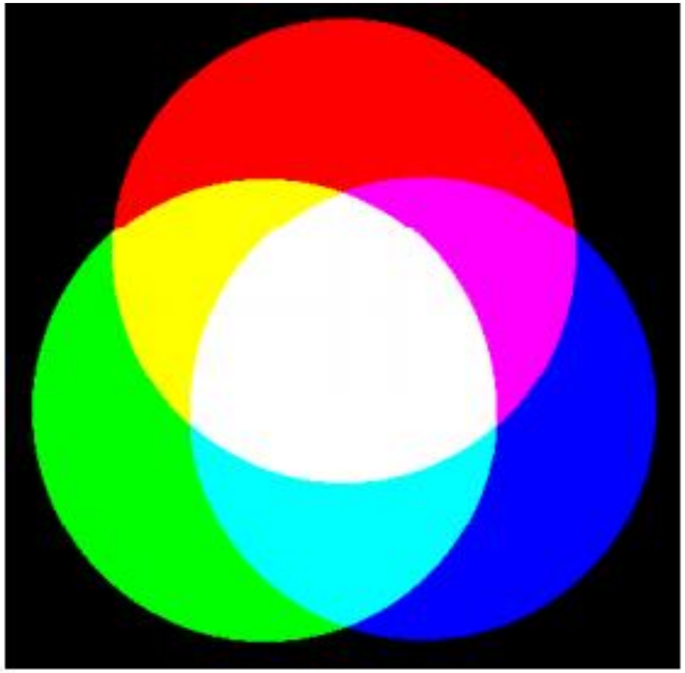
Color Models

- A mathematical system for representing color
- The human eye combines 3 primary colors (using the 3 different types of cones) to discern all possible colors.
- Colors are just different light frequencies
  - Red 700nm wavelength
  - Green 546.1 nm wavelength
  - Blue 435.8 nm wavelength

Primary Color

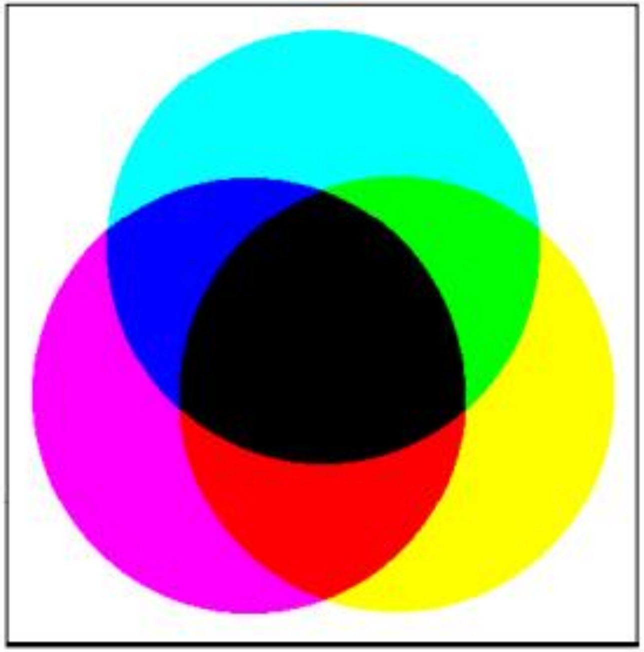
- Primary colors of light are additive
  - Primary g colors are red, green, and blue
  - Combining red + green + blue yields white
- Primary colors of pigment are subtractive
  - Primary colors are cyan, magenta, and yellow
  - Combining cyan Combining cyan magenta yellow yields + magenta + yellow yields black

RGB Color Model



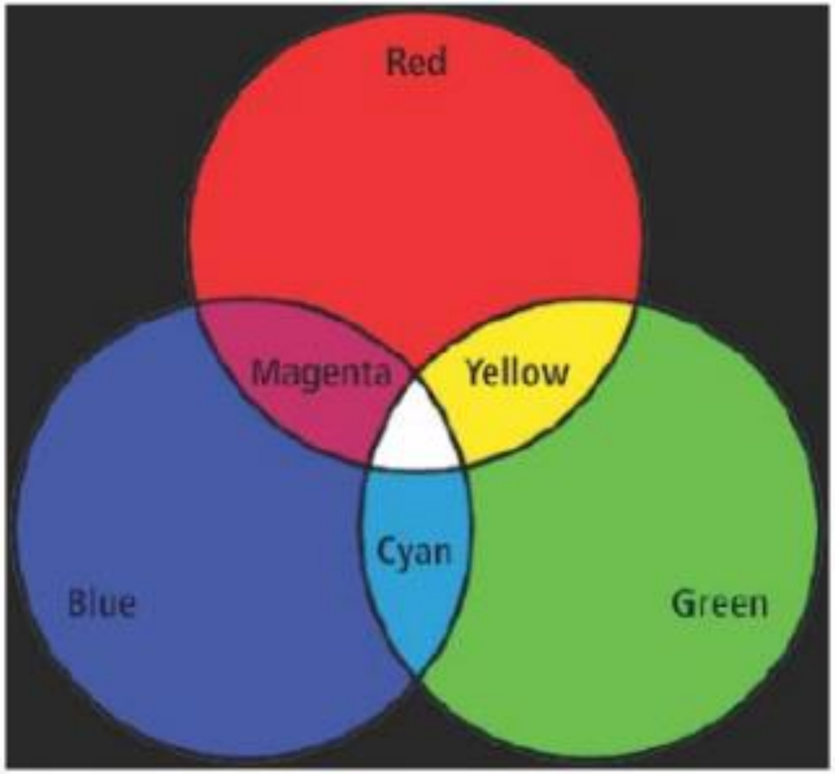
Active displays, such as computer monitors and television sets, emit combinations of red, green and blue light. This is an **additive** color model

CMY Color model

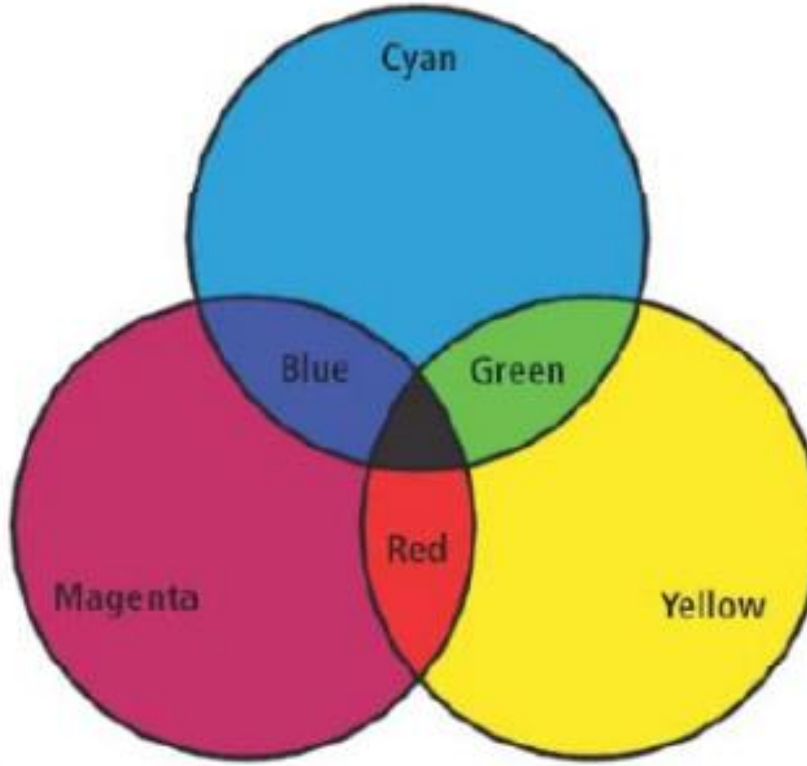


Passive displays, such as color inkjet printers, **absorb** light instead of emitting it. Combinations of **cyan**, **magenta** and **yellow** inks are used. This is a **subtractive** color model.

RGB vs CMY

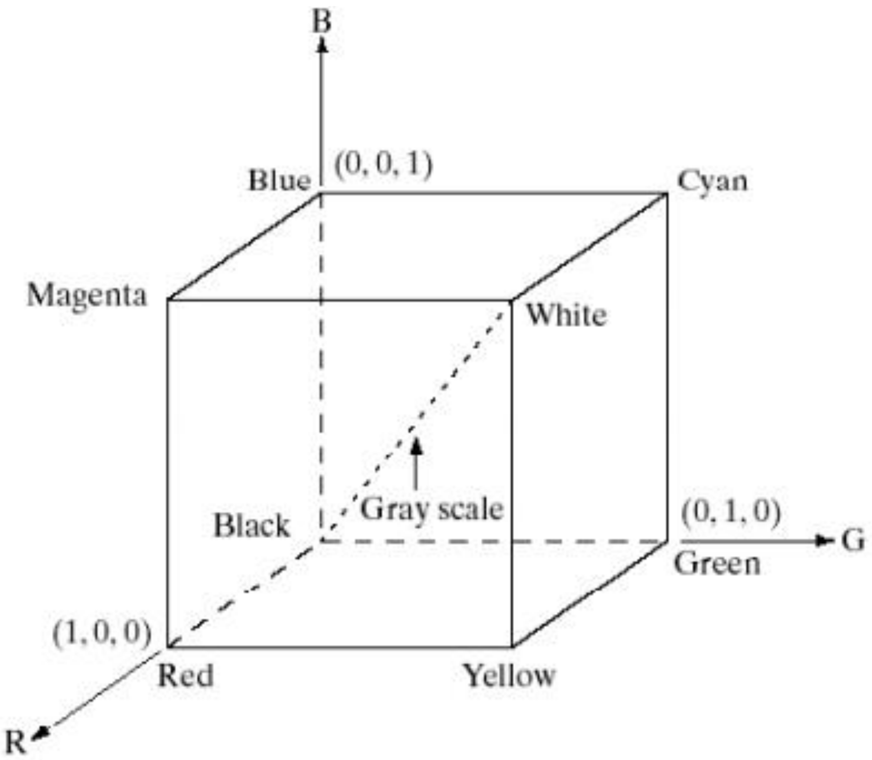


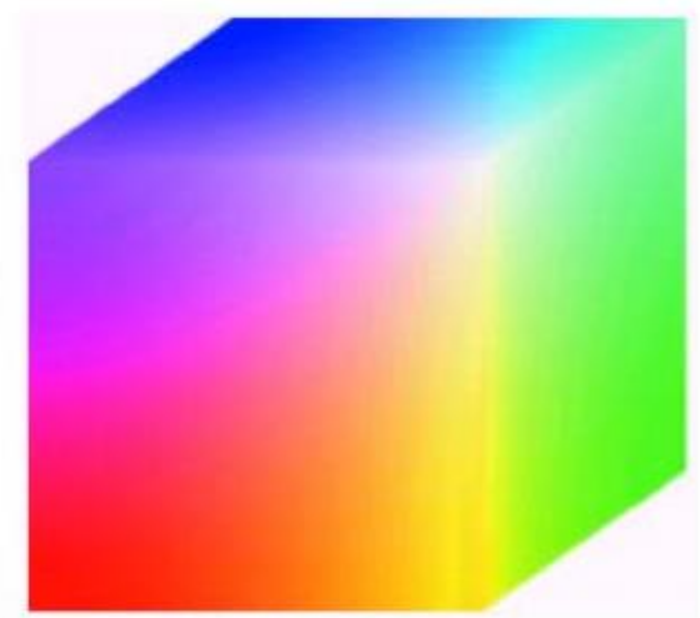
Magenta – Red + Blue
Cyan = Blue + Green
Yellow = Green + Red



Magenta – White - Green
Cyan = White - Red
Yellow = White - Blue

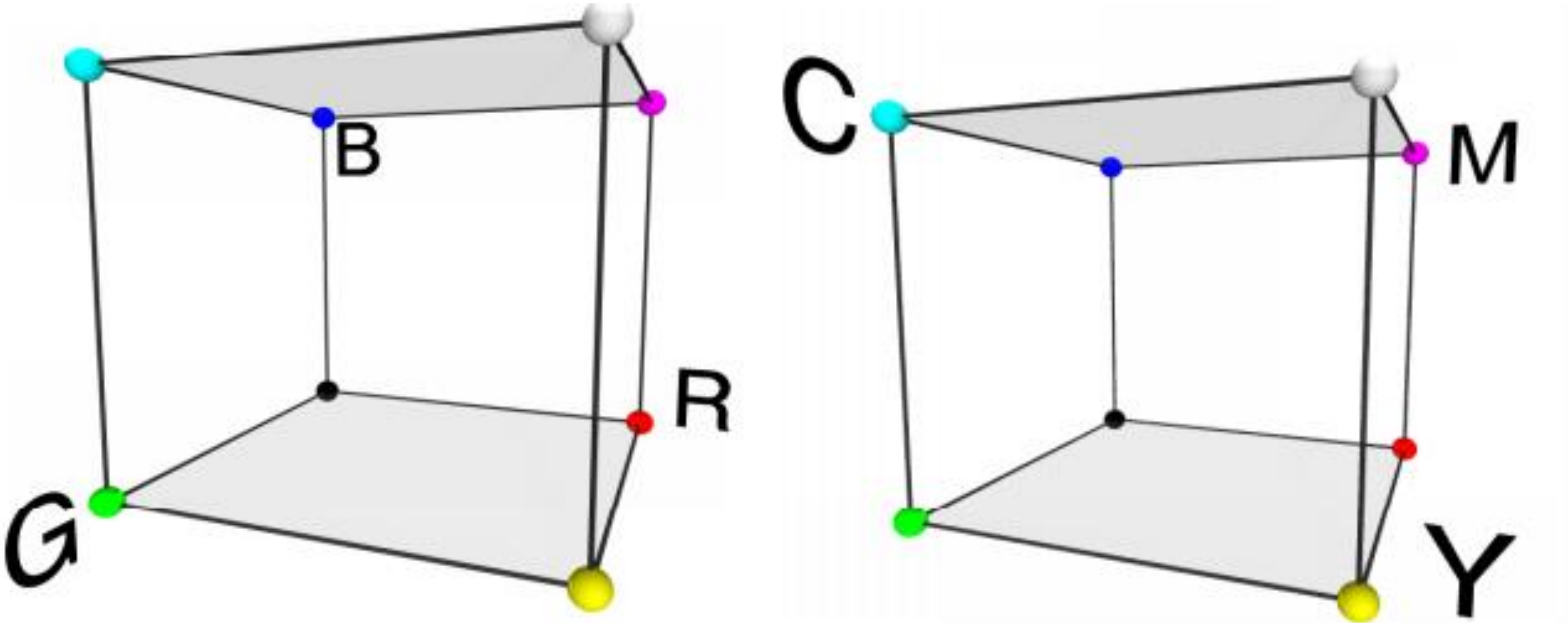
RGB Color Cube



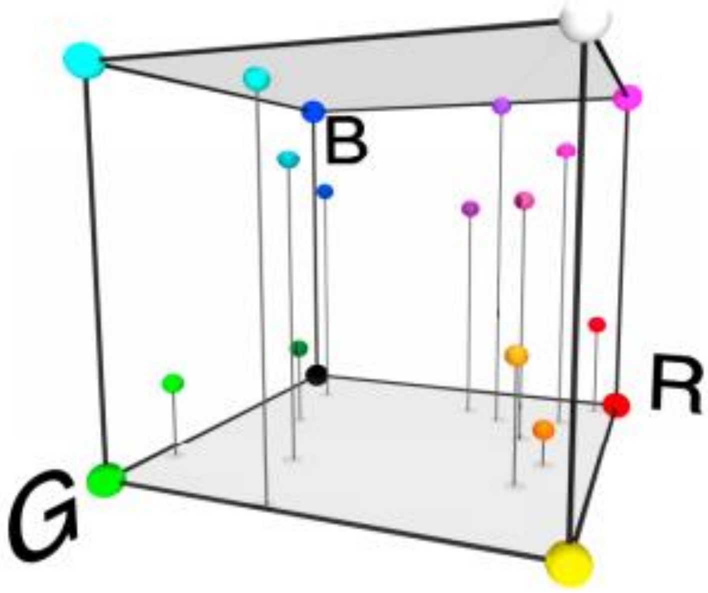


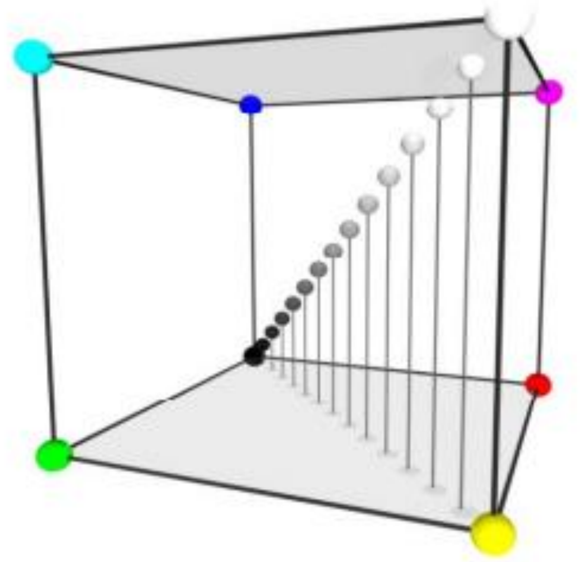
RGB 24-bit color cube

RGB and CMY Color Cubes



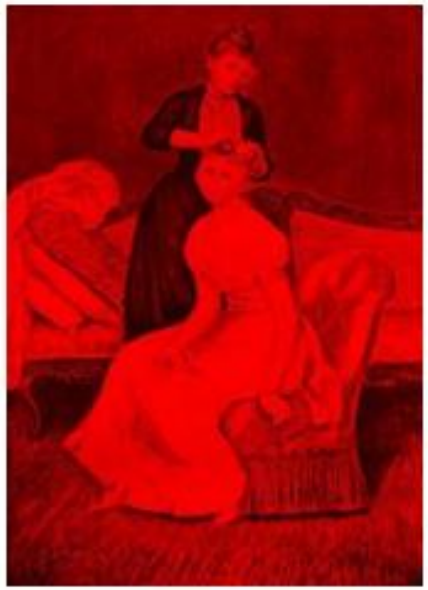
RGB and CMY Color Cubes





RGB Example

Original



Red Band

Green Band

Blue Band

RGB Example

Original

No Red

No Green

No Blue

HSI Color Model

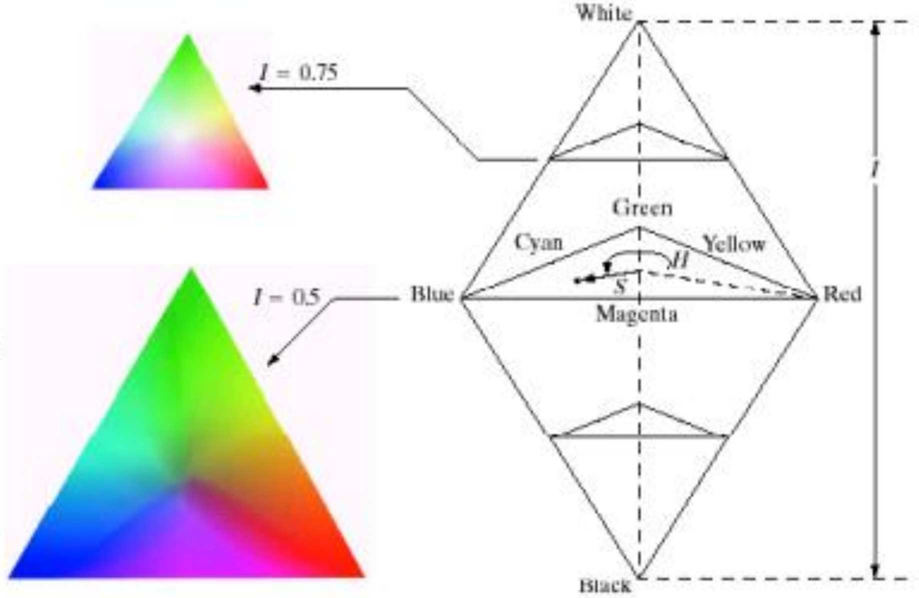
- Hue
  - A subjective measure of color
  - Average human eye can perceive ~200 diff t l different colors
- Saturation
  - Relative purity of the color. Mixing more “white” with a color reduces its saturation.
  - Pink has the same hue as red but less saturation
- Intensity
  - The brightness or darkness of an object

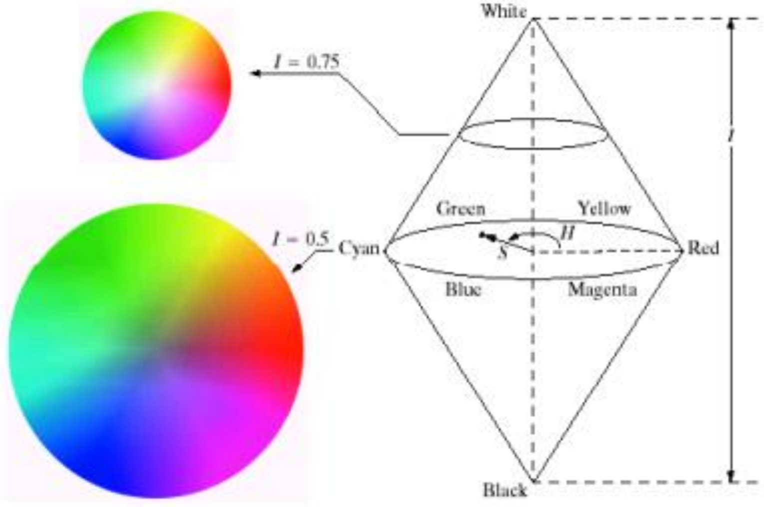
HSI Color Model

HSI Color Model

- Hue is defined as an angle
  - 0 degrees is RED
  - 120 d iegrees is GREEN
  - 240 degrees is BLUE
- Saturation is defined as the percentage of distance from the center of the HSI triangle to the pyramid surface.
  - Values range from 0 to 1.
- Intensity is denoted as the distance “up” the axis from black.
  - Values range from 0 to 1.

HSI Color Model





Conversion Between RGB and HSI

- Converting color from RGB to HSI

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360-\theta & \text{if } B > G \end{cases} \quad \text{with } \theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{\left[(R-G)^2+(R-B)(G-B)\right]^{\frac{1}{2}}} \right\}$$

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

$$I = \frac{1}{3}[R+G+B]$$

- Converting color from HSI to RGB

RG sector (0≤H<120)

$$B = I(1-S)$$

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

$$G = 1-(R+B)$$

GB sector (120≤H<240)

$$R = I(1-S)$$

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

$$B = 1-(R+G)$$

BR sector (240≤H<360)

$$G = I(1-S)$$

$$B = I\left[1+\frac{S\cos(H-240)}{\cos(60-(H-240))}\right]$$

$$R = 1-(G+B)$$

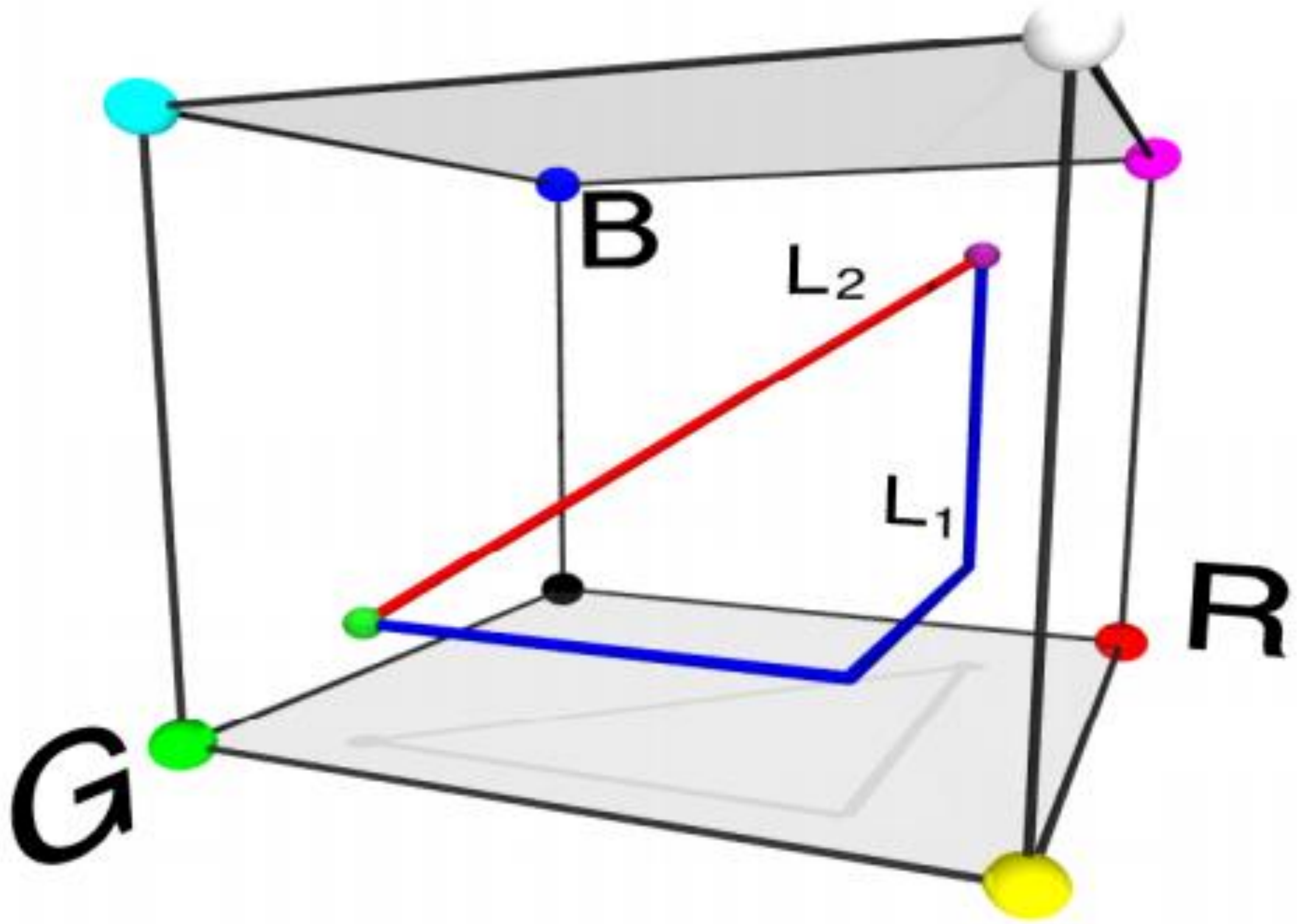
Other Color Models

- RGB (CIE), RnGnBn (TV - National Television Standard Committee)
- XYZ (CIE)
- UVW (UCS de la CIE), U*V*W* (UCS modified by the CIE)
- YUV, YIQ, YCbCr
- YDbDr
- DSH, HSV, HLS, IHS
- Munsel color space (cylindrical representation)
- CIELuv
- CIELab
- SMPTE-C RGB
- YES (Xerox)
- Kodak Photo CD, YCC, YPbPr, ...

Color Distance

- Quantifying the difference (or similarity) between two colors
  - L1 metric is the taxi-cab distance
  - L2 metric is the straight-line distance
- Distances are often normalized to the interval [0-1]
  - Compute the distance in normalized color space
  - Divide by maximum possible distance in that space

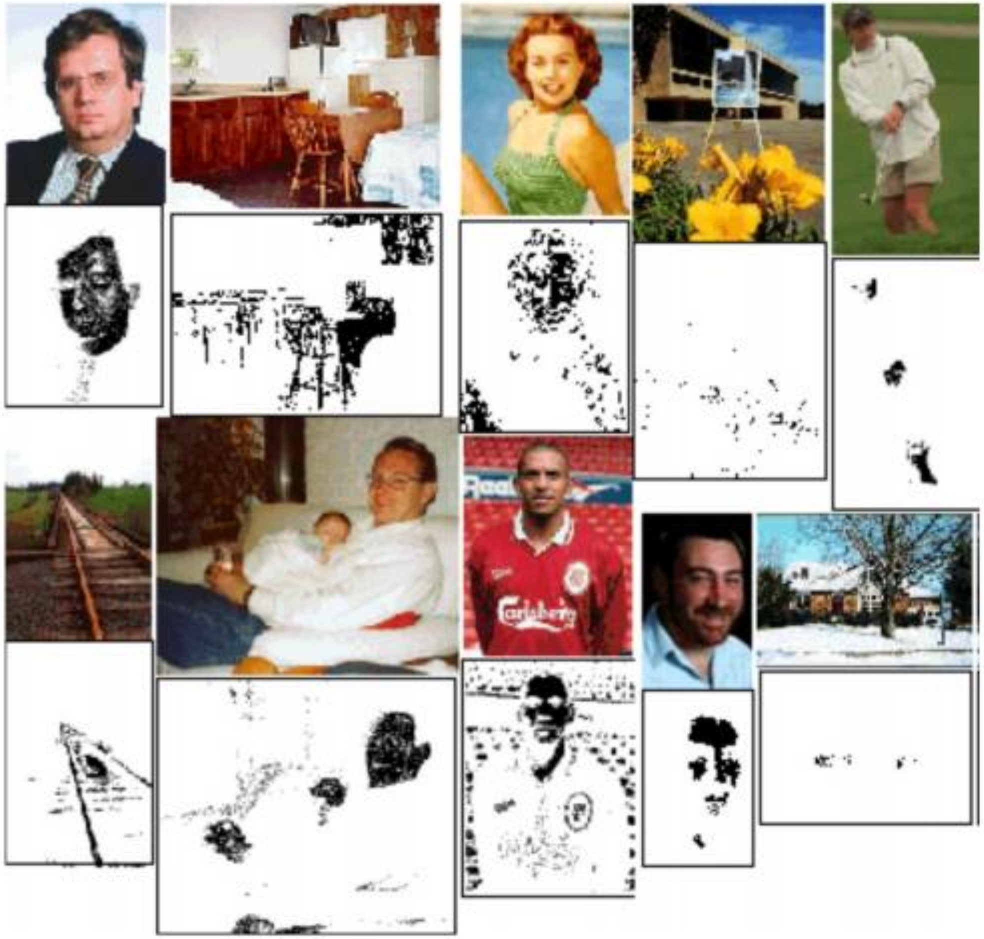
Color Distance



Color Model Selection

- The type of representation depends on the applications at hand.
  - For display or printing, choose primary colors so that more colors can be produced. E.g. RGB for displaying and CMY for printing.
  - For analysis of color differences, HSI is more suitable. They corresponds closely with the way humans describe and interpret color.
  - For transmission or storage choose a less redundant representation, eg. YIQ or YUV or YCbCr

Skin Detection



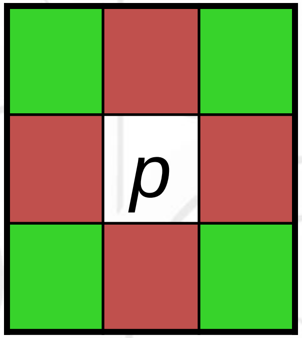
M. Jones and J. Rehg, Statistical Color Models with Application to Skin Detection, International Journal of Computer Vision, 2002.

Basic Relationship

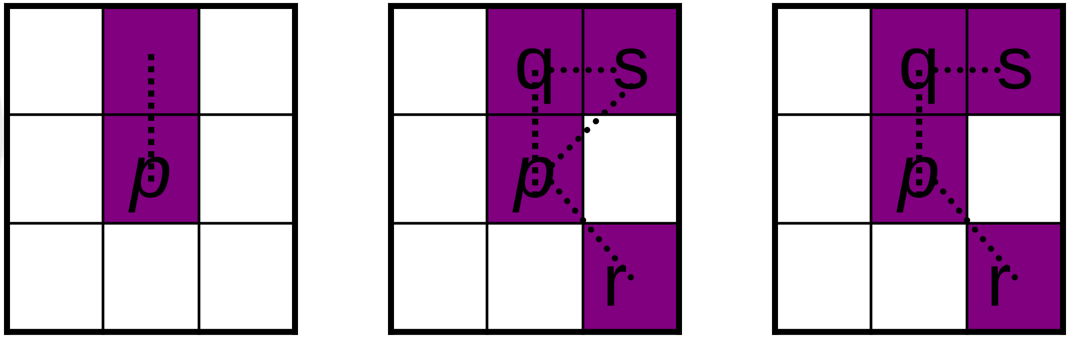
- Definitions:
  - f(x,y): digital image
  - Pixels: q, p ($p,q \in f$)
  - A subset of pixels of f(x,y): S
- A typology of relations:
  - Neighbourhood
  - Adjacency
  - Connectivity
  - Region & boundary
  - Distance

Neighboring, Adjacency

- $N_4(p)$: 4-neighbors
- $N_D(p)$: 4-diagonal neighbors
- $N_8(p) = N_4(p) \cup N_D(p)$: 8-neighbors

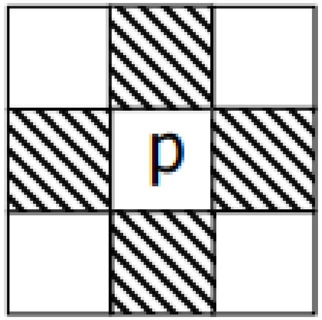


- Adjacency:
  - V: a set of gray levels s.t. if a pixel's gray level in V, it will be used to establish adjacency.
  - 4-adjacency
  - 8-adjacency
  - m-adjacency



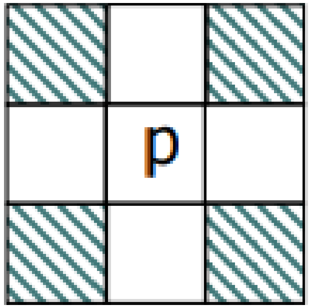
Neighbors of Pixel

- A pixel p at (x,y) has 2 *horizontal* and 2 *vertical* neighbors:
  - (x+1,y), (x-1,y), (x,y+1), (x,y-1)
  - This set of pixels is called the 4-neighbors of p: $N_4(p)$



Neighbors of Pixel

- The 4 diagonal neighbors of p are: ($N_D(p)$)
  - (x+1,y+1), (x+1,y-1), (x-1,y+1), (x-1,y-1)



- $N_4(p) + N_D(p) \rightarrow N_8(p)$: the 8-neighbors of p

Adjacent Pixels

- Two pixels are adjacent if:
  - They are neighbors in some sense (e.g. $N_4(p)$, $N_8(p)$, …)
  - Their gray levels satisfy a specified criterion of similarity **V** (e.g. equality, …)

- V is the set of gray-level values used to define adjacency (e.g. V={1} for adjacency of pixels of value 1)

Adjacent Pixels

- p is adjacent to q if:

$$\begin{cases} q \in \{N_4(p), N_8(p), \ldots\} \\ f(p) \in V \\ f(q) \in V \end{cases}$$

- We consider three types of 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 $N_8(p)$

Adjacent Pixels

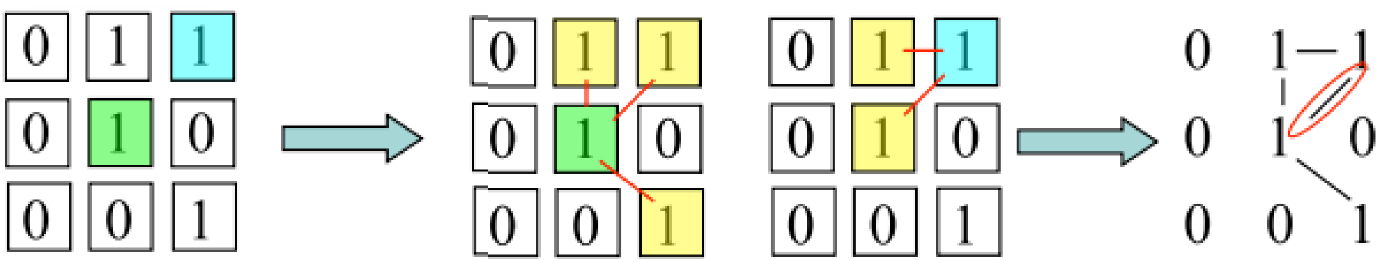
- The third type of adjacency:
  - m-adjacency: p and q with values from V are m-adjacent if:
    - q is in $N_4(p)$

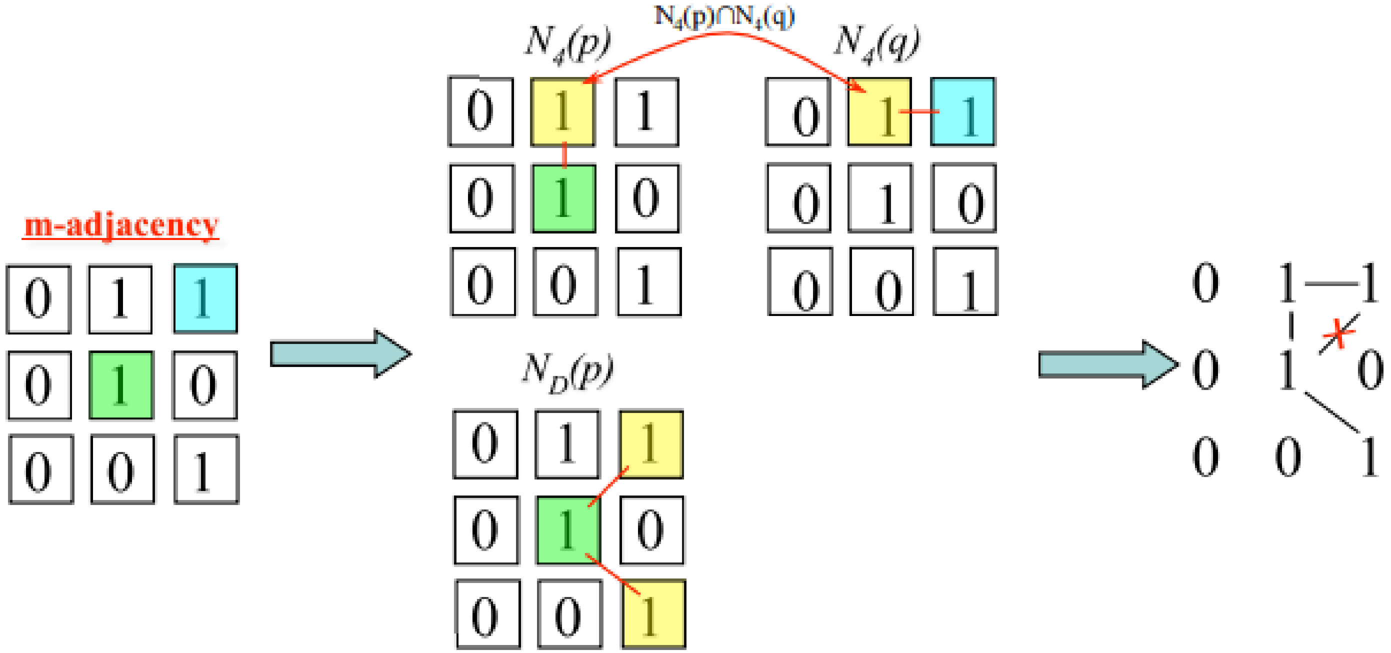
  or

    - q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixels with values from V

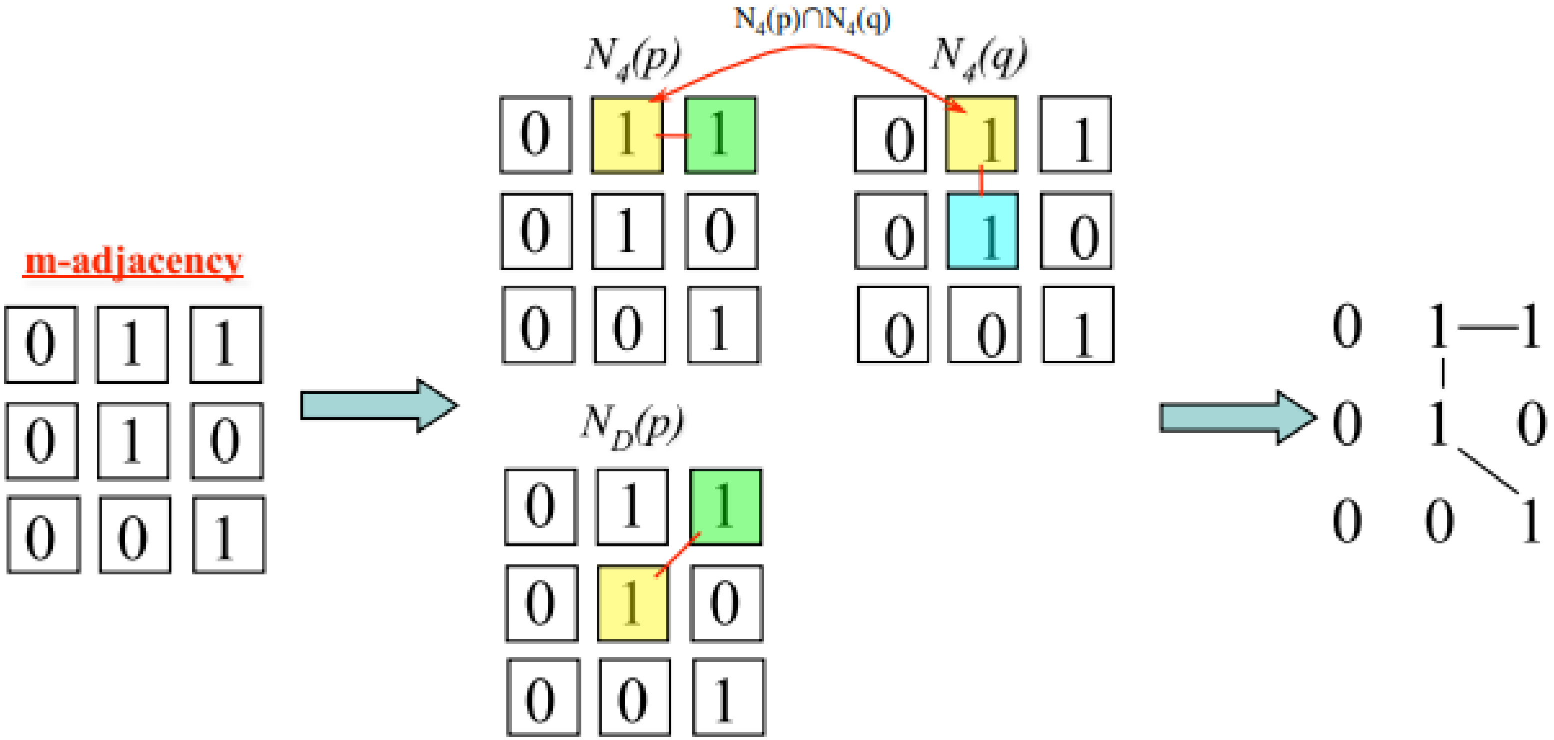
- Mixed adjacency is a modification of *8-adjacency* and is used to eliminate the multiple path connections that often arise when 8-adjacency is used.

Adjacency: Example



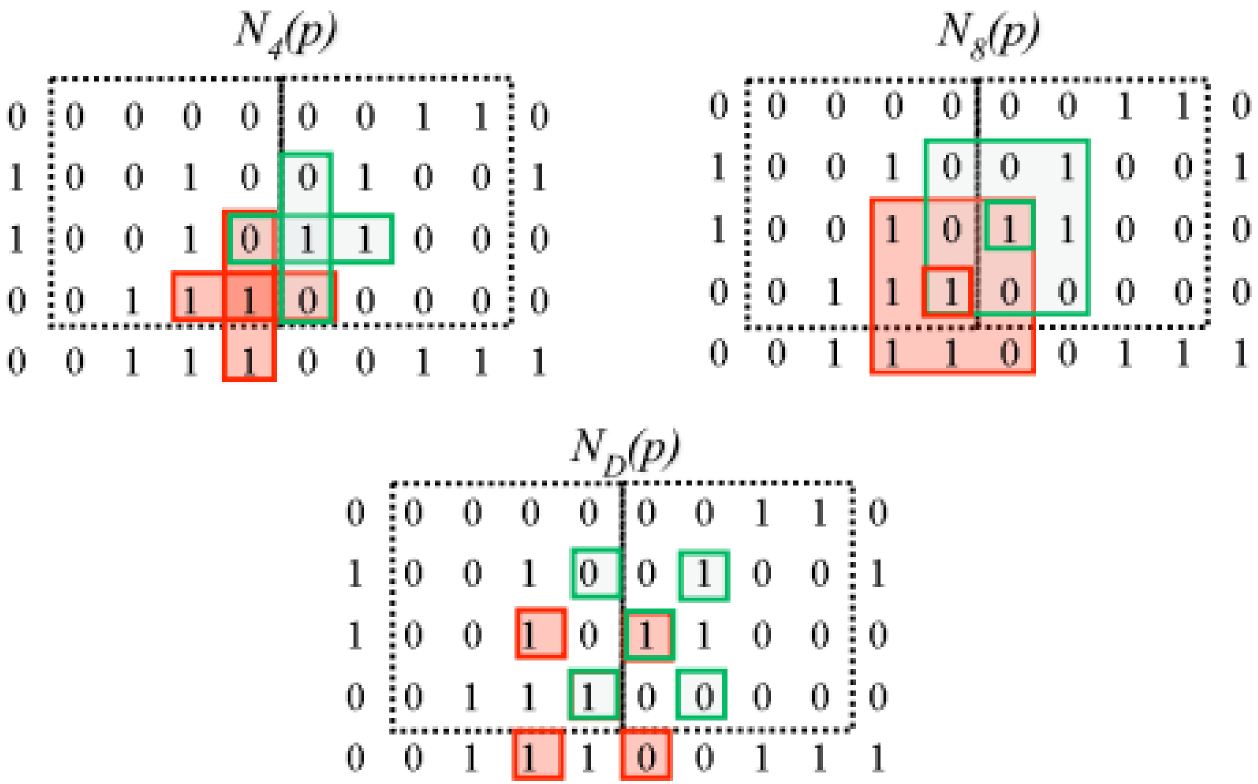


Adjacency: Example



Subset Adjacency

- Two image subsets S1 and S2 are adjacent if some pixel in S1 is adjacent to some pixel in S2.

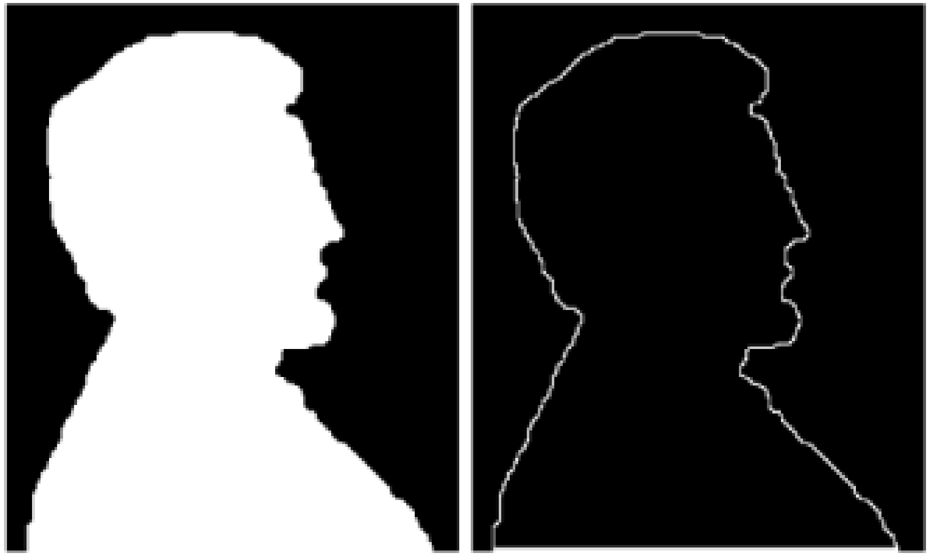


Path

- A *path* (curve) from pixel p with coordinates (x,y) to pixel q with coordinates (s,t) is a *sequence* of distinct pixels:
  - Q : (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 (x_i,y_i) is adjacent to (x_{i-1},y_{i-1}), for $1 \le i \le n$
  - n is the length of the path (|Q|).
- If $(x_0, y_0) = (x_n, y_n)$, then Q is a closed path
- 4-, 8-, and m-paths can be defined depending on the type of adjacency specified.

Connectivity

- Connectivity between pixels is important for establishing boundaries of objects and components of regions in an image



Connectivity

- Two pixels ($p \in S$, $q \in S$) are connected in S if there exists a path between them consisting *entirely* of pixels in S
- For any pixel p in S, the set of pixels in S that are connected to p is a connected component of S.
- If S has only one connected component then S is called a *connected set*.

Region and Boundary

- Let R be a subset of pixels:
  - R is a *region* if R is a connected set.
  - Its boundary (border, contour) is the set of pixels in R that have at least one neighbor *not* in R
  - An edge can be the region boundary (in binary images)

Distance Metric

- For pixels p,q,z with coordinates (x,y), (s,t), (u,v), D is a distance function or metric if:

  $D(p,q) \geq 0 \quad (D(p,q)=0 \text{ iff } p=q)$

  $D(p,q) = D(q,p)$ and

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

Distance Metric

- Euclidean distance:
  - $D_e(p,q) = [(x-s)^2 + (y-t)^2]^{1/2}$
  - Points (pixels) having a distance less than or equal to r from (x,y) are contained in a disk of radius r centered at (x,y).

Distance Metric

- D_4 distance (city-block distance):
  - $D_4(p,q) = |x-s| + |y-t|$
  - forms a diamond centered at (x,y)
  - e.g. pixels with $D_4 \leq 2$ from p

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

$D_4 = 1$ are the 4-neighbors of p

Distance Metric

- D_8 distance (chessboard distance):
  - $D_8(p,q) = \max(|x-s|,|y-t|)$
  - Forms a square centered at p
  - e.g. pixels with $D_8 \leq 2$ from p

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

$D_8 = 1$ are the 8-neighbors of p

Distance Metric

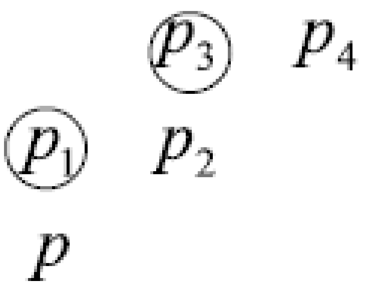
- D_4 and D_8 distances between p and q are independent of any paths that exist between the points because these distances involve *only the coordinates* of the points (regardless of whether a connected path exists between them).

- However, using m-adjacency the value of the distance (length of path) between two pixels depends on the values of the pixels along the path and those of their neighbors.

Distance Metric

- e.g. assume p, p_2, p_4 = 1

  p_1, p_3 = can have either 0 or 1



If only connectivity of pixels valued 1 is allowed, and p_1 and p_3 are 0, the m-distance between p and p_4 is 2.

If either p_1 or p_3 is 1, the distance is 3.

If both p_1 and p_3 are 1, the distance is 4 (p p_1 p_2 p_3 p_4)

Connected Component Labelling

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

(a)

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

(b)

Post Test

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

V={1}

2	3	7	6	4
2	1	3	3	4
1	7	3	6	7
1	2	1	2	6

V={2,3,7,6}

1. Gambarkan ketetanggaan dengan
   – 4-adjaceny
   – 8-adjacency
   – M-adjacency
2. Hitunglah e-distance, 4-distance dan m-distance dari pixel (0,0) ke (4,3)

THANK YOU

Mengakar Kuat
Menjulang
Tinggi