Lecture 8
Color image processing &
Morphological image processing

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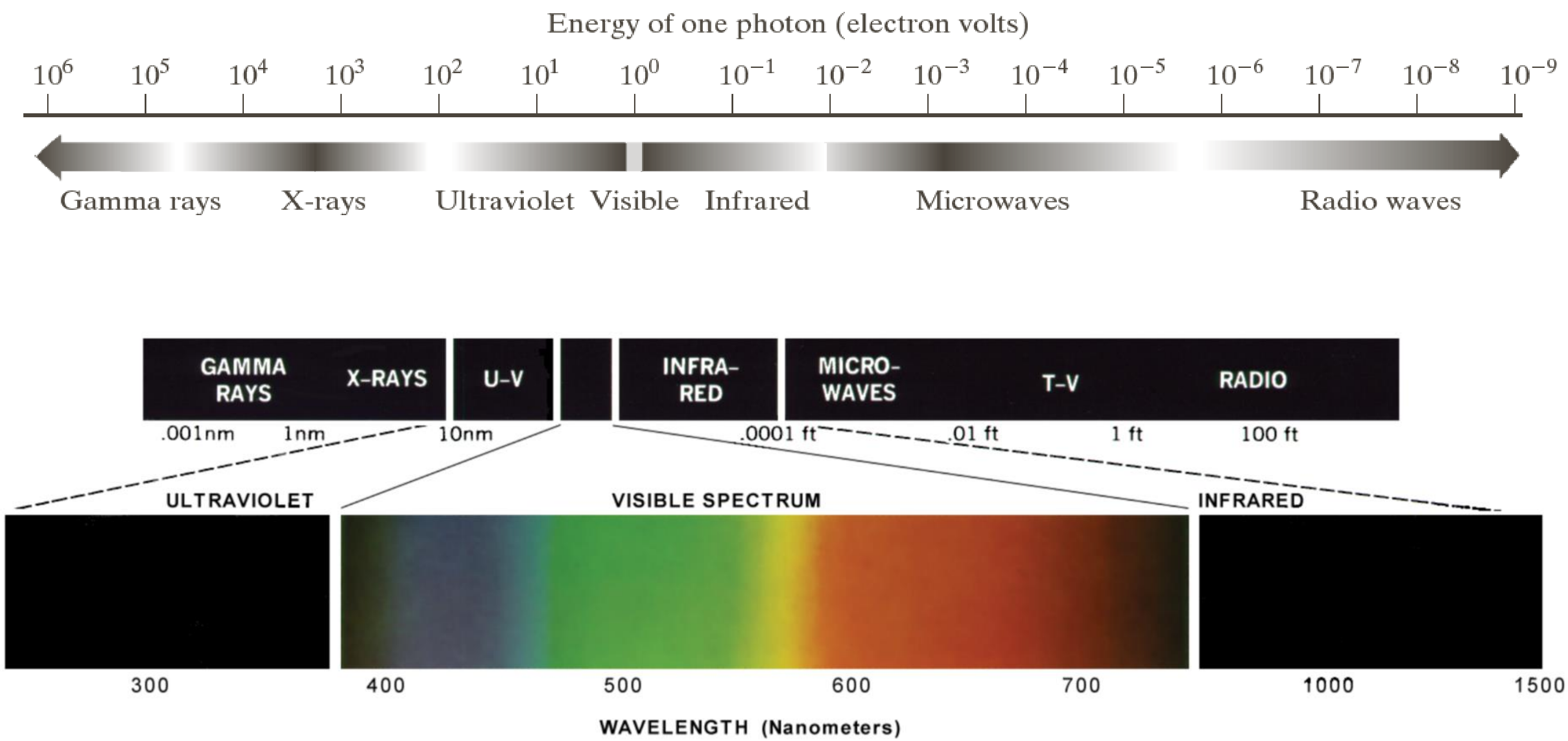
Color image processing: Outline

- Standard color spaces
  - RGB
  - CMYK
  - HSI/HSV
- Transform between color spaces
  - RGB to gray scale
  - RGB to HSI
- Color balance

Electromagnetic spectrum



Dispersion of light

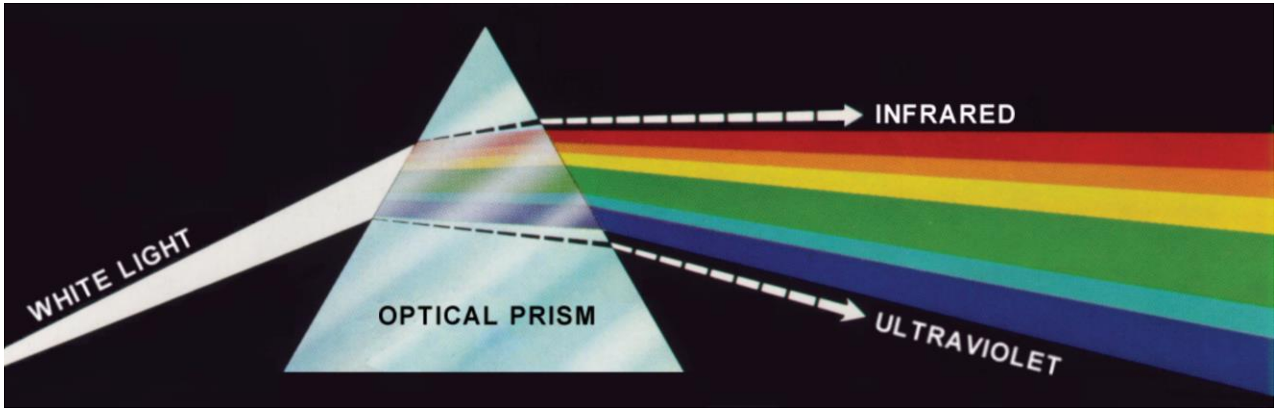


FIGURE 7.2
Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lighting Division.)

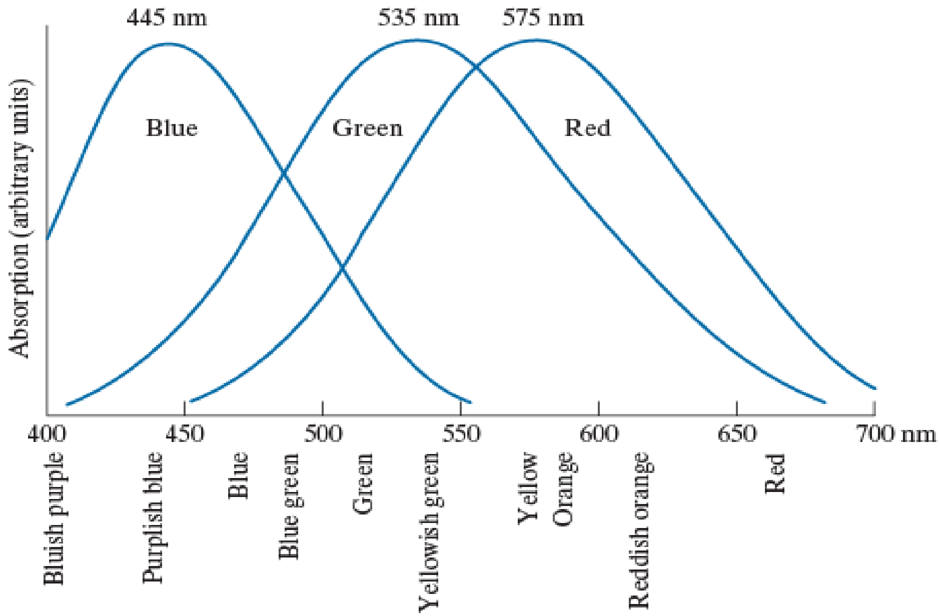
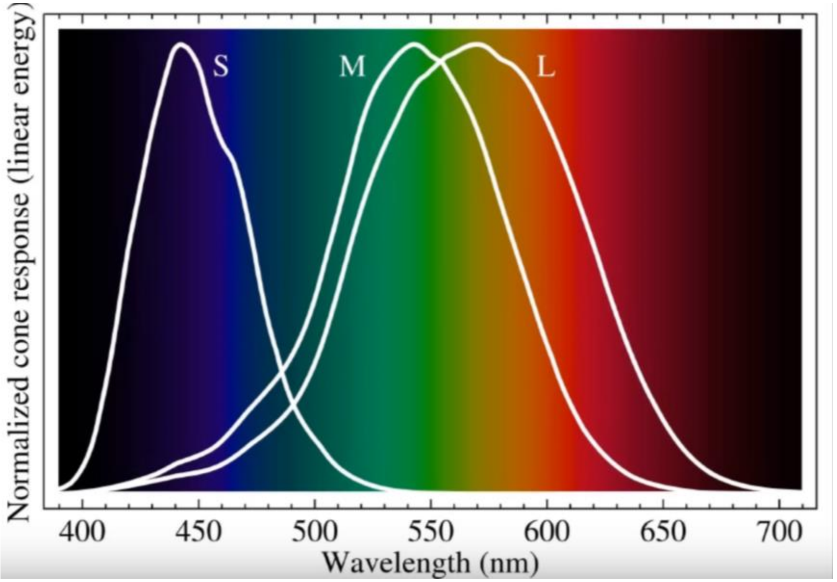


FIGURE 7.3
Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Human visual system color Space

- **The LMS color space:** Cones enable color perceptions;
- **3 Types** of cones:
  - **Long:** sensitive to "RED" (more yellow to blue) 65%
  - **Middle :** sensitive to "GREEN" (more green to blue) 33%
  - **Short :** sensitive to "BLUE" (more blue to purple) 2% (But most sensitive)



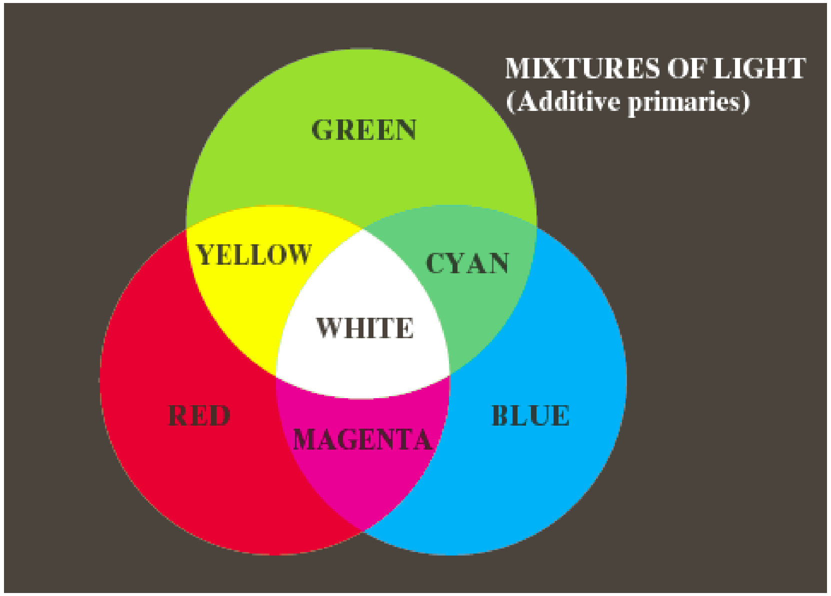
Primary colors

- **CIE RGB Standard (International Commission on Illumination)**
  French: Commission International d'elairage
  - Blue = 435.8 nm
  - Green = 546.1 nm
  - Red = 700 nm
- **The white light is** achieved with a mixture of RGB light with:
  - 1.0000 : 4.5907 : 0.0601 of intensity （Luminous intensity）.
- **CMY and CMYK color**
  - Cyan = White – Red
  - Magenta = White – Green
  - Yellow = White – Blue
  - Black = White – Red - Green - Blue

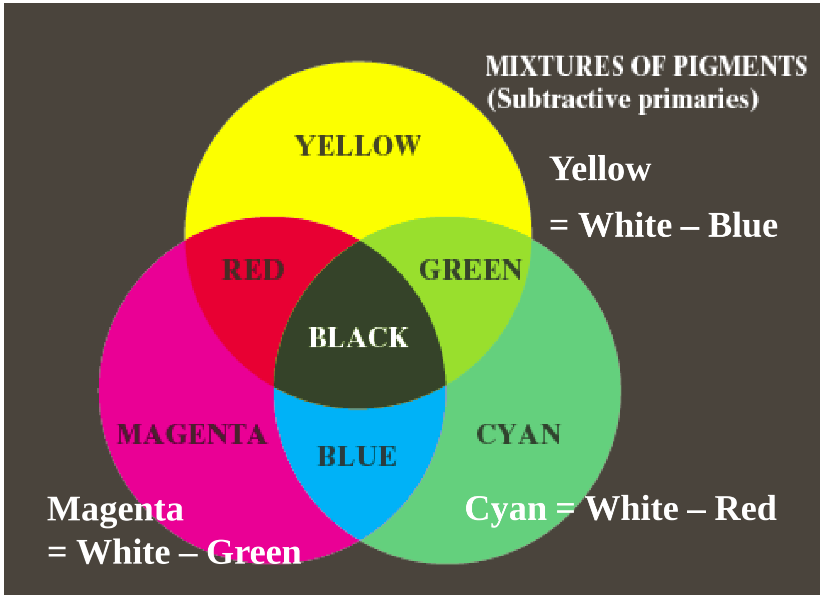
Human eye perception-based!
(e.g., metamerism, 同色异谱)

Secondary colors

RGB color

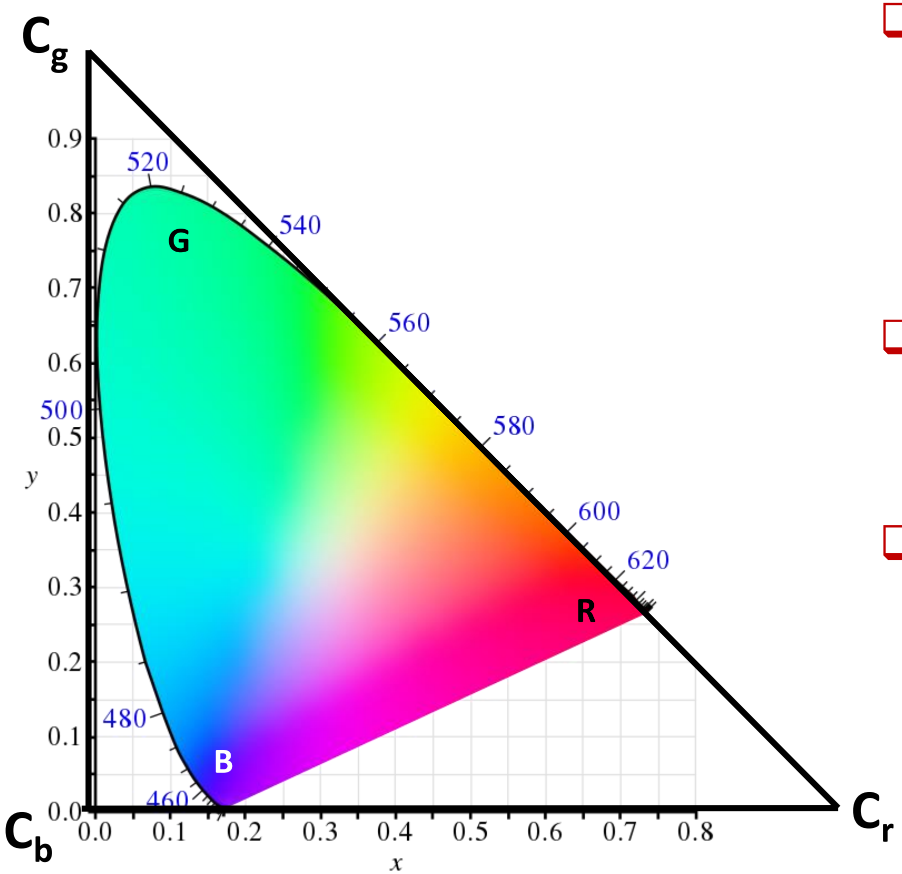


CMY and CMYK color



Black = White – Red - Green - Blue

Chromaticity diagram



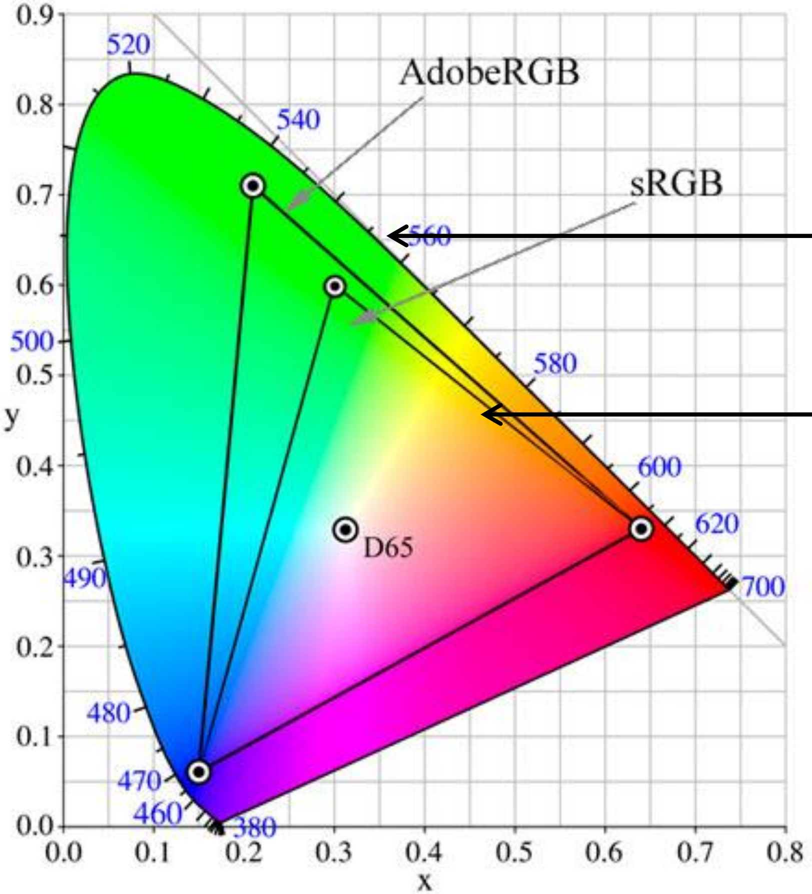
- $x = \frac{R}{R+G+B}, y = \frac{G}{R+G+B}, z = \frac{B}{R+G+B}$

  Then $z = 1 - x - y$.

  The color cube turns to a 2-D color gamut.

- It is seen that all visible chromaticities correspond to non-negative values of x, y, and z.
- An equal mixture of two equally bright colors will not generally lie on the midpoint of that line.

Color Gamut



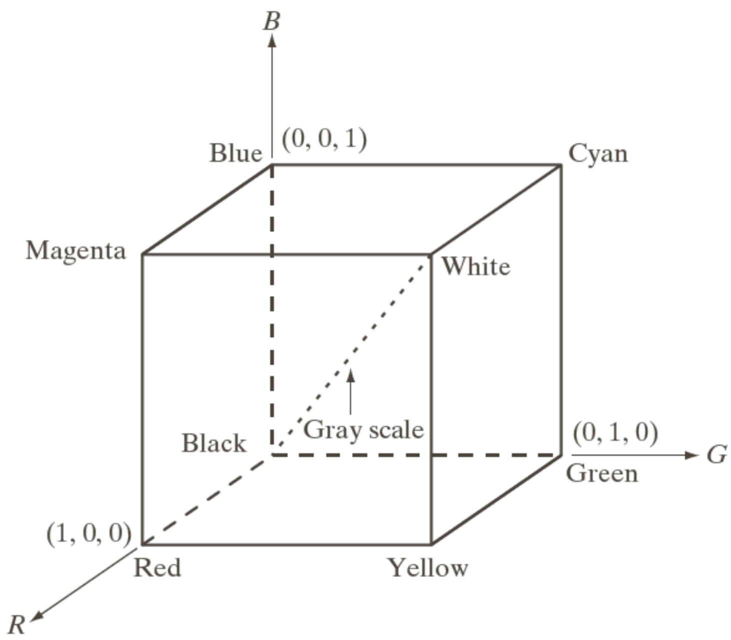
White：D65 [0.3127,0.3290]
Red：[0.6400, 0.3300]
Green：[0.3000, 0.6000]
Blue: [0.1500, 0.0600]

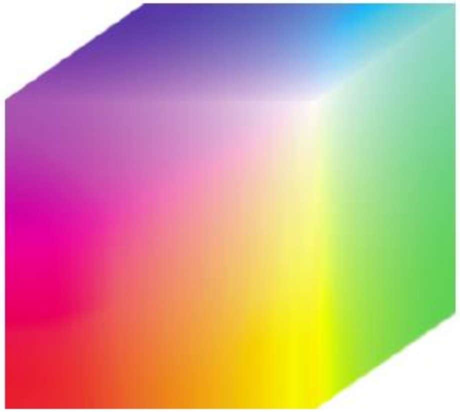
CIE Chromaticity diagram

Color gamut for monitor

- **sRGB** (**standard Red Green Blue**) is an RGB color space and Microsoft created cooperatively in 1996 to use on monitors, printers, and the Internet.
- The **Adobe RGB (1998) color space** is an RGB color space developed by Adobe System, Inc. in 1998.

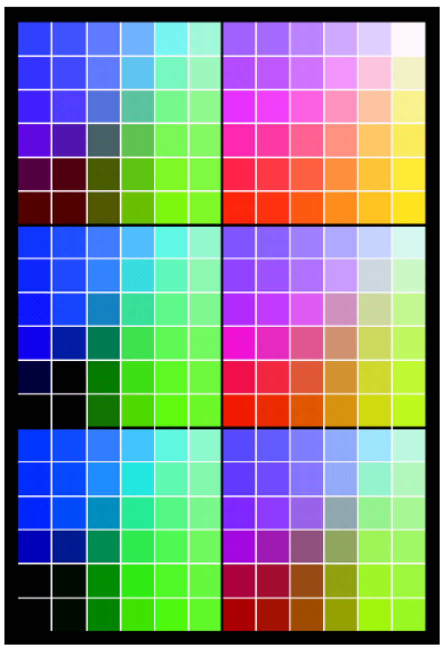
RGB Color Model

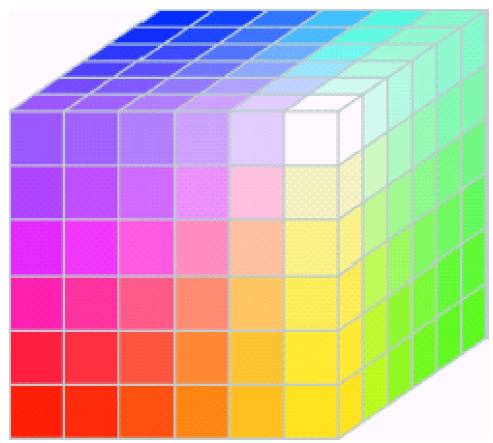


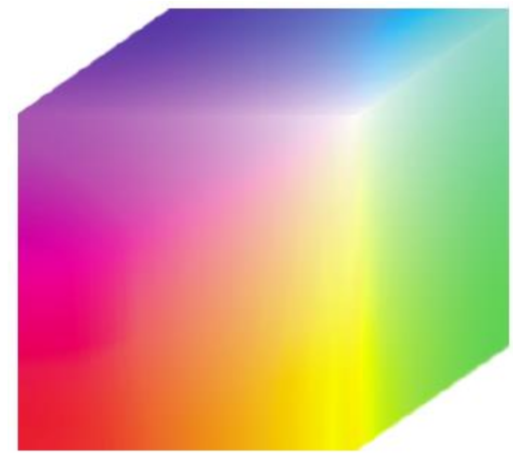


Safe/Standard RGB Color （24 bytes）

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







CMY Color Model

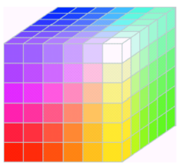
- **RGB to CMY conversion**

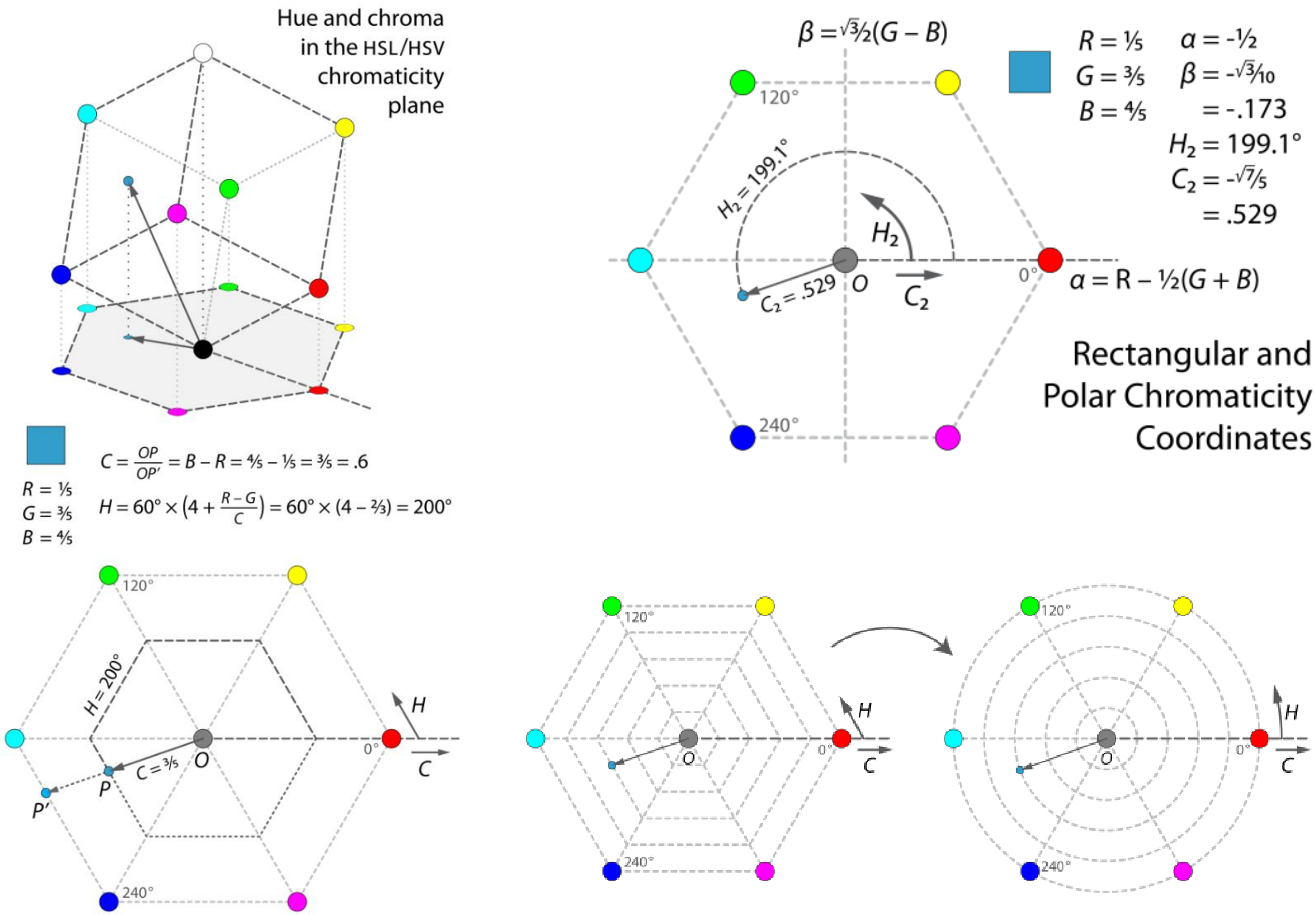
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

In order to produce true black in printing, a fourth color, black, is added into the CMYK color model

HSI/HSV Color Model

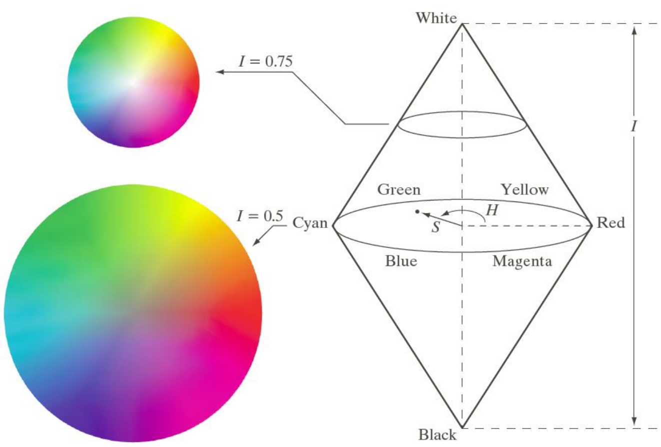
RGB color cube

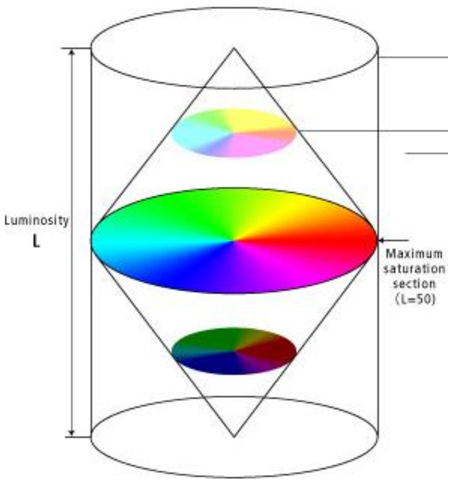


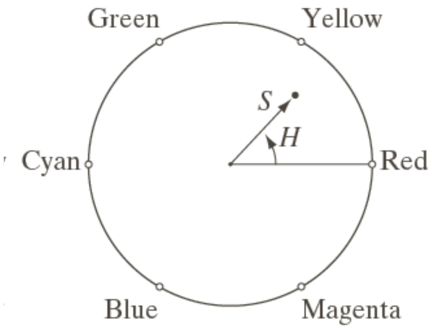


HSI/HSL Color Model

- **HSI Color Model**
  - **Hue:** Dominant color associated with wavelength.
  - **Saturation:** relative purity, the amount of white light mixed with a hue
  - **Intensity/Lightness.** $I = (r + g + b) / 3$

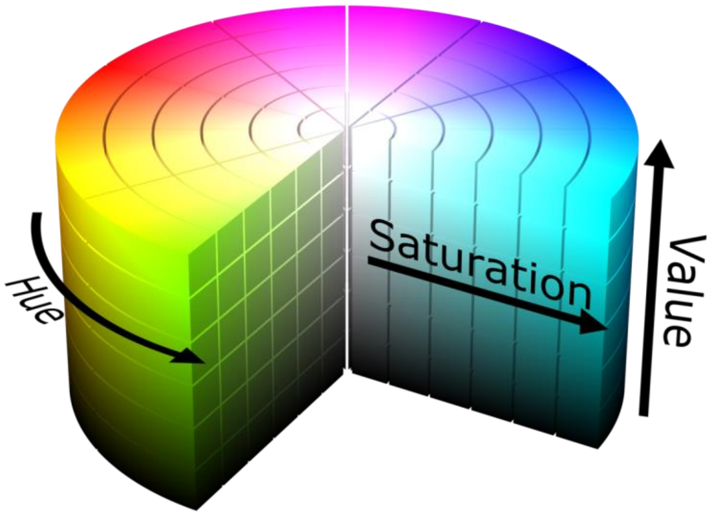


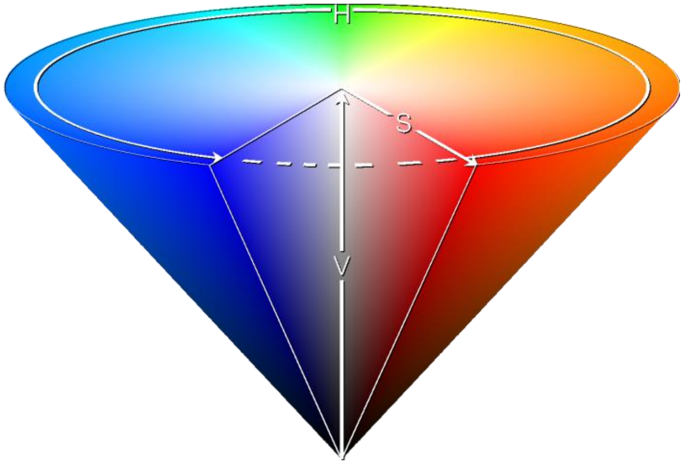




HSV Color Model

- **HSV Color Model**
  - **Hue:** Dominant color associated with wavelength.
  - **Saturation:** relative purity, the amount of white light mixed with a hue
  - **Value.** $v = \max(r, g, b)$;





Color image processing: Outline

- Standard color spaces
  - RGB
  - CMYK
  - HSI/HSV
  - Lab
- Transform between color spaces
  - RGB to gray scale
  - RGB to HSI
- Color balance

RGB to Gray scale

- **Maximum value:**

$$g_R(x,y) = g_G(x,y) = g_B(x,y) = \max[f_R(x,y), f_G(x,y), f_B(x,y)]$$

- **Average value**

$$g_R(x,y) = g_G(x,y) = g_B(x,y) = [f_R(x,y) + f_G(x,y) + f_B(x,y)]/3$$

- **Weighted value**

$$g_R(x,y) = g_G(x,y) = g_B(x,y) = 0.299f_R(x,y) + 0.587f_G(x,y) + 0.114f_B(x,y)$$




Transform to CMY Color Space

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

- $\begin{bmatrix} g_R(x,y) \\ g_G(x,y) \\ g_B(x,y) \end{bmatrix} = \begin{bmatrix} 255 - f_R(x,y) \\ 255 - f_G(x,y) \\ 255 - f_B(x,y) \end{bmatrix}$

Transform from RGB to HSI/HSV

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

$$H = \begin{cases} \theta, & G \geq B \\ 360-\theta, & G < B \end{cases}$$

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

$$I = \frac{R+G+B}{3} \qquad V = \max(r,g,b);$$

$$S=0 \rightarrow H=0\,,\quad I=0 \rightarrow S=0,\; H=0$$

Transform from HSI to RGB

- $0° \leq H < 120°$

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

- $120° \leq H < 240°$

$$R = I(1 - S), \qquad G = I\left[1 + \frac{S\cos(H - 120°)}{\cos(180° - H)}\right], \qquad B = 3I - (R + G)$$

- $240° \leq H < 360°$

$$G = I(1 - S), \qquad B = I\left[1 + \frac{S\cos(H - 240°)}{\cos(300° - H)}\right], \qquad R = 3I - (G + B)$$

Color Balance

- **White balance:**

$$I(x,y) = 0.299 f_R(x,y) + 0.587 f_G(x,y) + 0.114 f_B(x,y)$$

$$k_R = \frac{\bar{I}}{\overline{f_R}} \qquad k_G = \frac{\bar{I}}{\overline{f_G}} \qquad k_B = \frac{\bar{I}}{\overline{f_B}}$$

$$\begin{bmatrix} g_R(x,y) \\ g_G(x,y) \\ g_B(x,y) \end{bmatrix} = \begin{bmatrix} k_R & & \\ & k_G & \\ & & k_B \end{bmatrix} \begin{bmatrix} f_R(x,y) \\ f_G(x,y) \\ f_B(x,y) \end{bmatrix}$$

- **Maximum value balance**

$$S_{RGB} = \min[R_{max}, G_{max}, B_{max}]$$

$$k_R = \frac{S_{RGB}}{T_R} \qquad k_G = \frac{S_{RGB}}{T_G} \qquad k_B = \frac{S_{RGB}}{T_B}$$

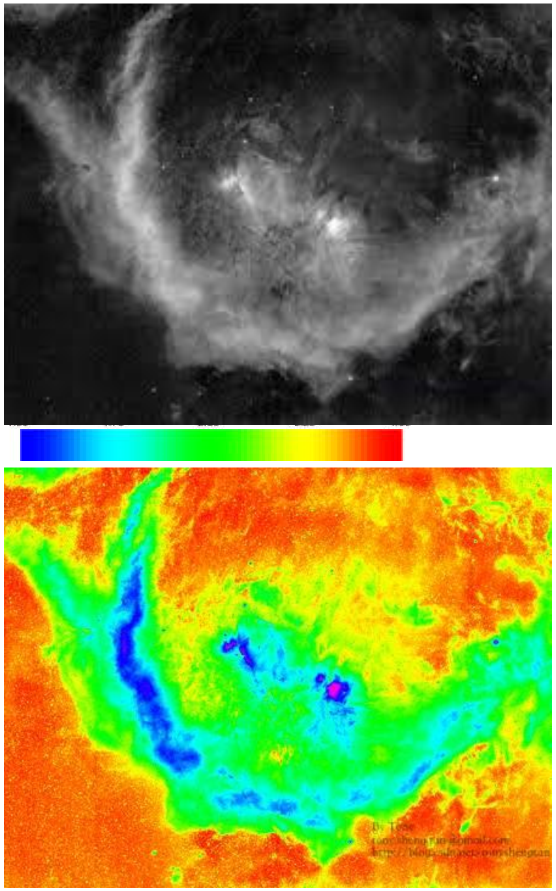
$$\begin{bmatrix} g_R(x,y) \\ g_G(x,y) \\ g_B(x,y) \end{bmatrix} = \begin{bmatrix} k_R & & \\ & k_G & \\ & & k_B \end{bmatrix} \begin{bmatrix} f_R(x,y) \\ f_G(x,y) \\ f_B(x,y) \end{bmatrix}$$

1.Find the smallest max value S_{RGB} in each color channel.

2.Calculate the number of intensities Nr, Ng, Nb that larger than S_{RGB} in each color channel. Then find the largest number Nmax = max[Nr,Ng,Nb].

3.Sort the intensities in each channel and find the the Nmax_{th} intensity value [Tr, Tg, Tb] in each color channel.

Pseudo color enhancement



Take home message

- The color that you perceived depends on the cone cells in your eye.
- There are variety of different color space defined by CIE. Each color space has its unique advantage.
- When the intensity in each color channel is unbalance, the color looks weird. Try to practice color space transform by implementing a color balance correction method.

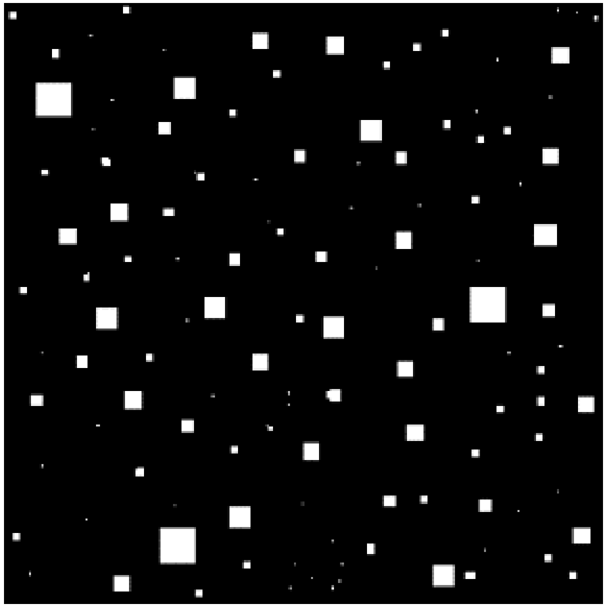
Morphological image processing: Outline

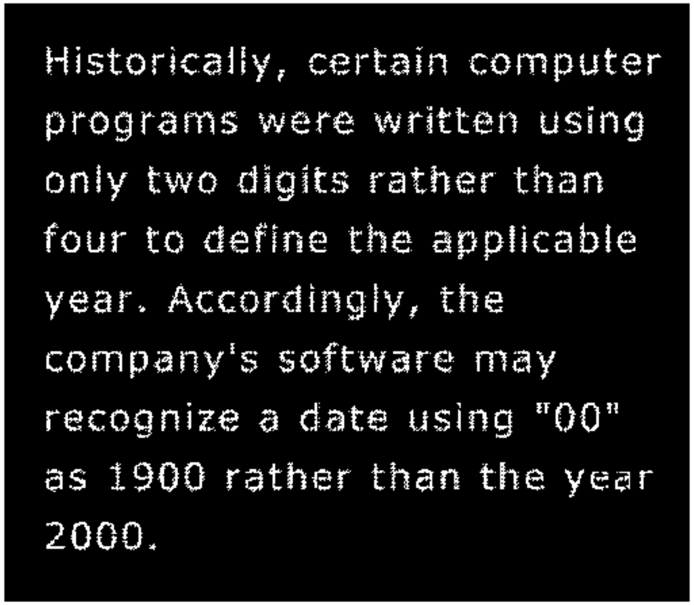
Morphology Image Processing （形态学图像处理）

- Morphological operation.
- Morphological algorithms.

Problem try to solve

- Imperfect from image segmentation.

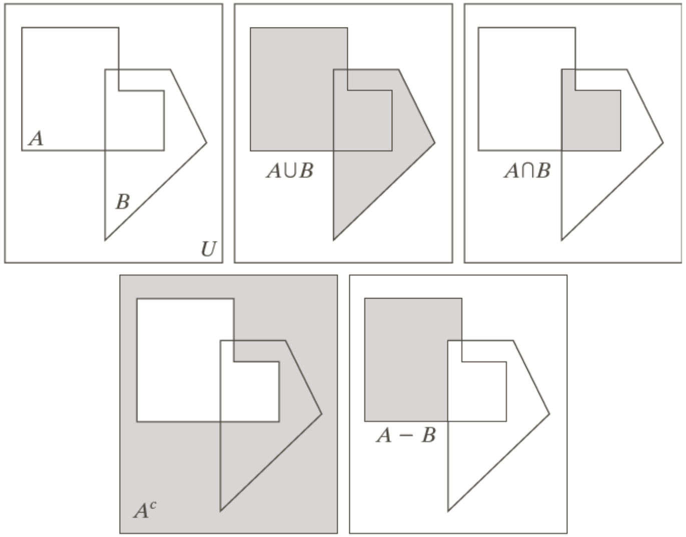




Preliminaries: Set Operation

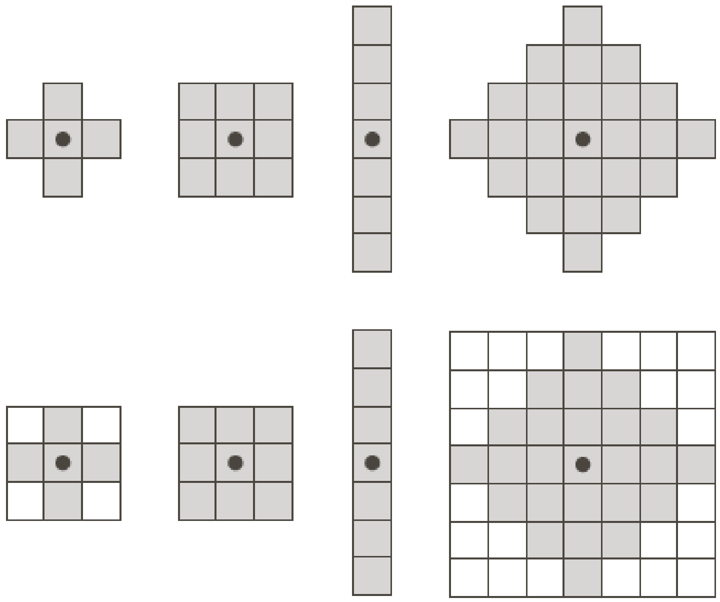
A digital image $f(x, y)$ can be considered as a set A， if $w(x, y)$ in 2D integer space Z^2, then

- $w \in A$: w is an element of A.
- $w \notin A$: w is not an element of A.
- $B = \{w|condition\}$: all elements which meet the specific condition.
  - $A \cup B = \{w|w \in A\ or\ w \in B\}$: union (并集)
  - $A \cap B = \{w|w \in A\ and\ w \in B\}$: intersection (交集)
  - $A^C = \{w|w \notin A\}$: complement (补集)
  - $A - B = \{w|w \in A\ and\ w \notin B\}$: difference (差集)



Structuring element (结构元)

- **Structuring Element (SE):** small sets or sub-images used to probe an image under study for properties of interest.
- **SE Selection**
  - Simpler than the image
  - With boundary
  - Convex
- **Structures**
  - Origin
  - Rectangular



Erosion (腐蚀)

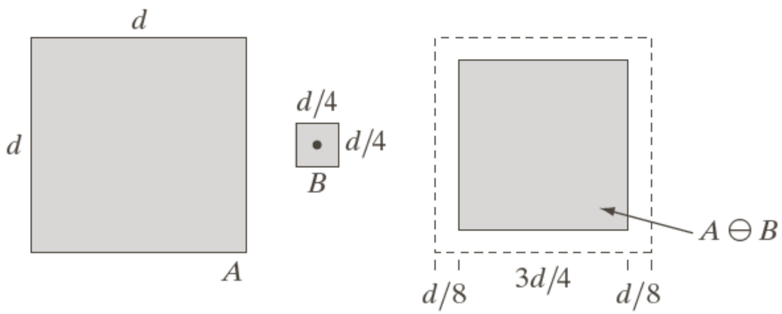
- **Definition:**

  $A \ominus B = \{z \mid (B)_z \subseteq A\}$

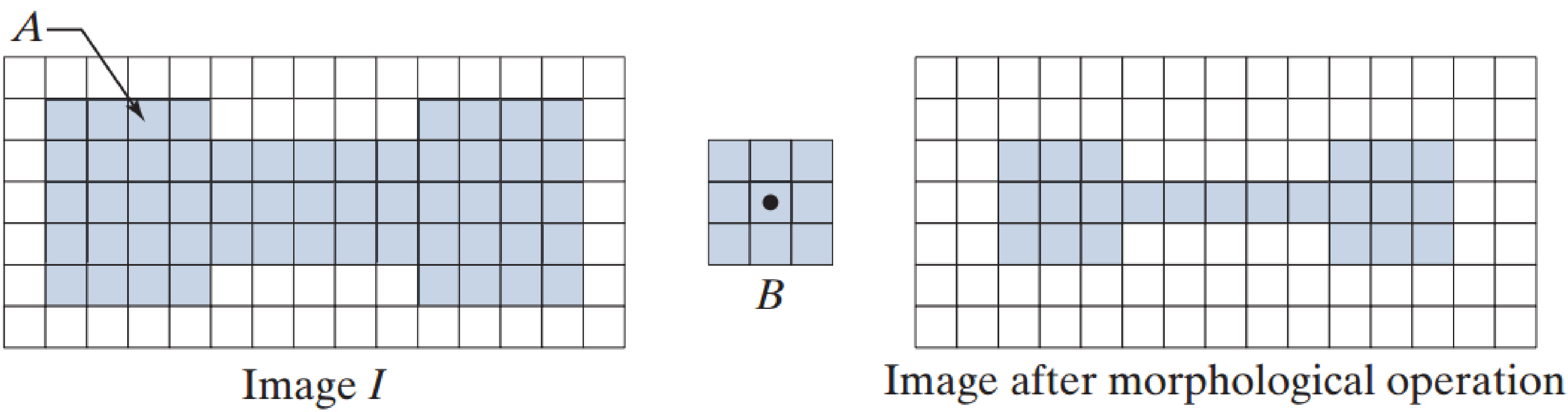
  or

  $A \ominus B = \{z \mid (B)_z \cap A^c = \emptyset\}$

- **Erosion will do:**
  - removes thin lines
  - isolate dots
  - leaves gross details
  - "Peeling away" layers
  - Is always a sub-set of A



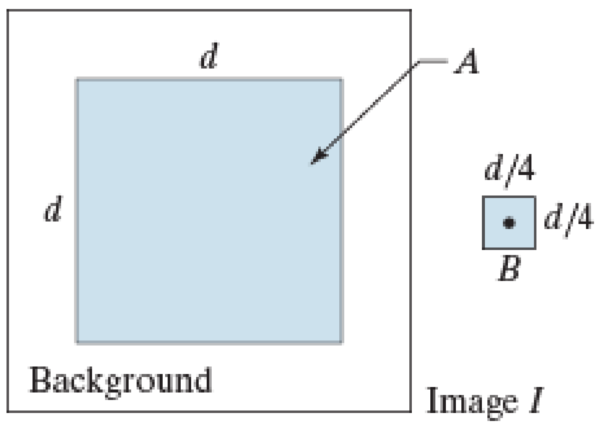
Erosion (腐蚀), example

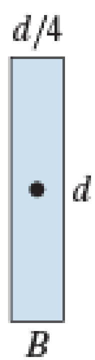


a b c

FIGURE 9.3
(a) A binary image containing one object (set), A. (b) A structuring element, B. (c) Image resulting from a morphological operation (see text).

Erosion (腐蚀), example

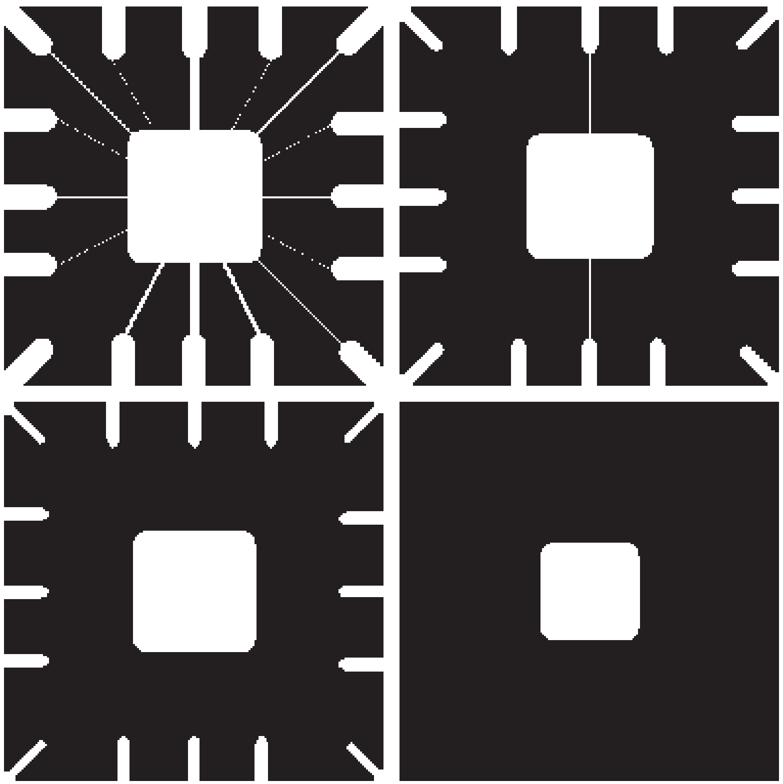




a b c
d e

FIGURE 9.4
(a) Image I, consisting of a set (object) A, and background.
(b) Square SE, B (the dot is the origin).
(c) Erosion of A by B (shown shaded in the resulting image).
(d) Elongated SE.
(e) Erosion of A by B. (The erosion is a line.) The dotted border in (c) and (e) is the boundary of A, shown for reference.

Erosion application



a b
c d

FIGURE 9.5 Using erosion to remove image components. (a) A 486×486 binary image of a wire-bond mask in which foreground pixels are shown in white. (b)–(d) Image eroded using square structuring elements of sizes 11×11, 15×15, and 45×45 elements, respectively, all valued 1.

Dilation (膨胀)

- **Definition**

  $A \oplus B = \{z | \widehat{B}_z \cap A \subseteq A\}$

  or

  $A \oplus B = \left\{z \middle| \widehat{B}_z \cap A \neq \emptyset\right\}$

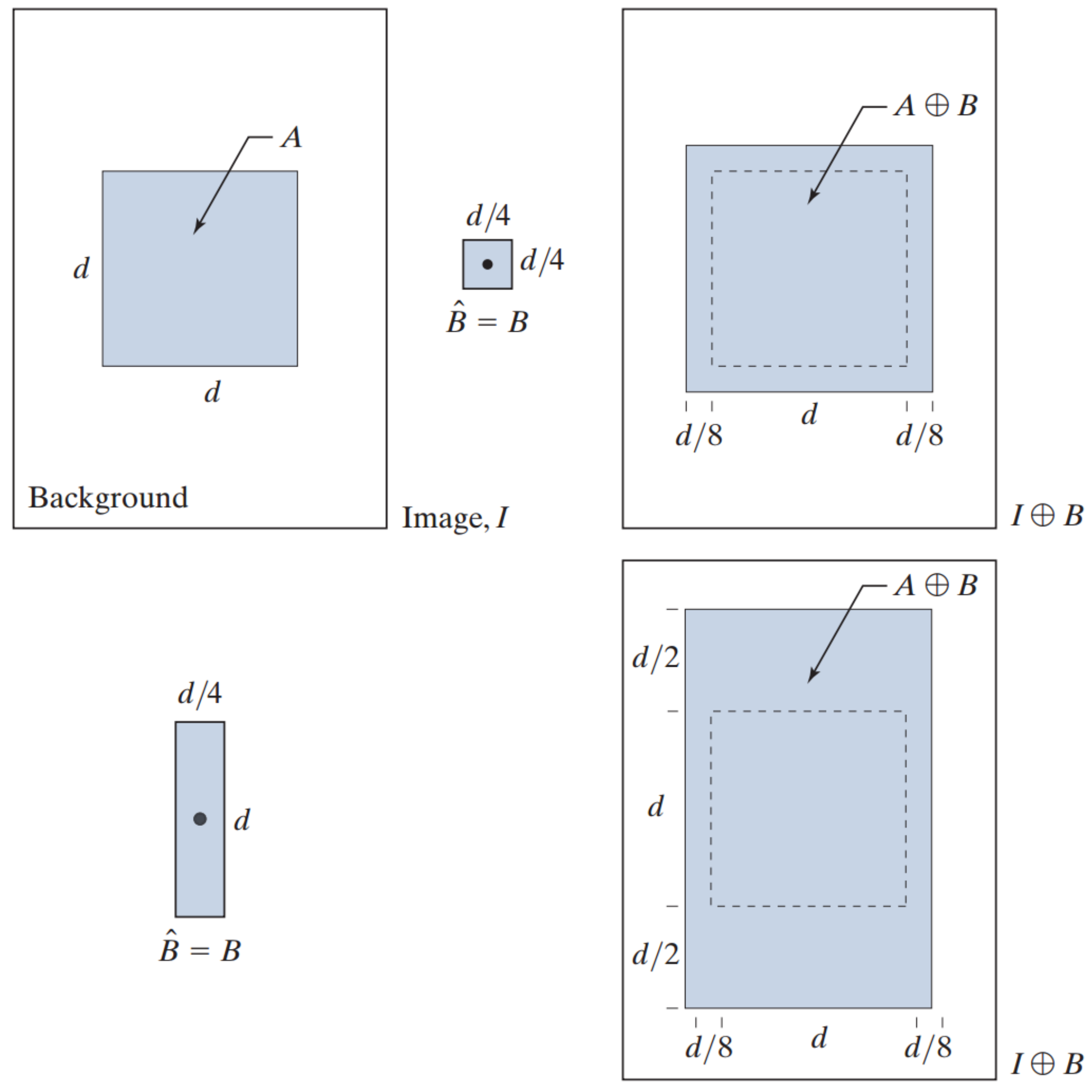
  - **Dilation** will do:
    - Fatten up. Kind of opposite of Erosion.
    - Bridge gaps, fill holes, without change
    - overall size of object.

$\widehat{B}_z$ overlap at least one element of A

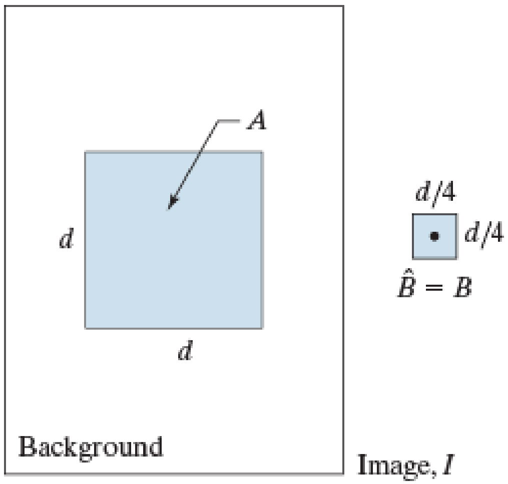
Dilation (膨胀), example

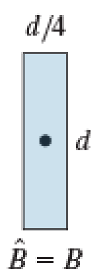
a b c
d e

FIGURE 9.6
(a) Image I, composed of set (object) A and background.
(b) Square SE (the dot is the origin).
(c) Dilation of A by B (shown shaded).
(d) Elongated SE.
(e) Dilation of A by this element. The dotted line in (c) and (e) is the boundary of A, shown for reference.

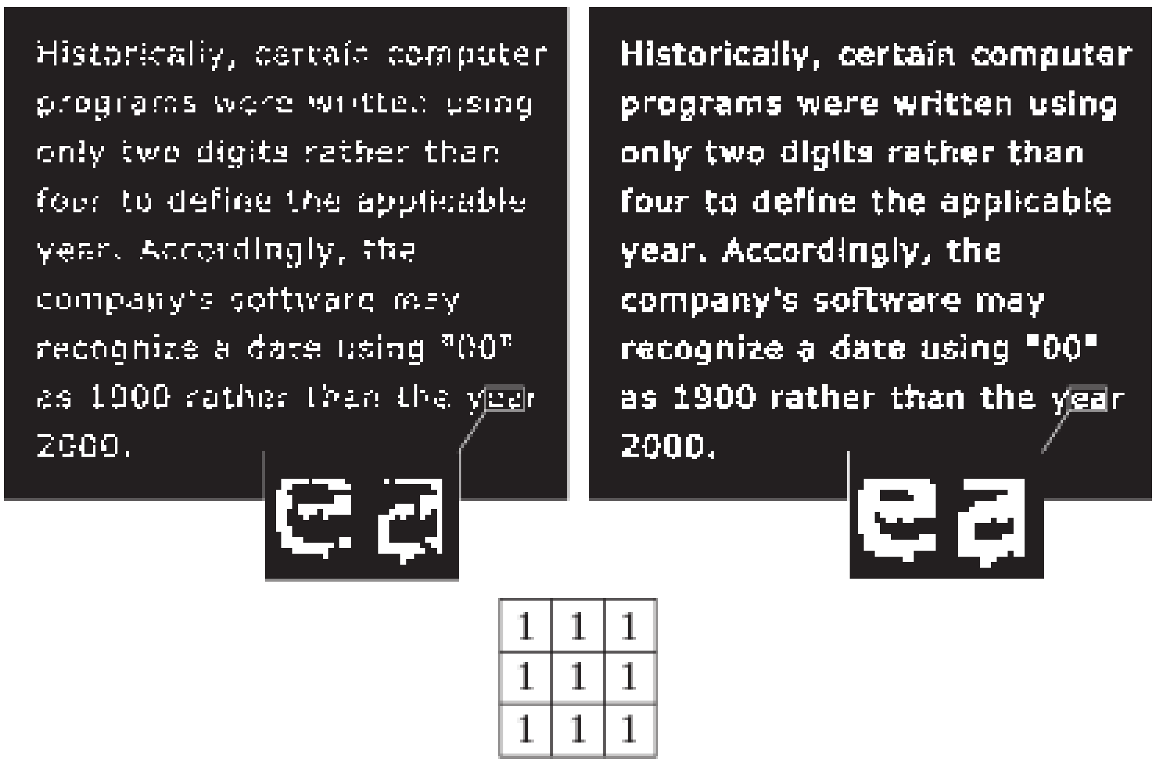


Dilation (膨胀), example





Dilation application



a c
b

FIGURE 9.7
(a) Low-resolution text showing broken characters (see magnified view).
(b) Structuring element.
(c) Dilation of (a) by (b). Broken segments were joined.

Opening (开操作)

- **Definition:**

$$A \circ B = (A \ominus B) \oplus B$$

or

$$A \circ B = \bigcup \{ (B)_z \mid (B)_z \subseteq A \}$$

- **Erode then dilate: break narrow bridges, eliminate thin structures**
- **Matlab Function:** J = imopen(I,SE)
- **Properties:**

①$A \circ B$ is a subset (subimage) of A

②If C is a subset of D, the $C \circ B$ is a subset of $D \circ B$

③$(A \circ B) \circ B = A \circ B$

Closing (闭操作)

- **Definition:**

  $A \bullet B = (A \oplus B) \ominus B$

- **Dilate, then erode: fuse narrow breaks, eliminate small holes**
- **Matlab Function:** J = imclose(I,SE)
- **Properties:**

  ① A is a subset (subimage) of $A \bullet B$

  ② If C is a subset of D, the $C \bullet B$ is a subset of $D \bullet B$

  ③ $(A \bullet B) \bullet B = A \bullet B$

Opening & Closing

- **Opening**
  - Smooth the contour of an object
  - Break narrow bridges
  - Eliminate thin structures

- **Closing**
  - Smooth the contour of an object
  - Fuse narrow breaks and long thin gulfs
  - Eliminate small holes
  - Fill gaps in the contour

The Hit-or-Miss Transformation

$$A \circledast B = (A \ominus B_1) \cap (A^c \ominus B_2)$$

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

B_1

$$\begin{array}{ccc} & 1 & \\ 1 & \boxed{1} & 1 \\ & 1 & \end{array}$$

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

B_2

$$\begin{array}{ccc} 1 & & 1 \\ & \boxed{} & \\ 1 & & 1 \end{array}$$

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

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

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

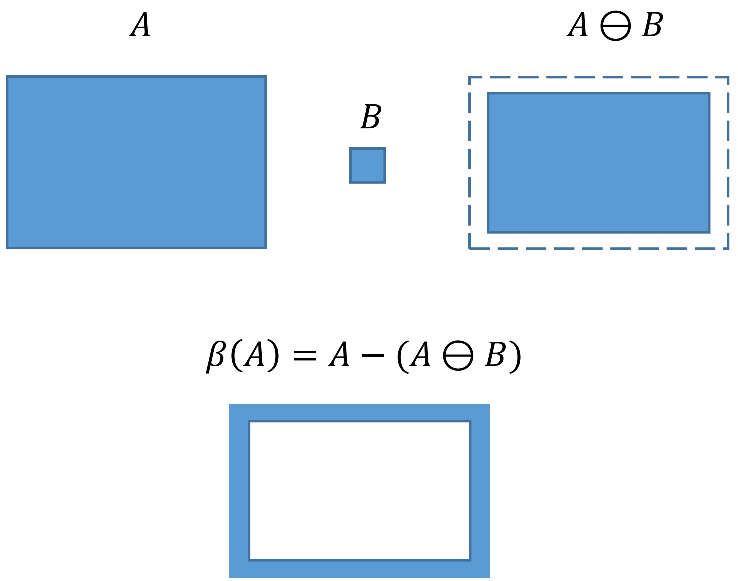
The Hit-or-Miss Transformation

- A method to find the location of a shape B_1 in an image A.
  - -Erosion of $A \ominus B_1$ gives all places where B_1 fits in A.
- So also require the boundary around the shape, B_2 to be empty.
  - -Erosion of $A^c \ominus B_2$ gives all places where B_2 fits in empty places of A.
- Then take the intersection:

$$A \circledast B = (A \ominus B_1) \cap (A^c \ominus B_2)$$

Boundary Extraction

Morphological algorithm: $\beta(A) = A - (A \ominus B)$

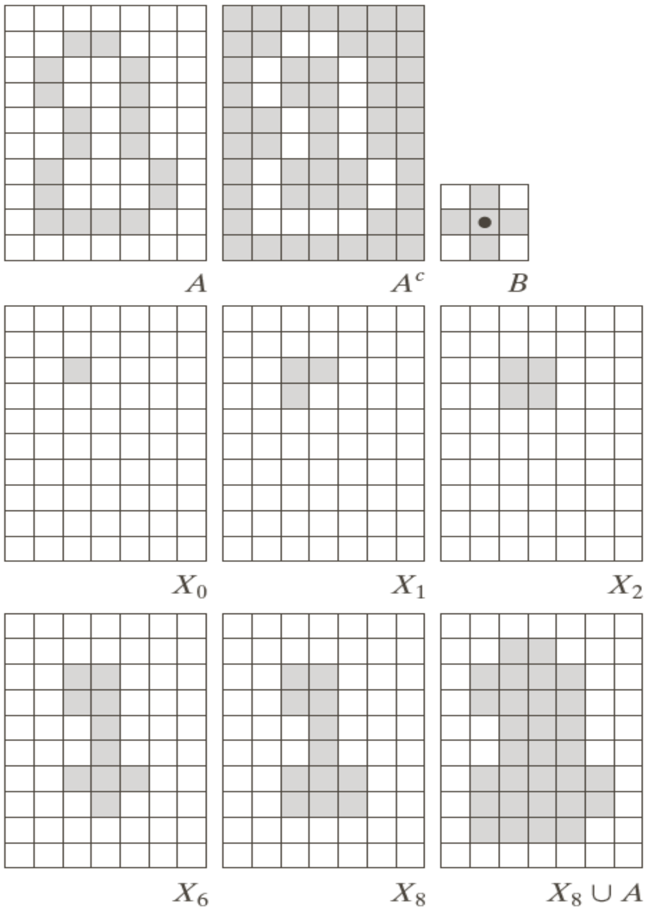


Hole Filling

- Let A be the set of 8-connected boundary points of a region
- Start with a point inside the region
- Repeatedly dilate
- At each step, the points corresponding to the region boundary are set to zero：

$$X_k = (X_{k-1} \oplus B) \cap A^c, k = 1,2,3, \dots$$

- Stop when no more changes



Take home message

- Morphological Language: Set theory (集合)
- Morphological operations take a set of pixels
- Key element: "structuring element"
- Insensitive to noise & Smooth edge
- Key operations
  - Erosion
  - Dilation
  - Opening
  - Closing
  - HMT (Hit or Miss Transformation)