Lecture 8
Color image processing & Morphological image processing

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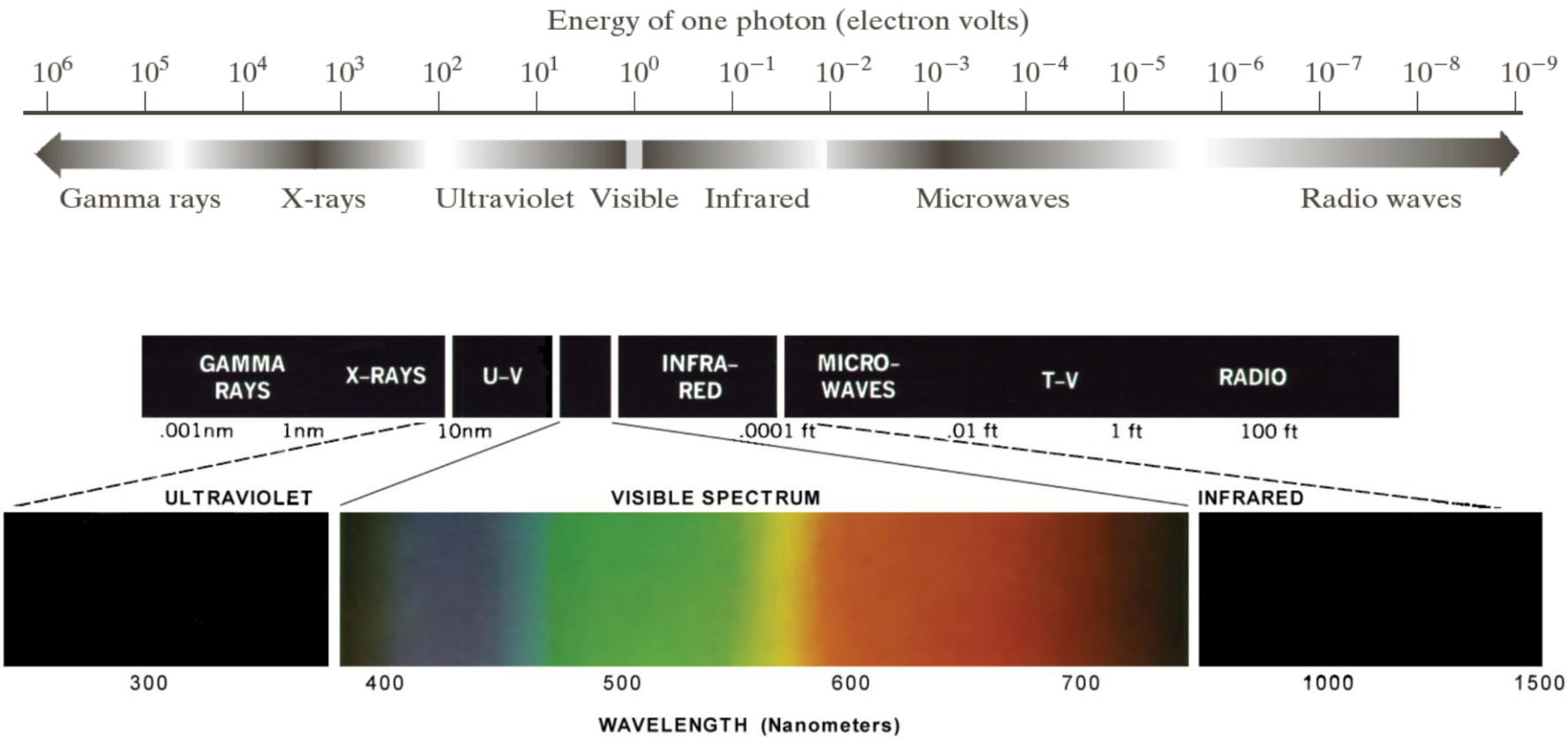
Color image processing: Outline

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

Electromagnetic spectrum



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Dispersion of light

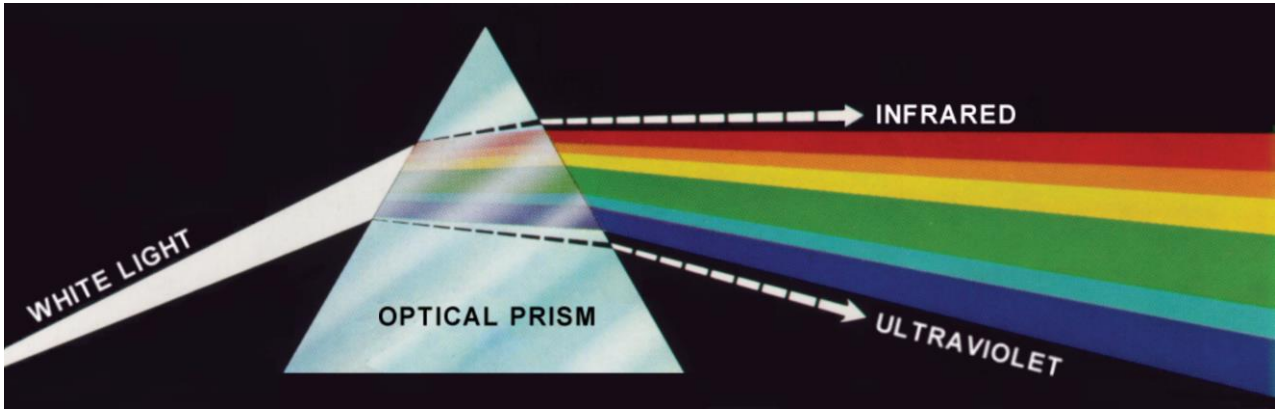

FIGURE 7.2
Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lighting Division.)

车轴三棱镜实验

习波动性

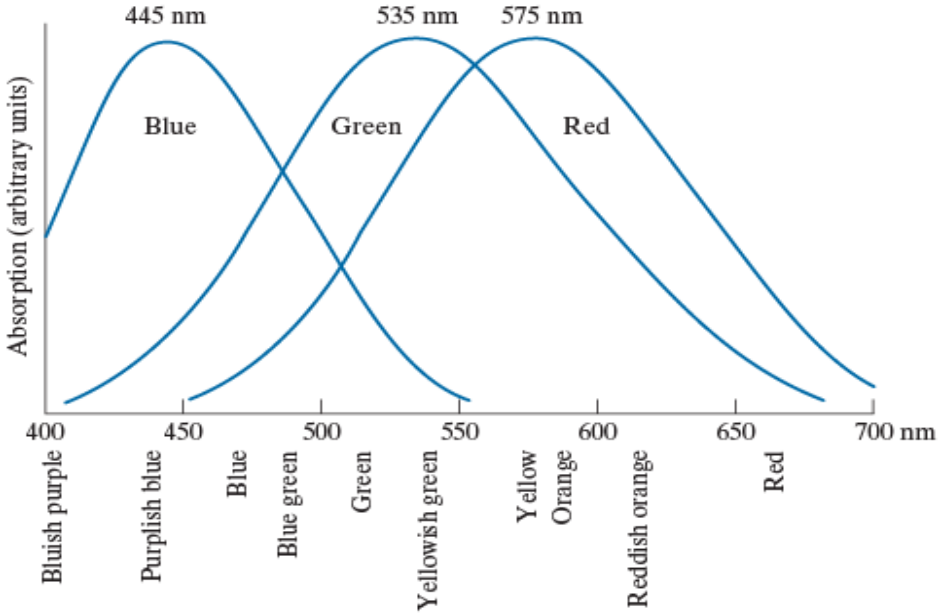

FIGURE 7.3
Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

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Human visual system color Space

锥状细胞

- **The LMS color space:** Cones enable color perceptions;
- **3 Types** of cones:
  - **Long:** sensitive to

"RED" (more yellow to blue) 65%

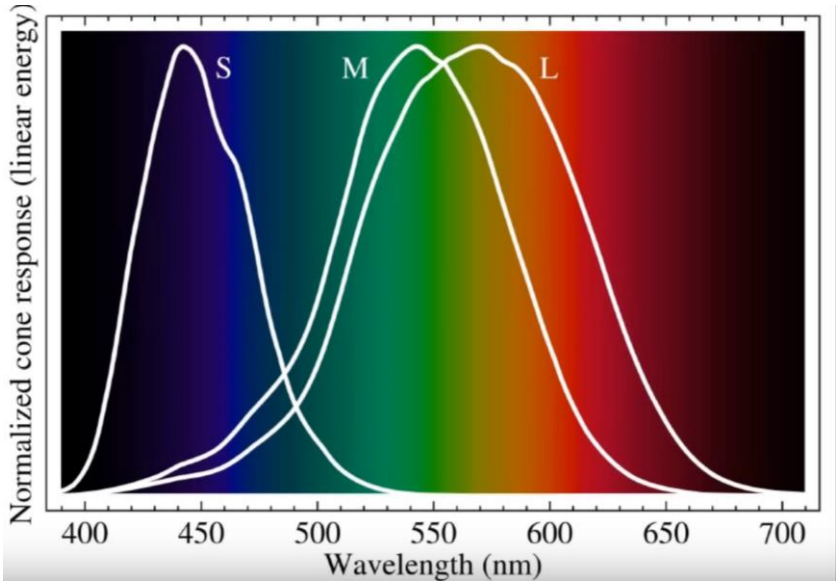
  - **Middle :** sensitive to

"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

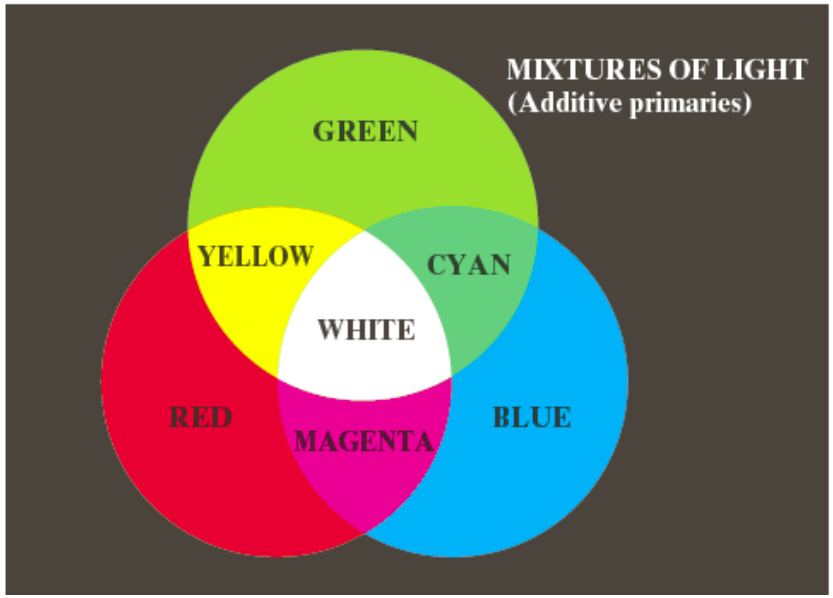
  - Blue = 435.8 nm
  - Green = 546.1 nm
  - Red = 700 nm
- **The white light is** achieved with a mixture of RGB light with:
  - 1.0000 : 4.5907 : 0.0601 of intensity （Luminous intensity）.
- **CMY and CMYK color**
  - Cyan = White – Red
  - Magenta = White – Green
  - Yellow = White – Blue
  - Black = White – Red - Green - Blue

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

Secondary colors

自己会发光

RGB color (显示器)



自己不发光，吸收一部分光反射

CMY and CMYK color

Black = White – Red - Green - Blue

=

R+G+B

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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

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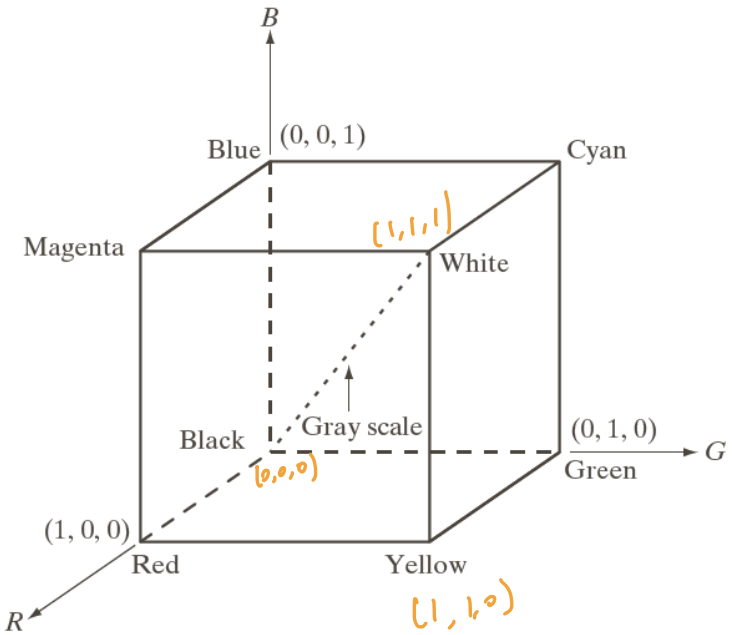
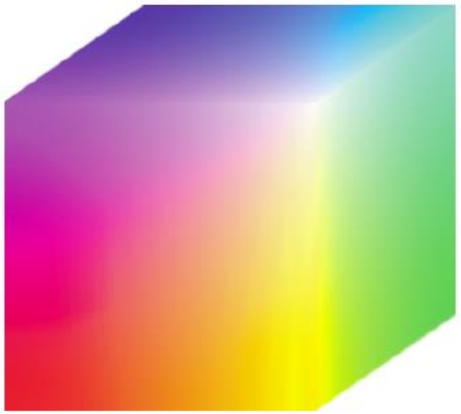
RGB Color Model





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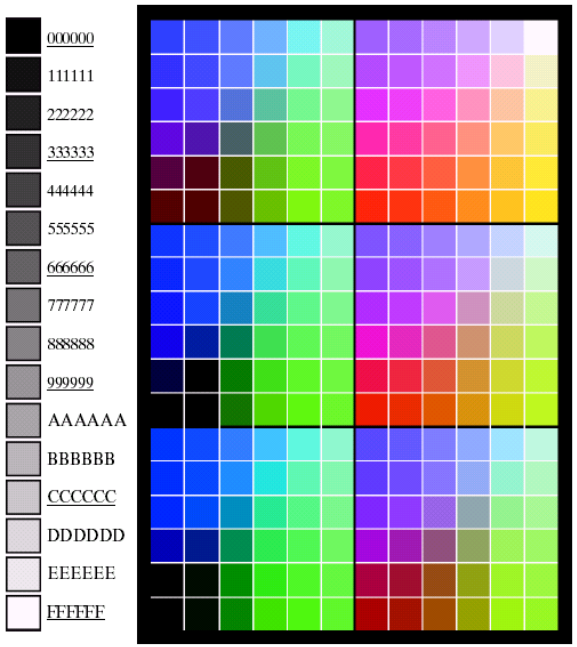
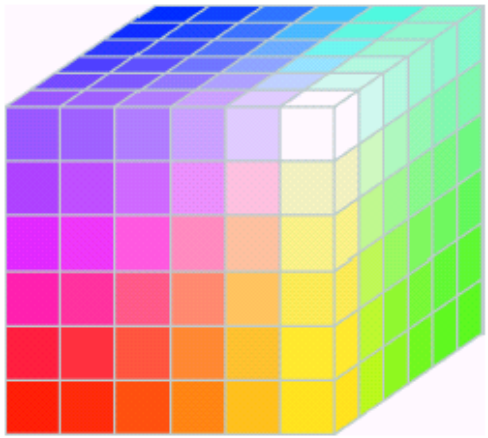
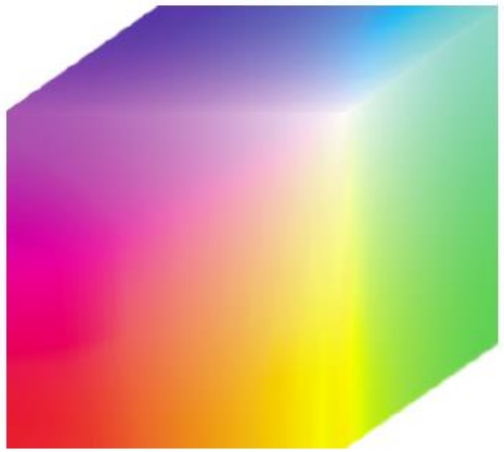
Safe/Standard RGB Color (24 bytes)

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







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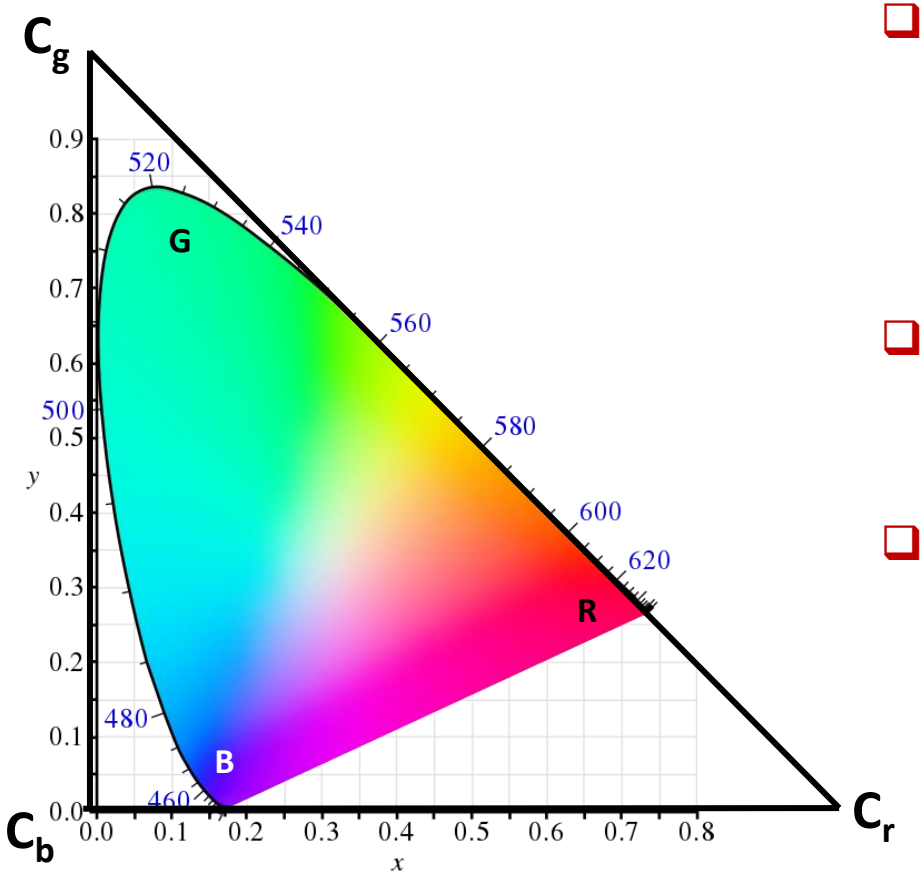
Chromaticity diagram



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

  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.

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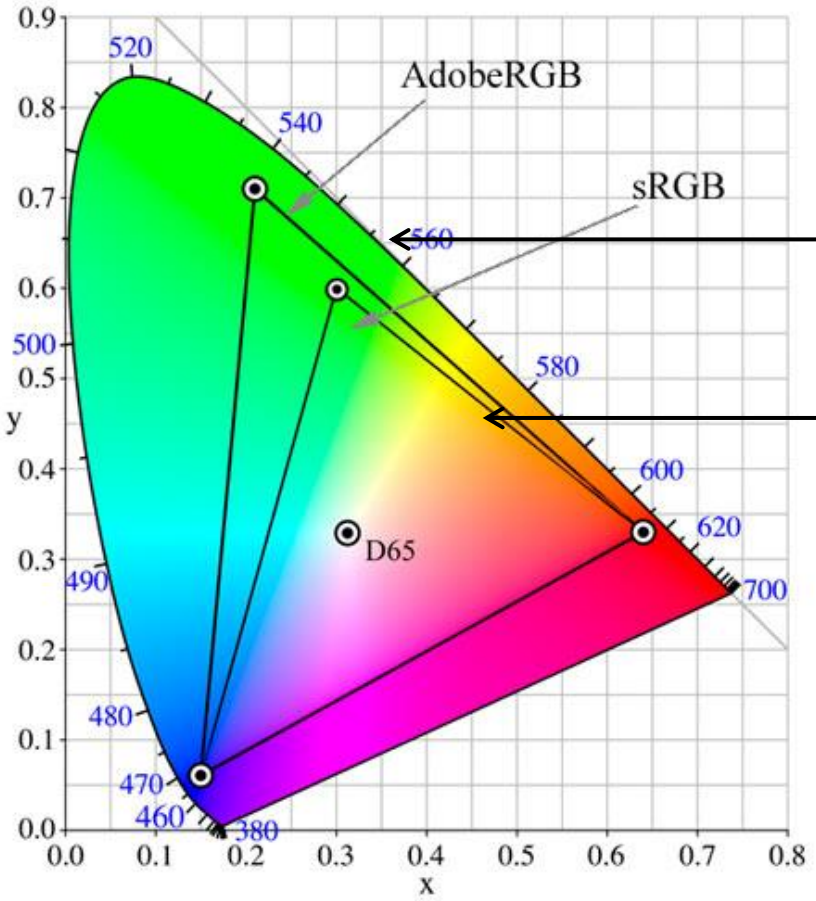
Color Gamut 色域



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

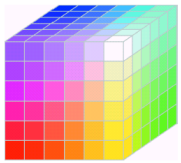
CIE Chromaticity diagram

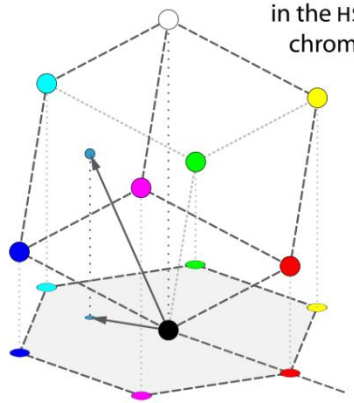
Color gamut for monitor

- **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.

HSI Color Model

RGB color cube

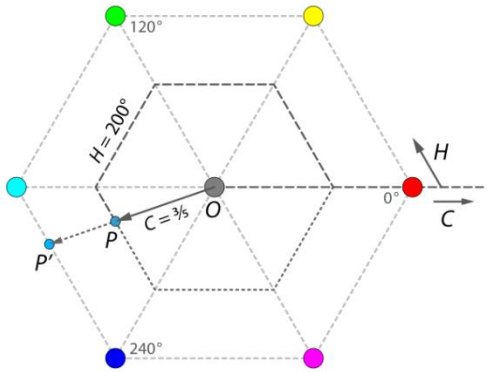


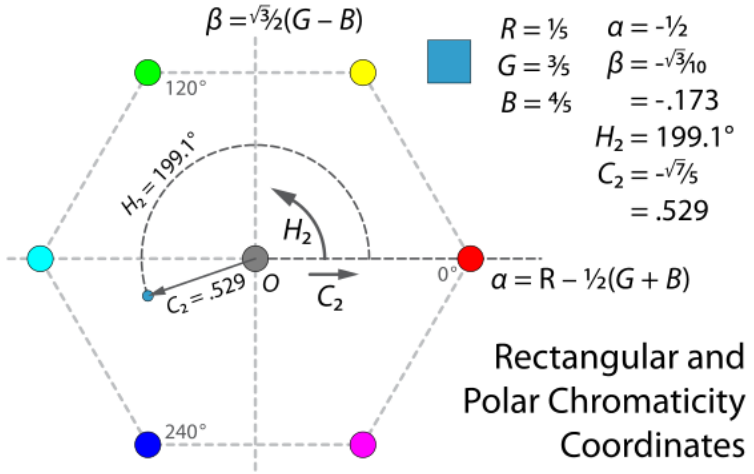


$R = 1/5$
$G = 3/5$
$B = 4/5$

$C = \frac{OP}{OP'} = B - R = 4/5 - 1/5 = 3/5 = .6$

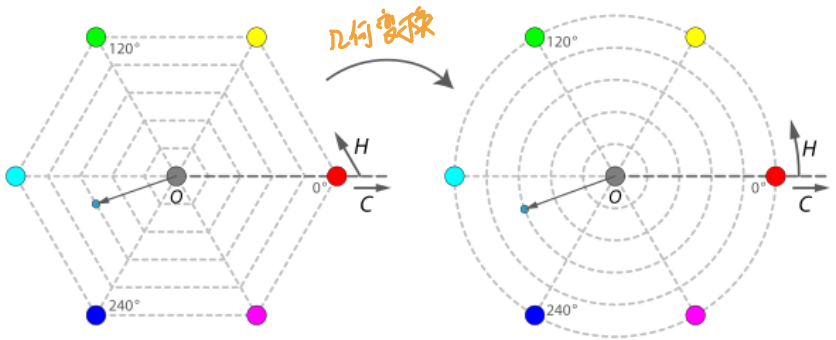
$H = 60° \times \left(4 + \frac{R-G}{C}\right) = 60° \times (4 - 2/3) = 200°$





$R = 1/5$ $\quad \alpha = -1/2$
$G = 3/5$ $\quad \beta = -\sqrt{3}/10$
$B = 4/5$ $\quad = -.173$
$H_2 = 199.1°$
$C_2 = -\sqrt{7}/5$
$= .529$

Rectangular and
Polar Chromaticity
Coordinates



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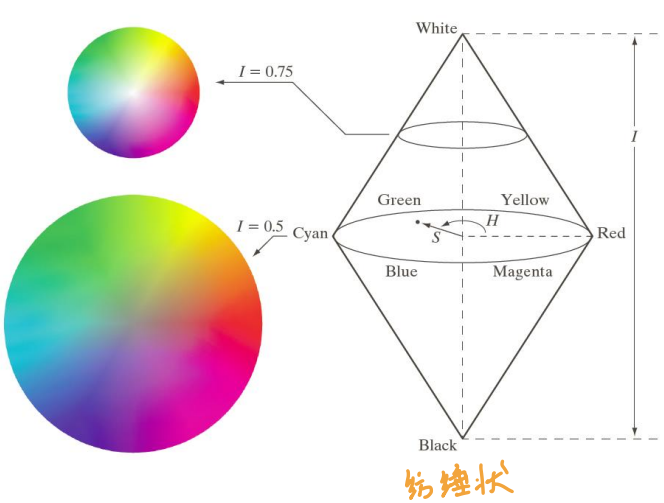
HSI Color Model

HSI Color Model

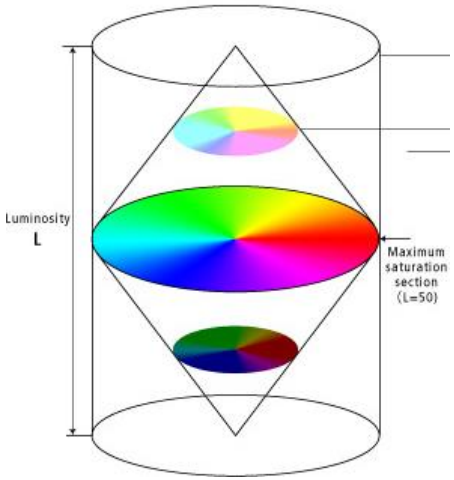
色调
- **Hue:** Dominant color associated with wavelength.

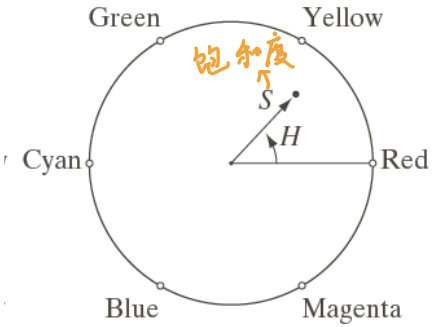
饱和度
- **Saturation:** relative purity, the amount of white light mixed with a hue

纯不纯，是否有白光
- **Intensity/Lightness.** $I = (r + g + b) / 3$



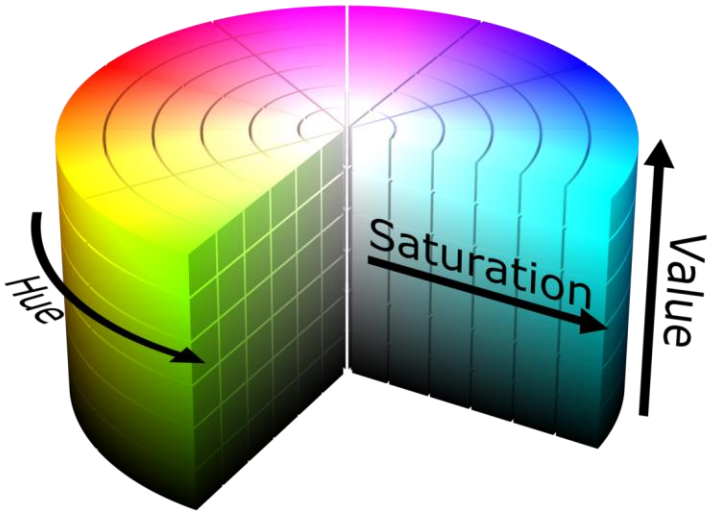
纺锤状

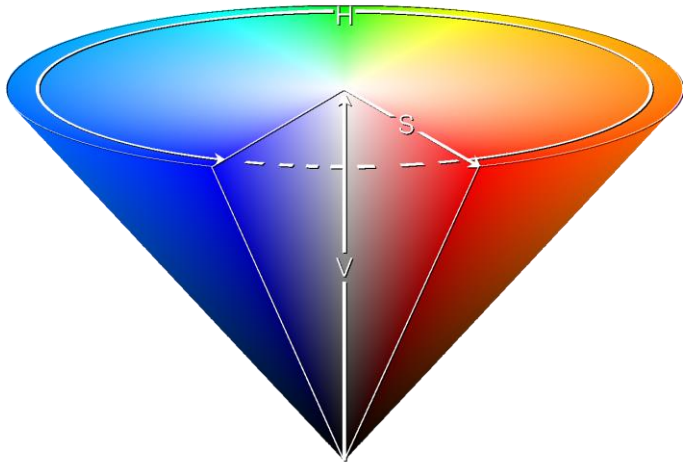




HSV Color Model

- **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

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RGB to Gray scale

- **Maximum value:** RGB 最大值作为 intensity 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**

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

亮点

max

偏暗

average

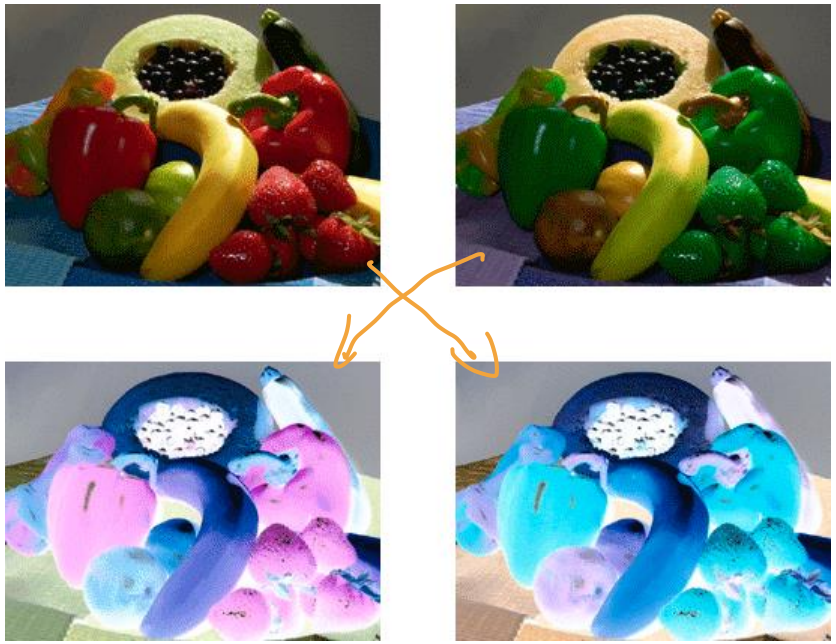
颜色分布更宽

weight

Transform to CMY Color Space

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

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



Transform from RGB to HSI/HSV

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

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

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

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

$$V = \max(r,g,b);$$

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

Transform from HSI to RGB

- $0° \leq H < 120°$

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

- $120° \leq H < 240°$

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

- $240° \leq H < 360°$

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

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Color Balance 白平衡

- **White balance:**

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

彩色图转灰度

估计每个 pixel 上 intensity 信息

$$k_R = \frac{\bar{I}}{\bar{f}_R} \quad k_G = \frac{\bar{I}}{\bar{f}_G} \quad k_B = \frac{\bar{I}}{\bar{f}_B}$$

灰度图 over

$\bar{I}$ → 色彩通道平均强度

balance ← R弱 $k_R > 1$ 强: $k < 1$

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

R: 0~150 $\bar{f}_R$: 75 $k_R = \frac{100}{75} = \frac{4}{3}$

B: 50~200 $\bar{f}_B$: 125 => $k_B = \frac{100}{125} = \frac{4}{5}$

$\bar{I}$: 100

R值域上拉

B值域下调

- **Maximum value balance**

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

0~150 50~200 100~250

N_R:0 N_G:50 N_B:100

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

T_R:150 T_G:100 T_B:150 = 100

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

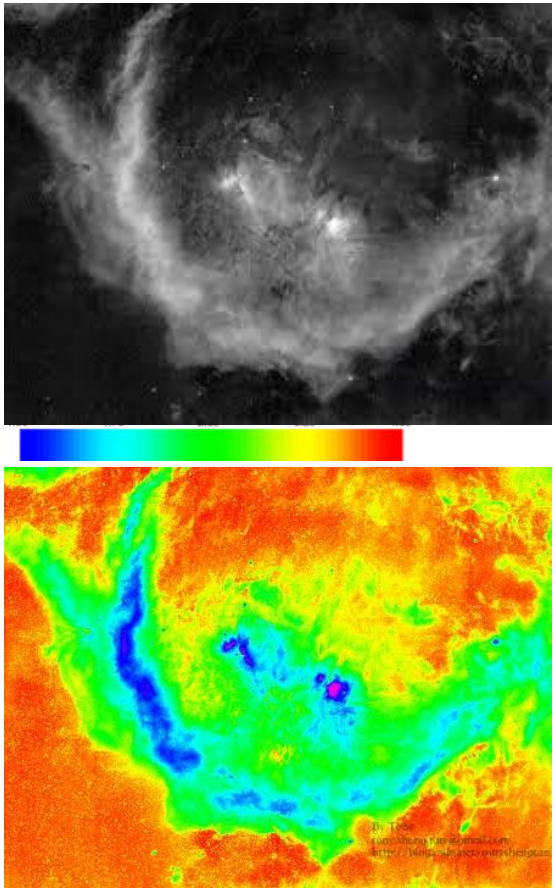
k_R: 3 k_G: 1.5 k_B: 1

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. 从大到小排列第100个的值

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.

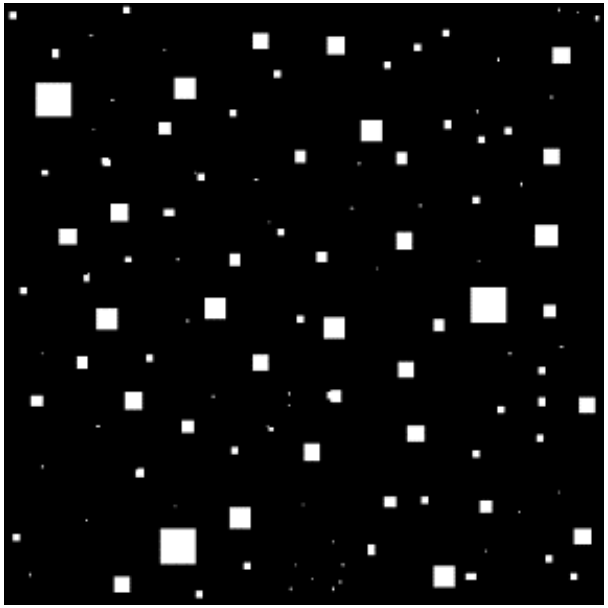
Morphological image processing: Outline

Morphology Image Processing （形态学图像处理）

- Morphological operation.
- Morphological algorithms.

Problem try to solve

- Imperfect image segmentation.



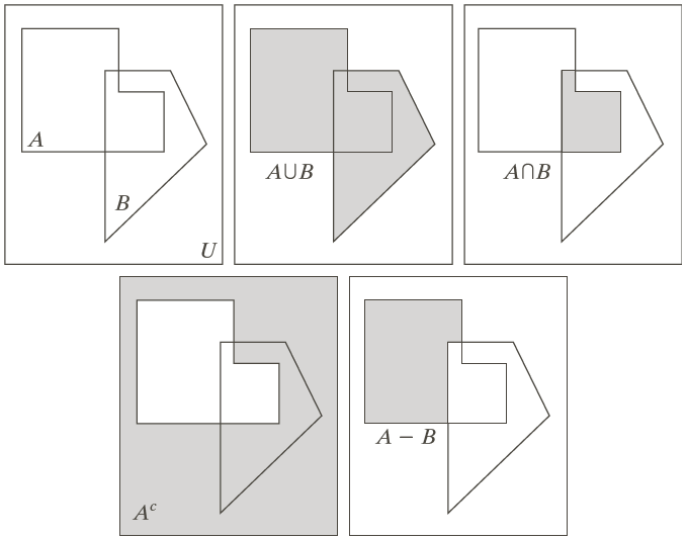
Historically, certain computer programs were written using only two digits rather than four to define the applicable year. Accordingly, the company's software may recognize a date using "00" as 1900 rather than the year 2000.

Preliminaries: Set Operation

集合操作

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)



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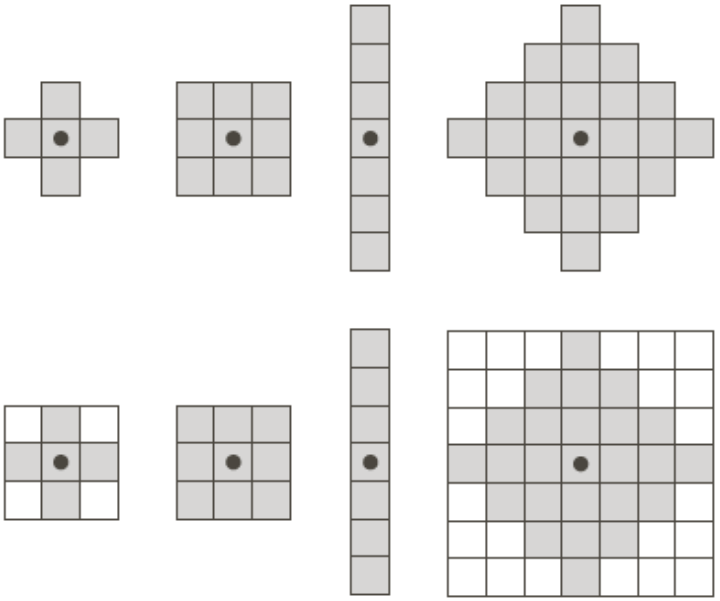
Structuring element (结构元)

- **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:**

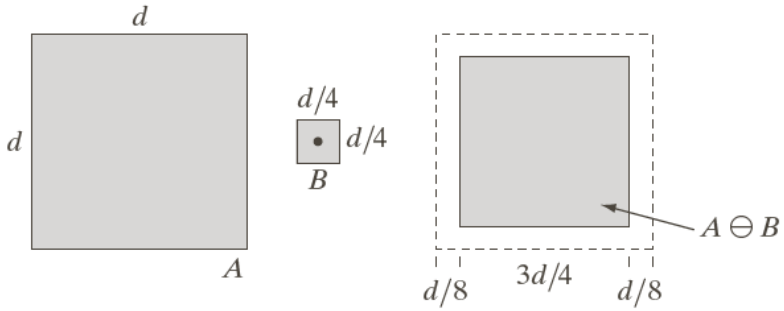
$$A \ominus B = \{z \mid (B)_z \subseteq A\}$$

结构元集合

结构元的 origin

or

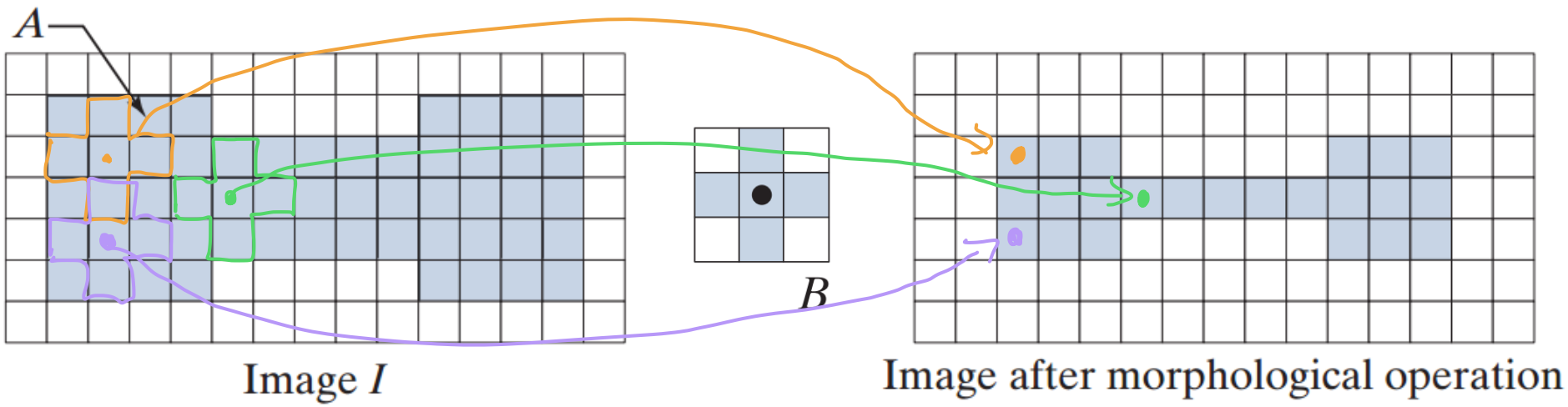
$$A \ominus B = \{z \mid (B)_z \cap A^c = \emptyset\}$$



- **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

case 1: no match → 0
case 2: somehow match (partial) → 0
Case 3: perfect match → 1



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).

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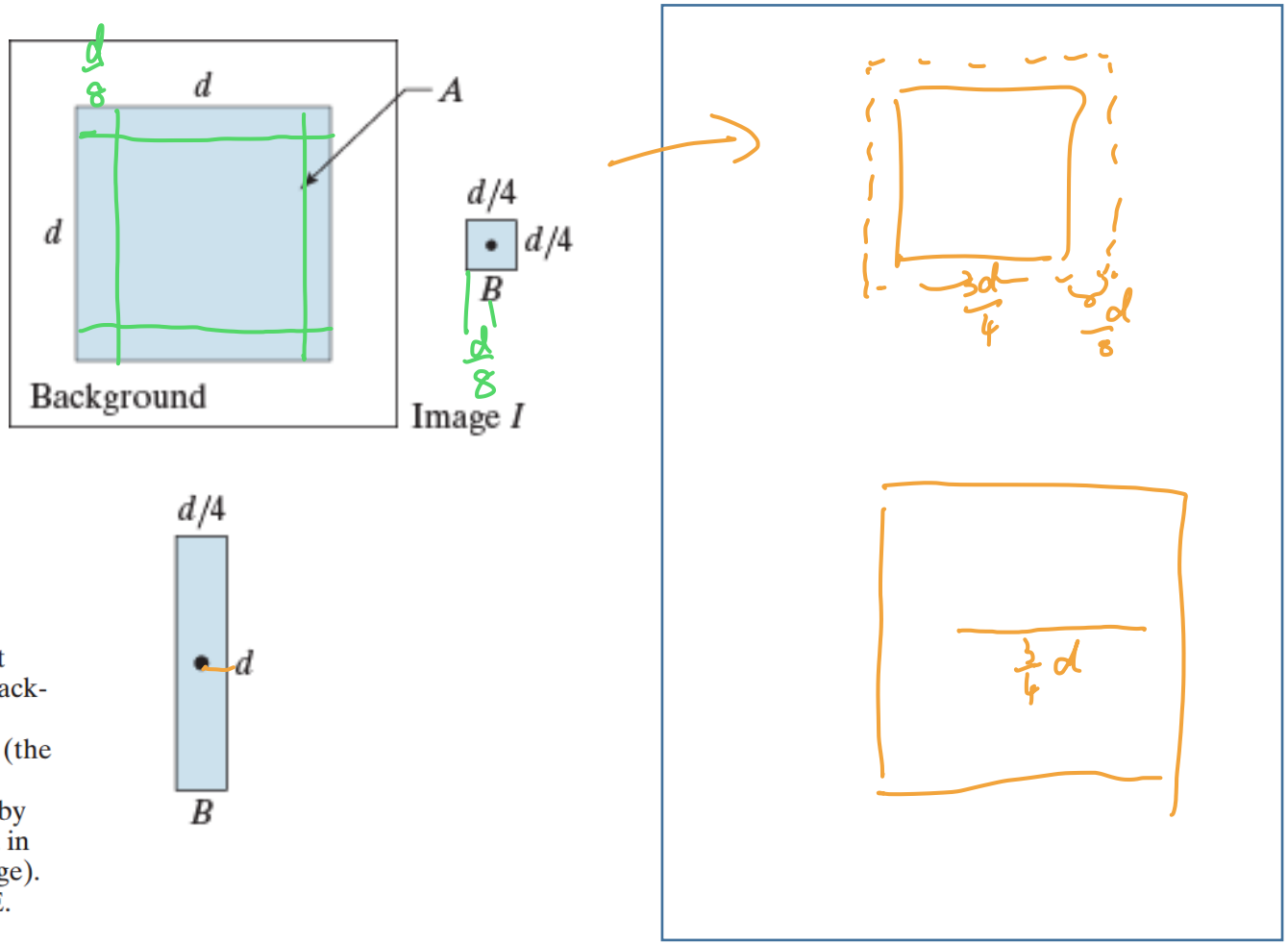
Erosion (腐蚀), example



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.

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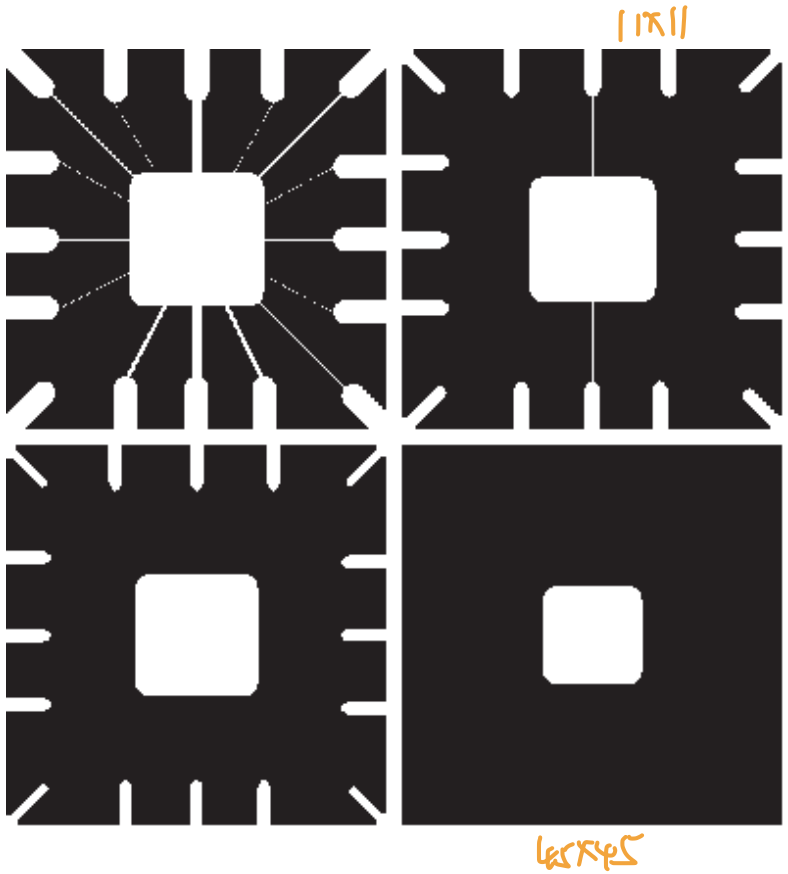
Erosion application



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

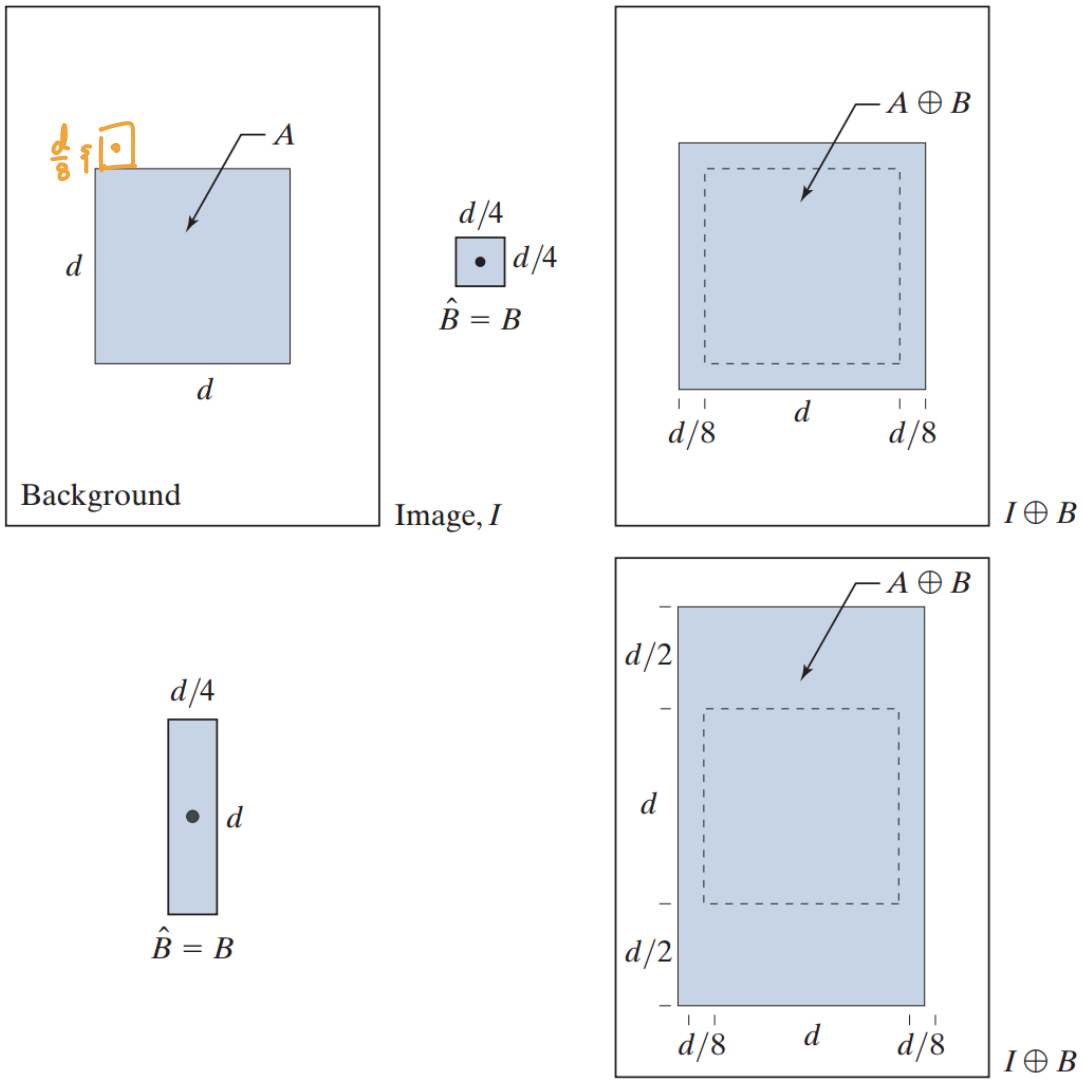
$A \oplus B = \{z | \widehat{B_z} \cap A \neq \emptyset\}$

  - **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

至少有一个element 相交

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.

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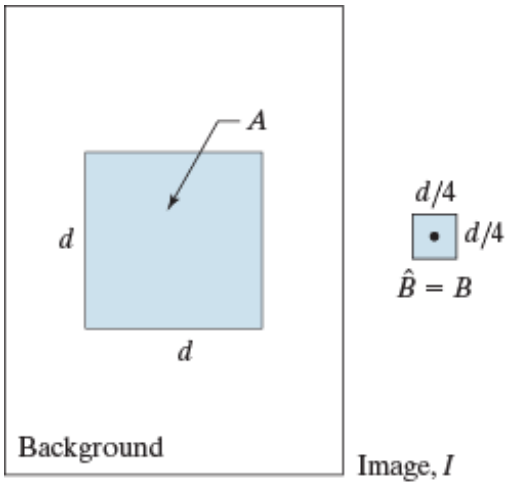
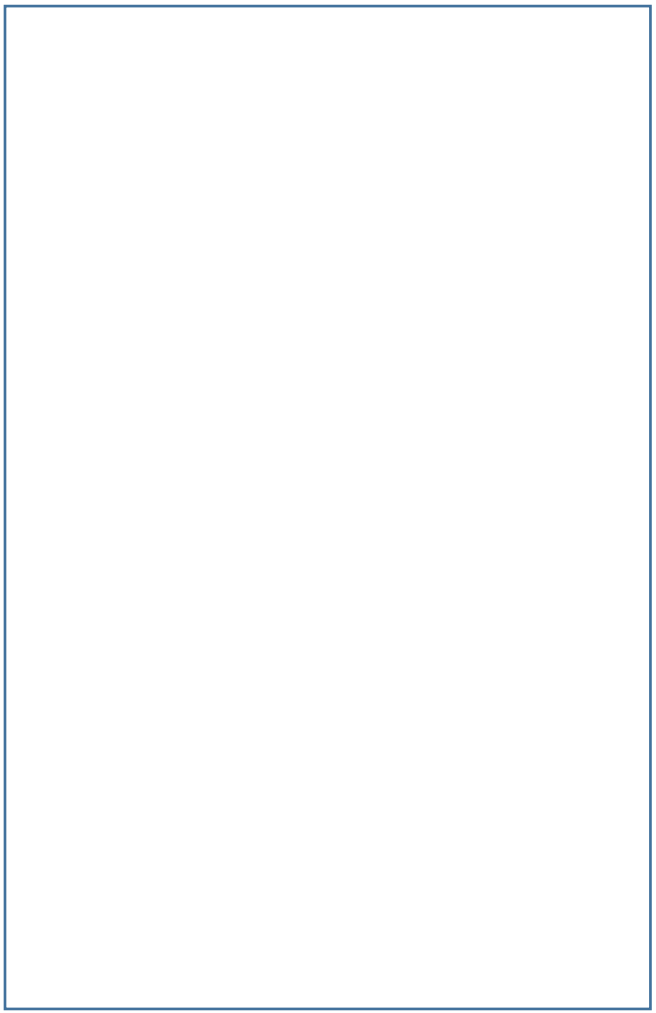
Dilation (膨胀), example





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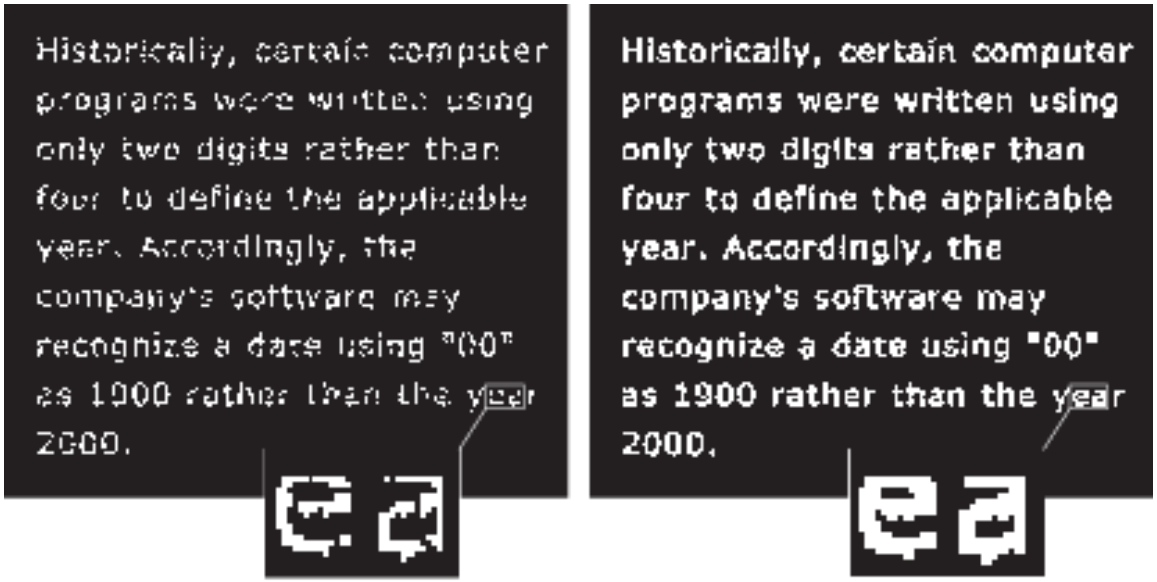
Dilation application



1	1	1
1	1	1
1	1	1

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.

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Opening (开操作)

- **Definition:**

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

or

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

腐蚀 膨胀

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

① A ∘ B is a subset (subimage) of A

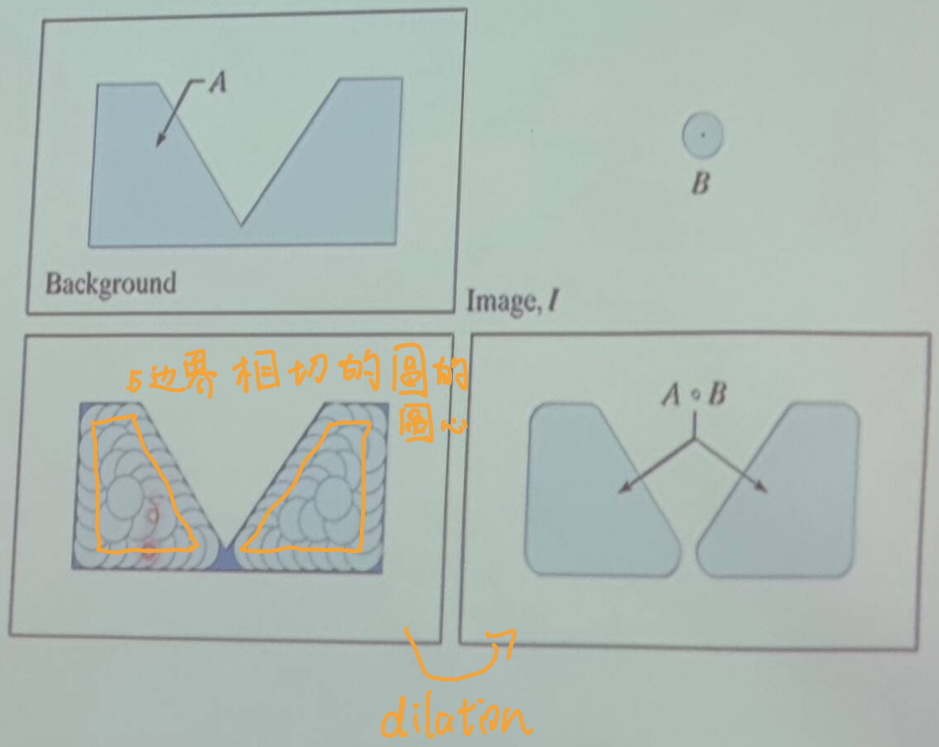
② If C is a subset of D, the C ∘ B is a subset of D ∘ B

③ (A ∘ B) ∘ B = A ∘ B

Opening (开操作)

a b
c d

FIGURE 9.8
(a) Image I, composed of set (object) A and background.
(b) Structuring element, B.
(c) Translations of B while being contained in A. (A is shown dark for clarity.)
(d) Opening of A by 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:**

  ①A is a subset (subimage) of A • B

  ②If C is a subset of D, the C • B is a subset of D • B

  ③(A • B) • B = A • B

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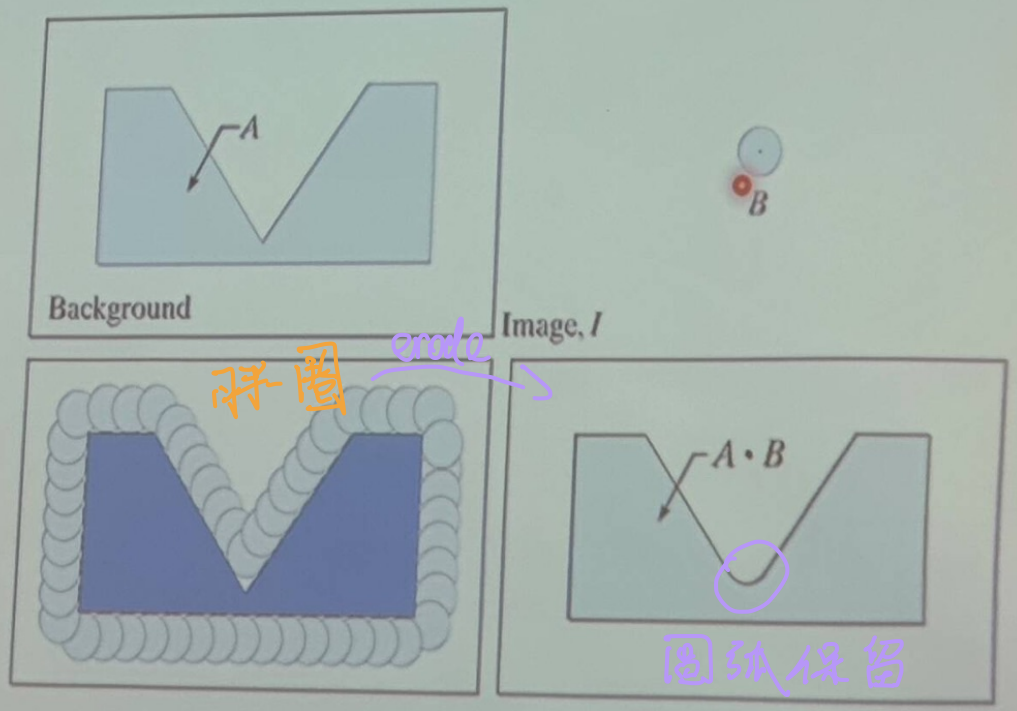
Closing (闭操作)

a b
c d

FIGURE 9.9
(a) Image I, composed of set (object) A, and background.
(b) Structuring element B.
(c) Translations of B such that B does not overlap any part of A. (A is shown dark for clarity.)
(d) Closing of A by B.

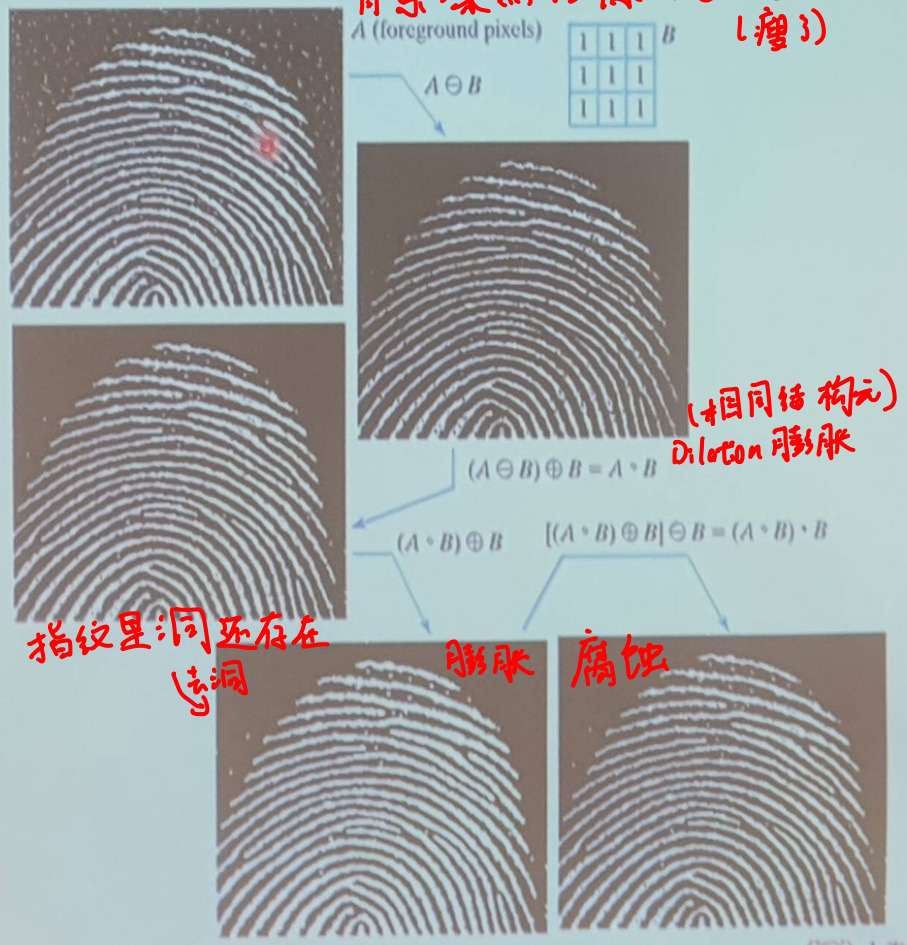


Opening & Closing

- **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

Opening & Closing



a b
d c
e f

FIGURE 9.11
(a) Noisy image. (b) Structuring element. (c) Eroded image. (d) Dilation of the erosion (opening of A). (e) Dilation of the opening. (f) Closing of the opening. (Original image courtesy of the National Institute of Standards and Technology.)

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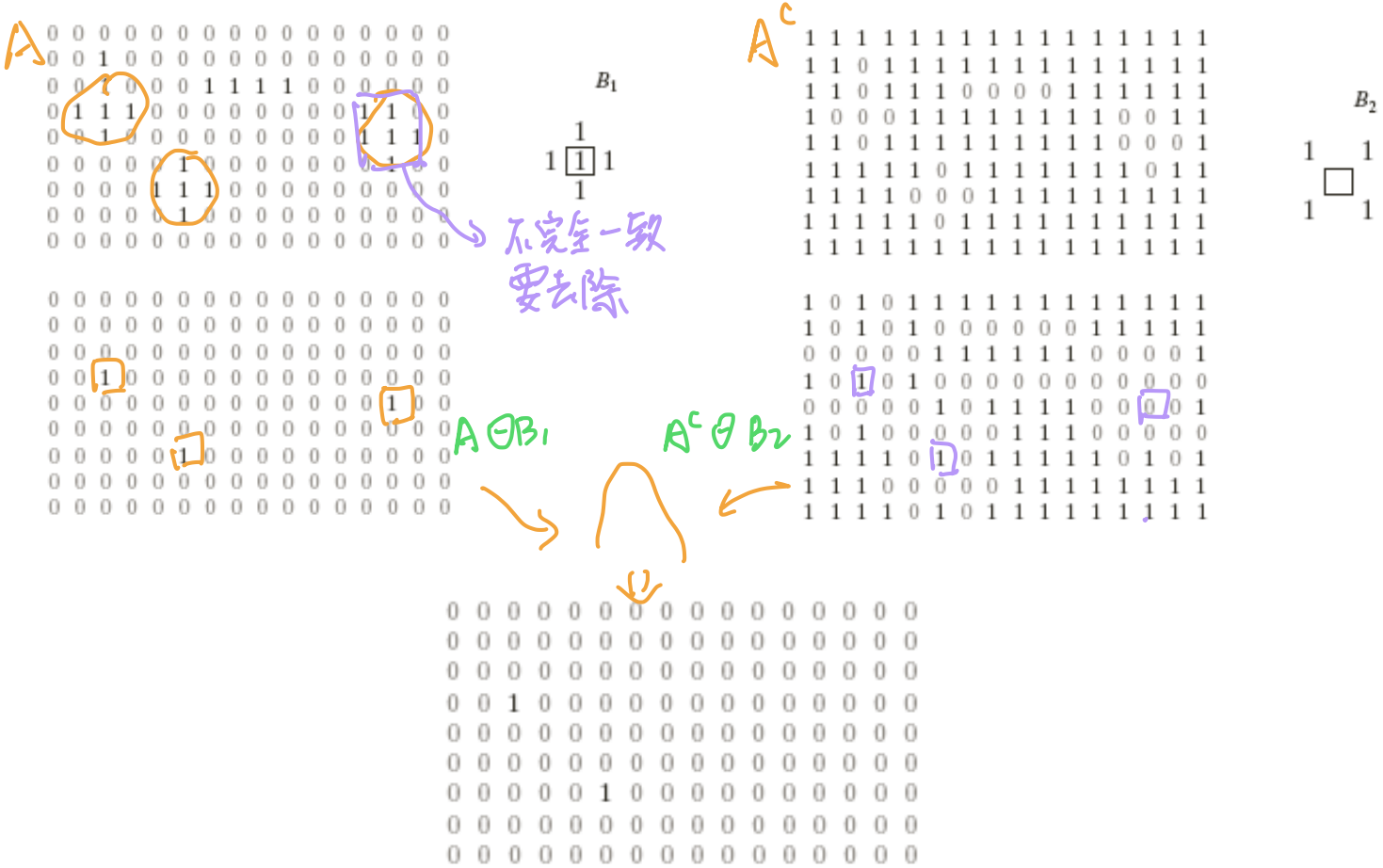
The Hit-or-Miss Transformation

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



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:

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

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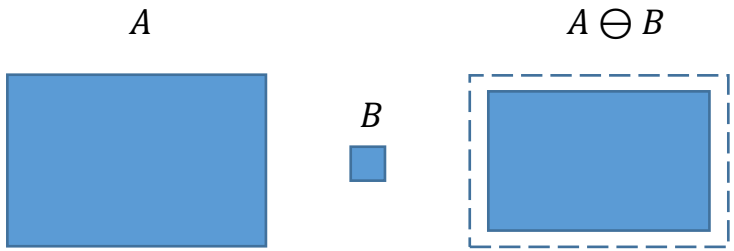
Boundary Extraction

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

边界提取[内边界]



$\beta(A) = A - (A \ominus B)$

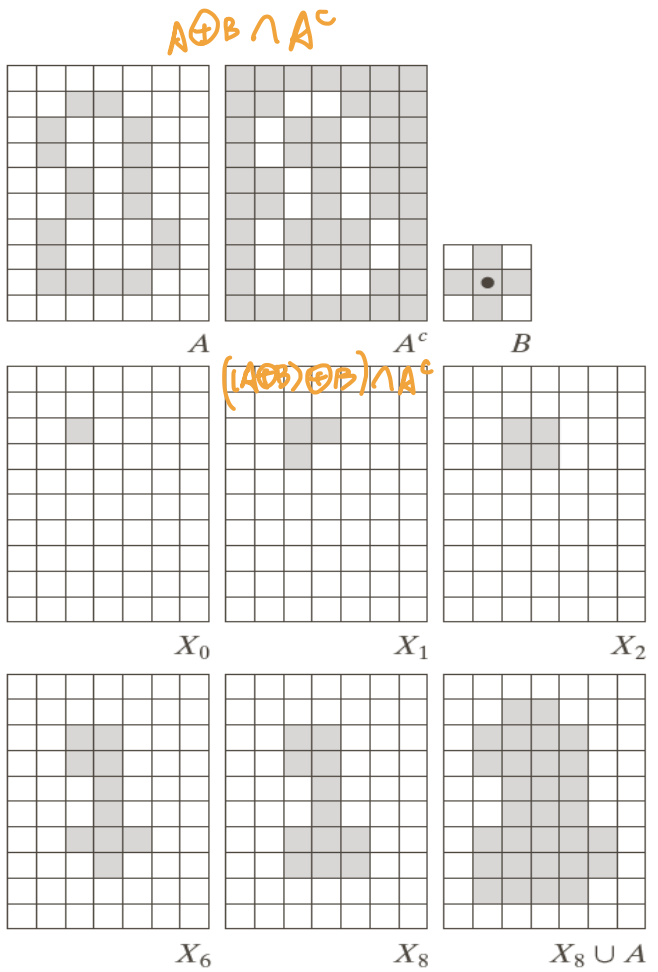
$(A \oplus B) - A$ [外边界]

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：

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

- Stop when no more changes



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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)