EE 604
Digital Image Processing

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Lecture outline

- **Morphological image processing**
- Color fundamentals

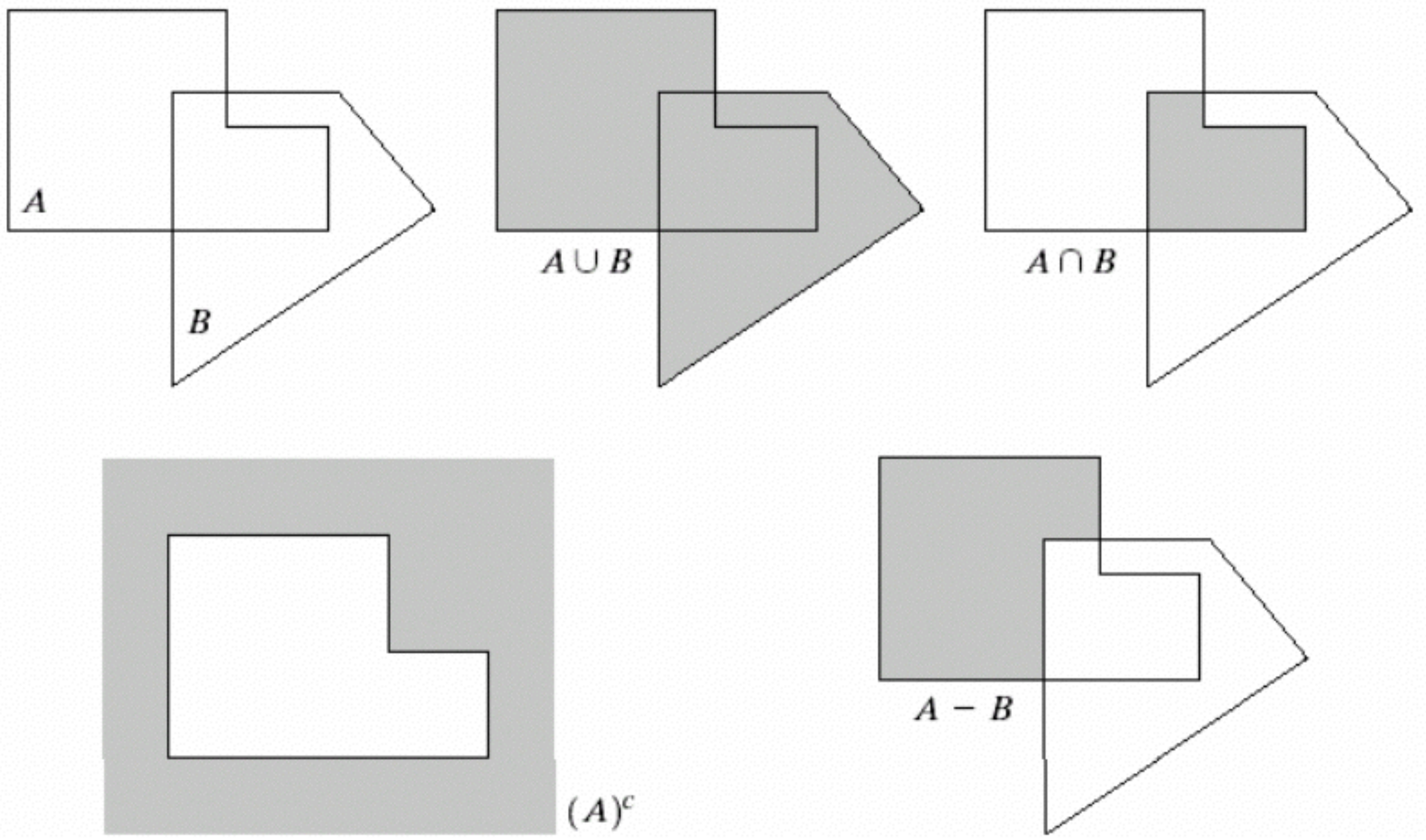
Morphological image processing

- Morphology means shape, form and structure
- Modify, change, extract shapes and structures
- Processing is based on simple set-theoretic operations
- Primarily useful for <u>binary images</u>
- Often used for preprocessing or post-processing

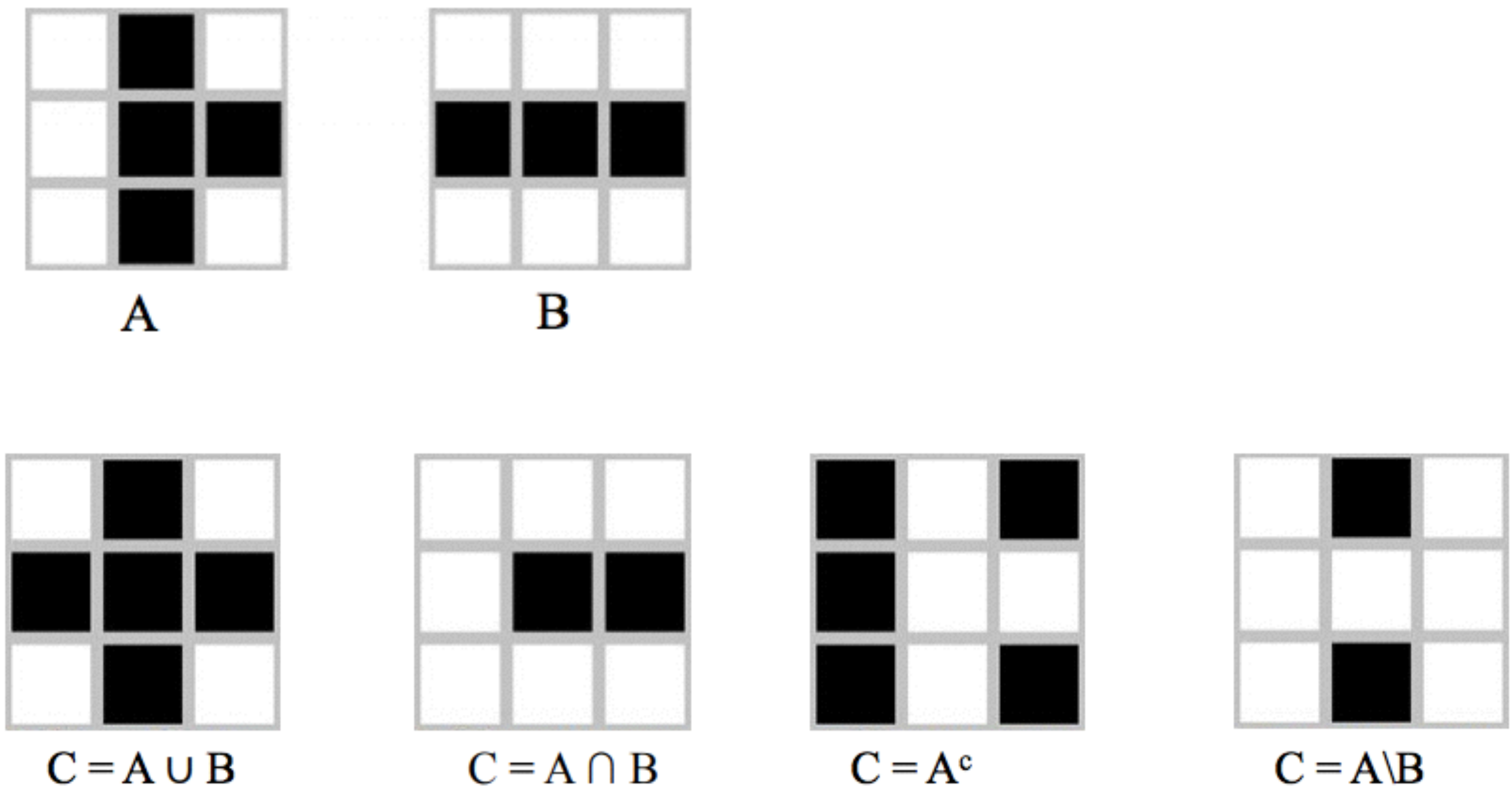
Basic set operations

- ***A*, *B*** are sets in $\mathbb{Z}^2$
- An element in ***A***: $a = (a_1, a_2)$
- Union: $A \cup B = \{w : w \in A \text{ or } w \in B\}$
- Intersection: $A \cap B = \{w : w \in A \text{ and } w \in B\}$
- Complement: $A^c = \{w : w \notin A\}$
- Difference: $\boldsymbol{A \backslash B} = \{w : w \in A, w \notin B\}$

Basic set operations



Basic set operations



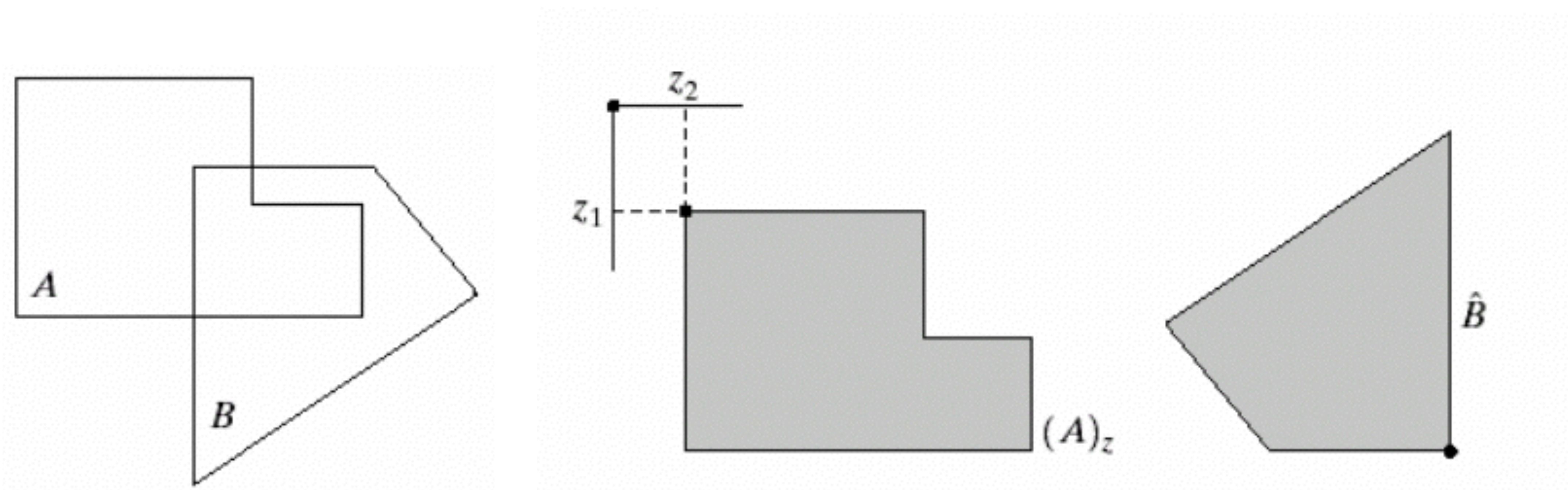
Basic set operations

- Reflection:

$$\hat{B} = \{w : w = -b, b \in B\}$$

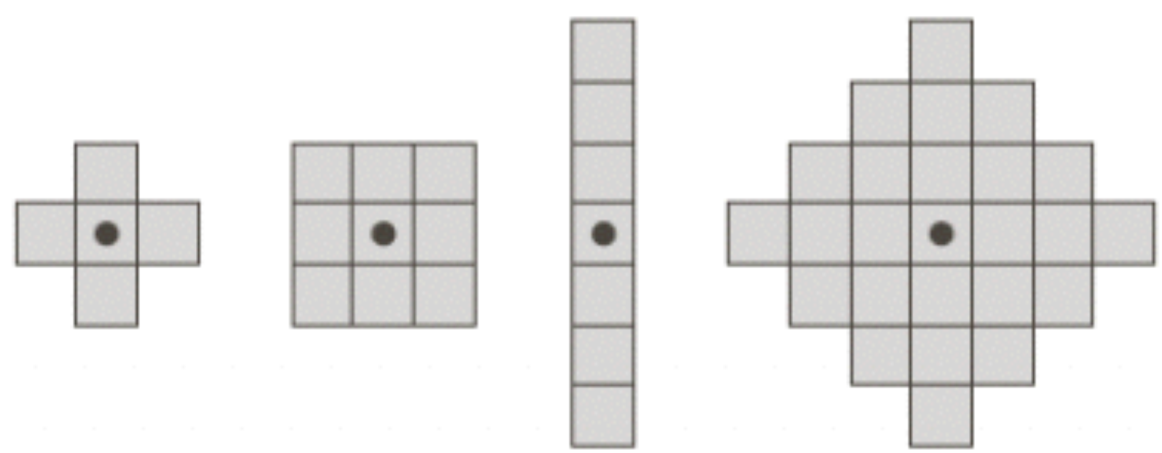
- Translation:

$$(A)_z = \{c : c = a + z, a \in A\}$$



Morphological processing

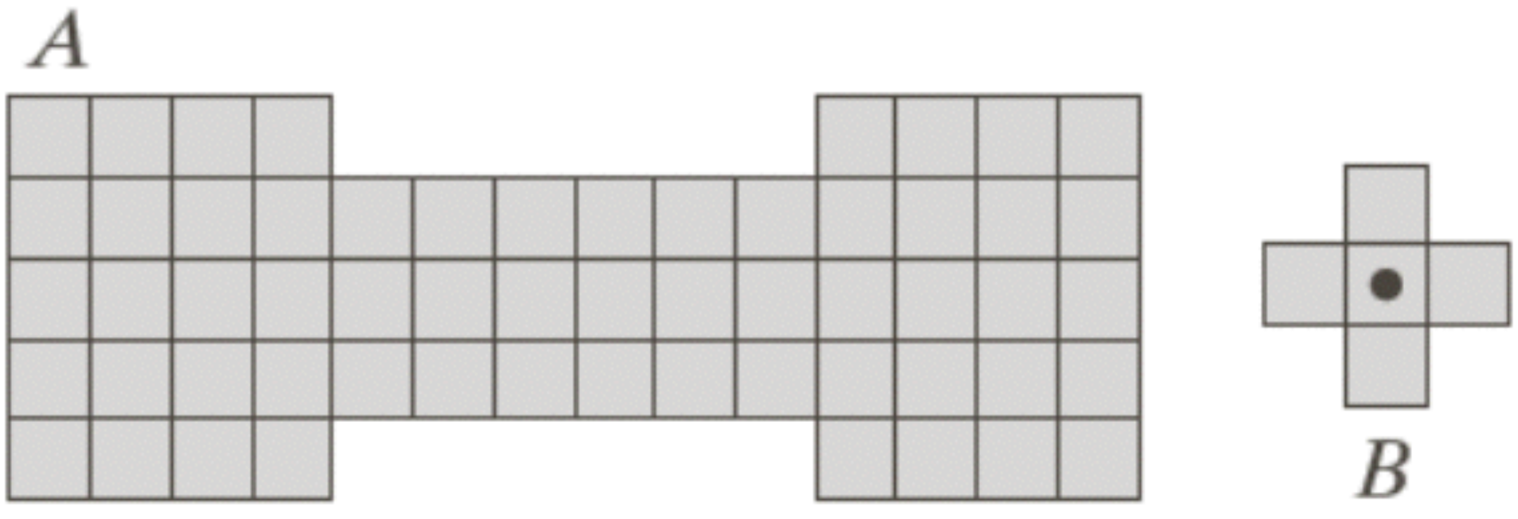
- Operations are defined in terms an image (set A) and a structuring element (set B).
- B can designed to have any shape and size. Often, symmetric in practice.
- Think of B as small mask that is translated over the entire image set A.



Dilation

- Dilation of ***A*** by ***B***

$$A \oplus B = \left\{ z \,\middle|\, \left(\hat{B} \right)_z \cap A \neq \varnothing \right\}$$



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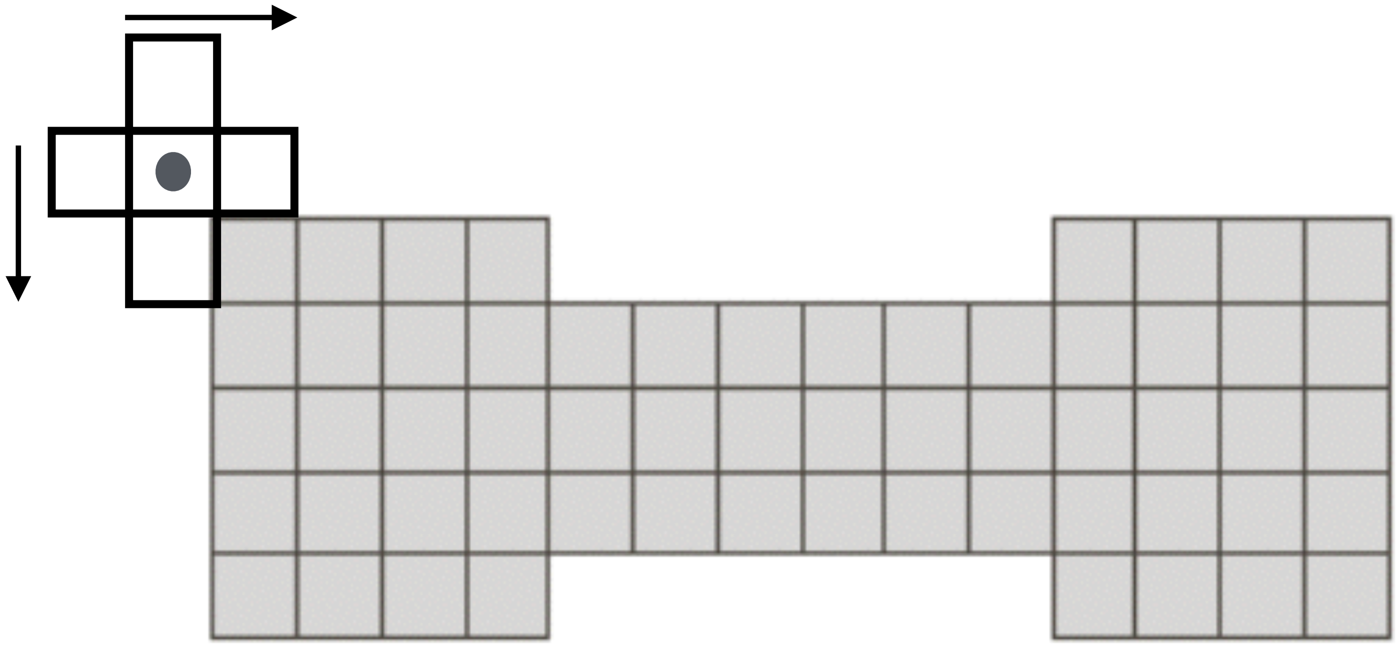

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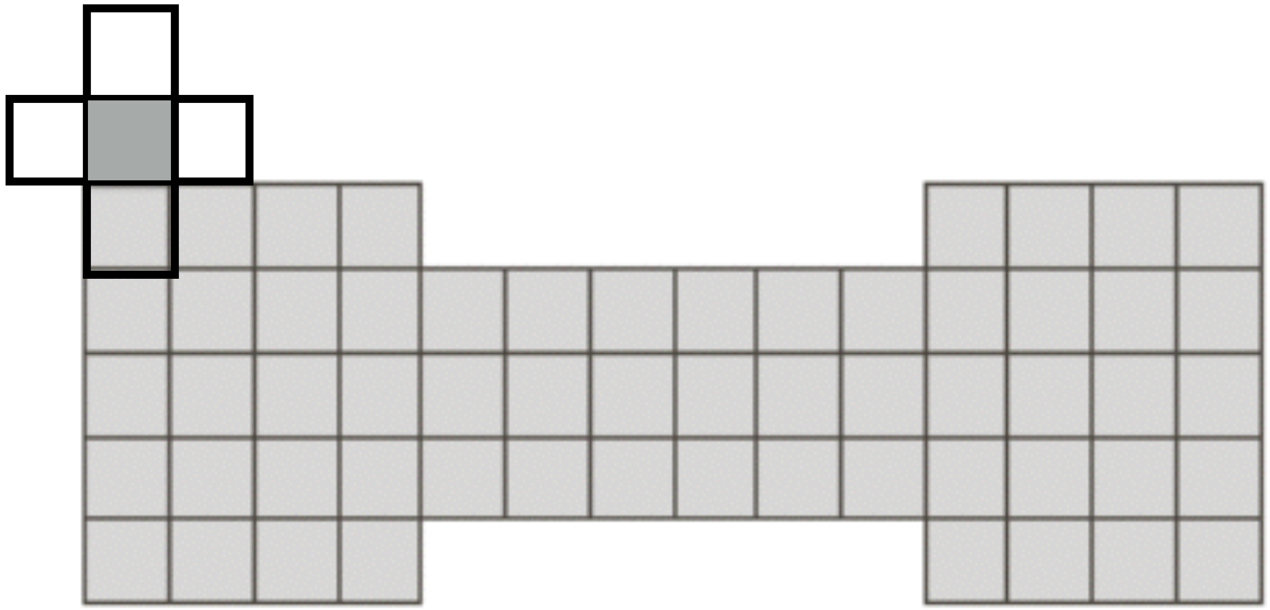

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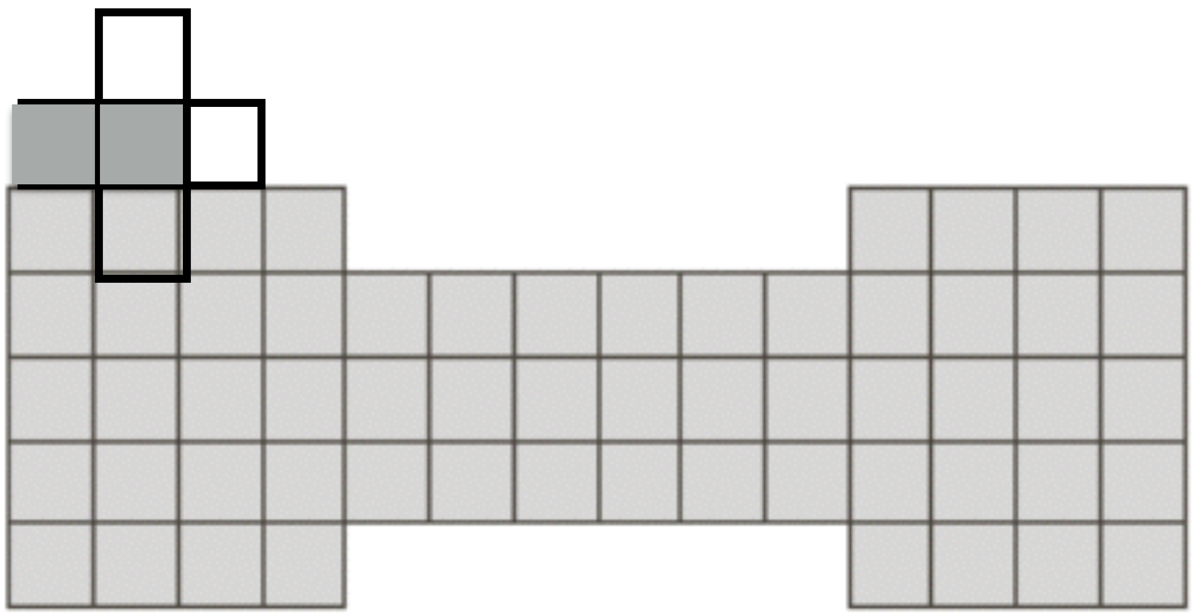

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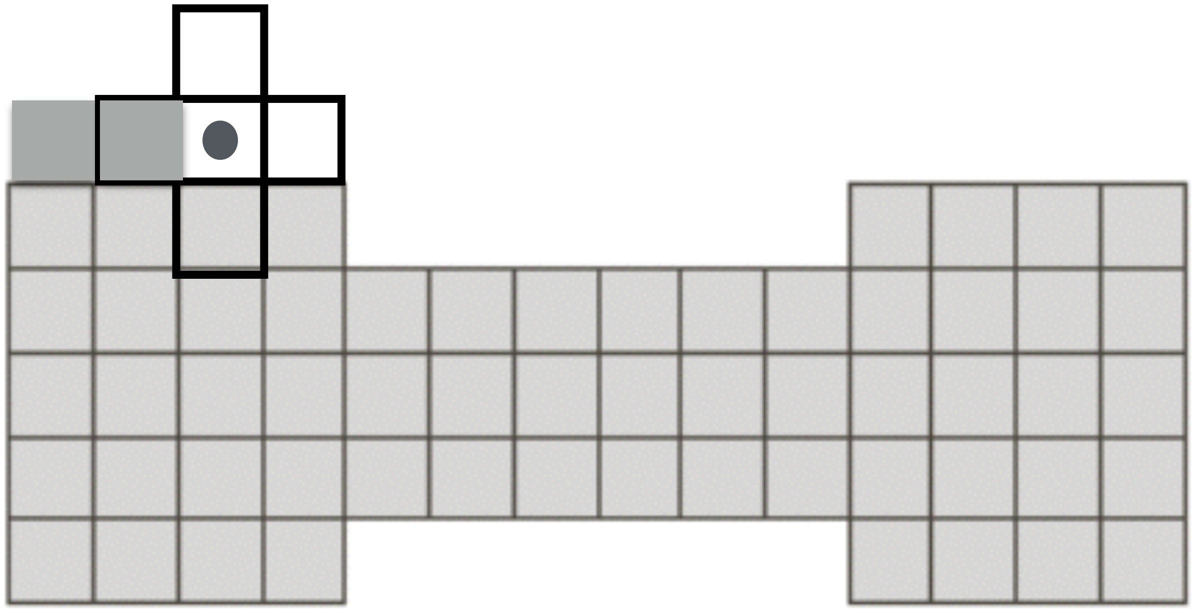

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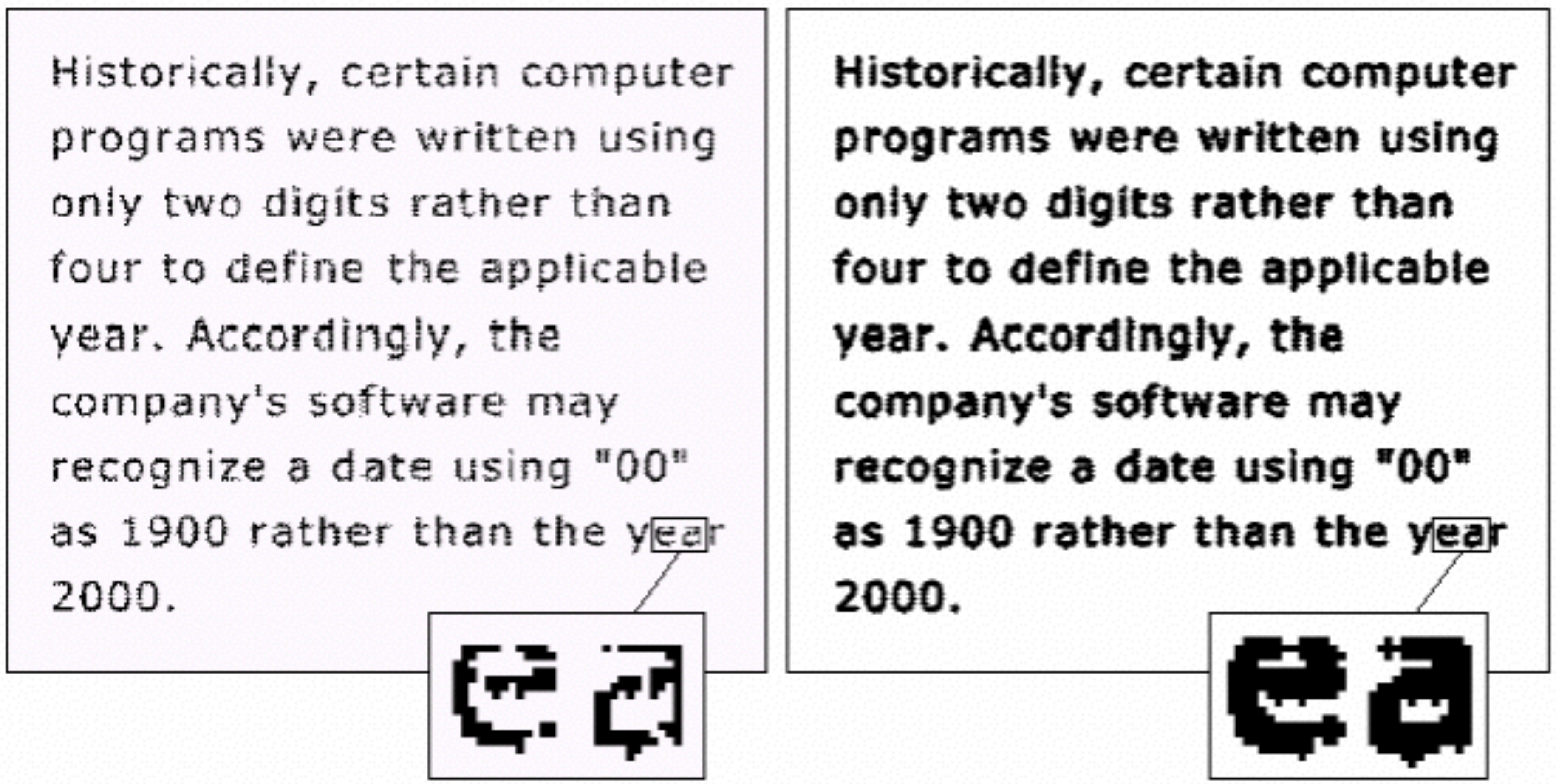
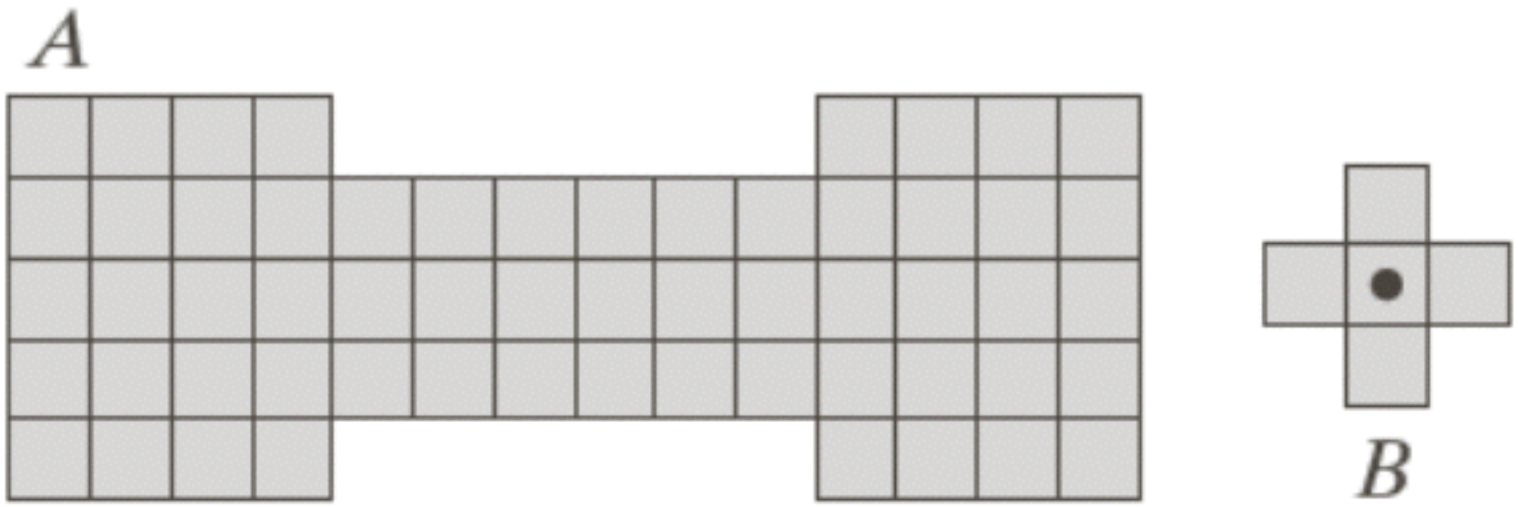


0	1	0
1	1	1
0	1	0

Erosion

- Erosion of ***A*** by ***B***

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



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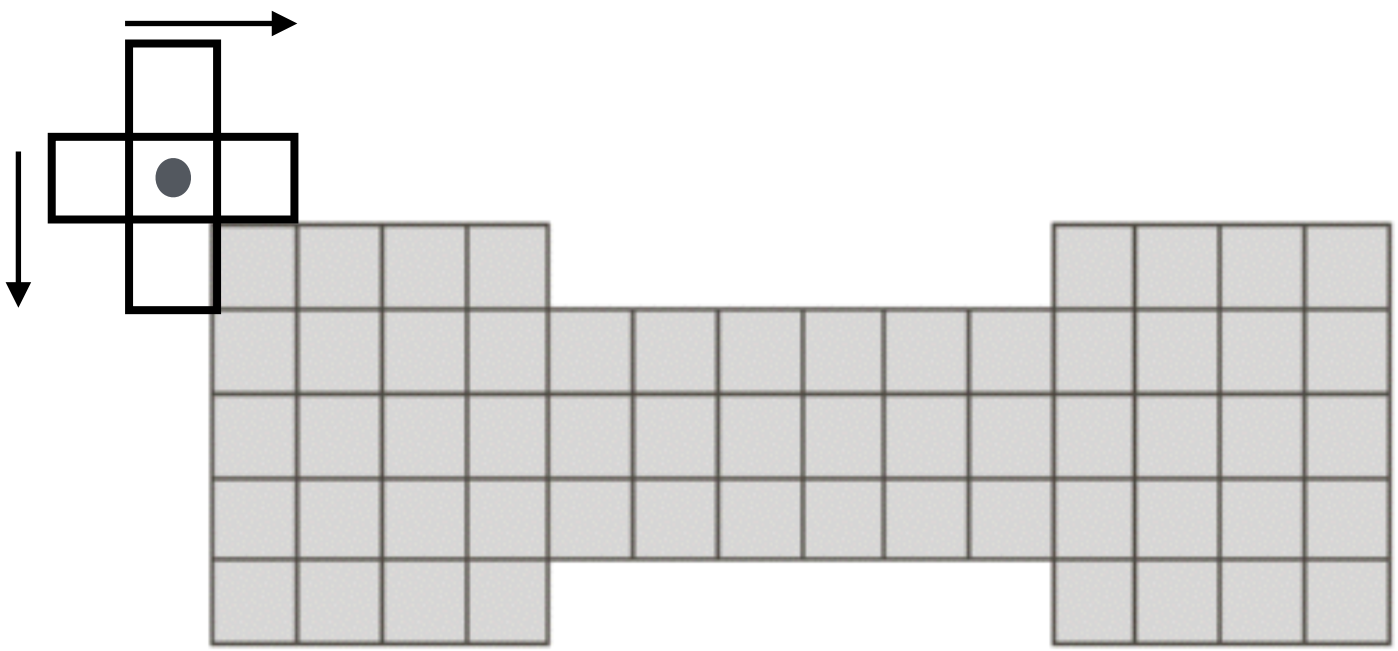

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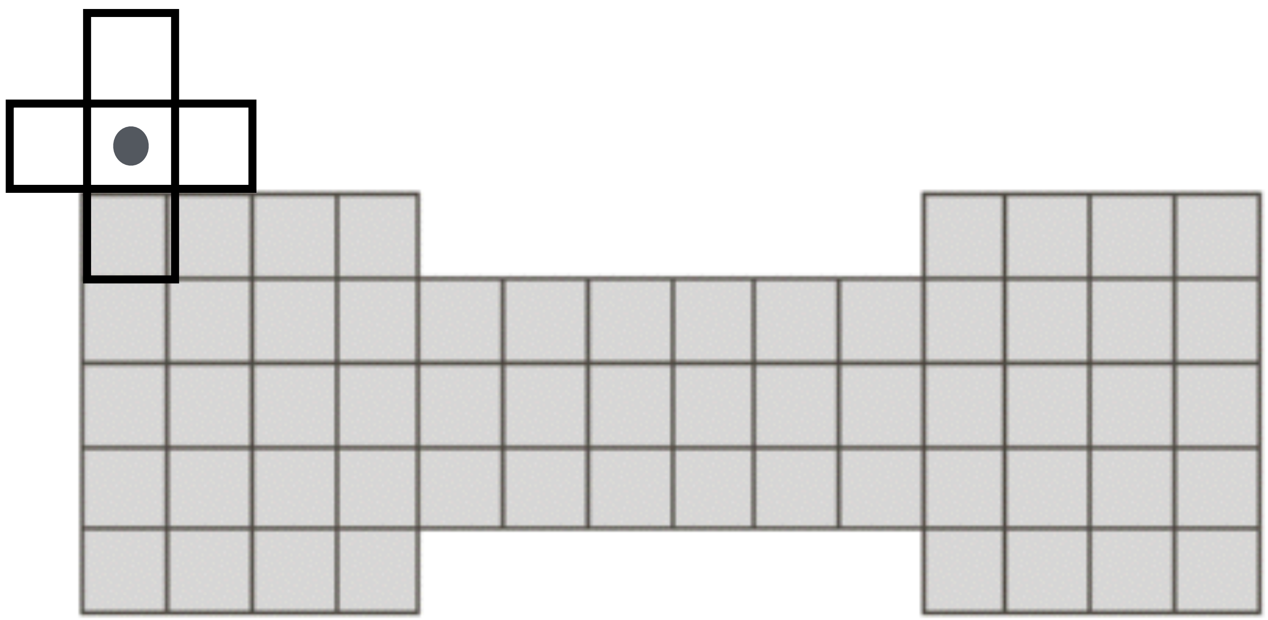

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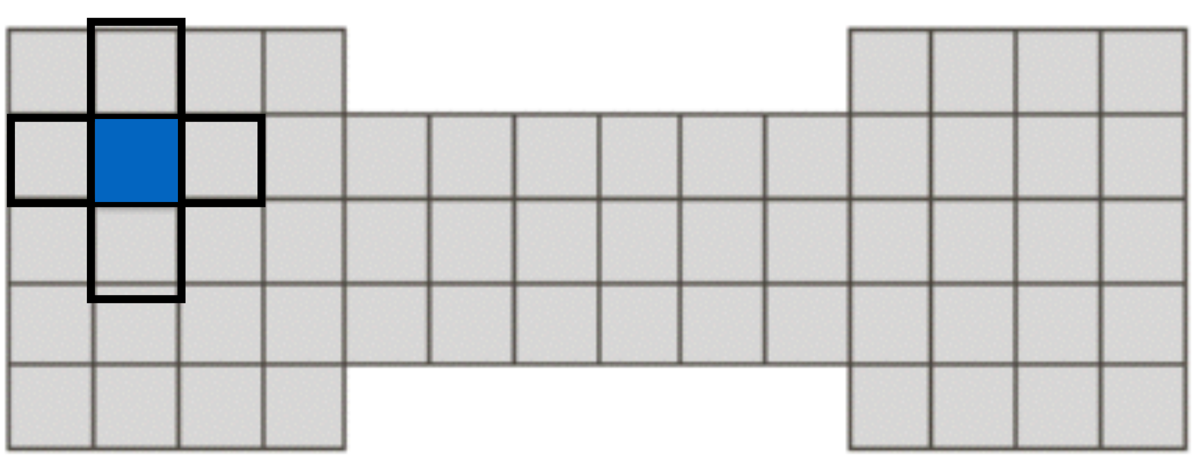

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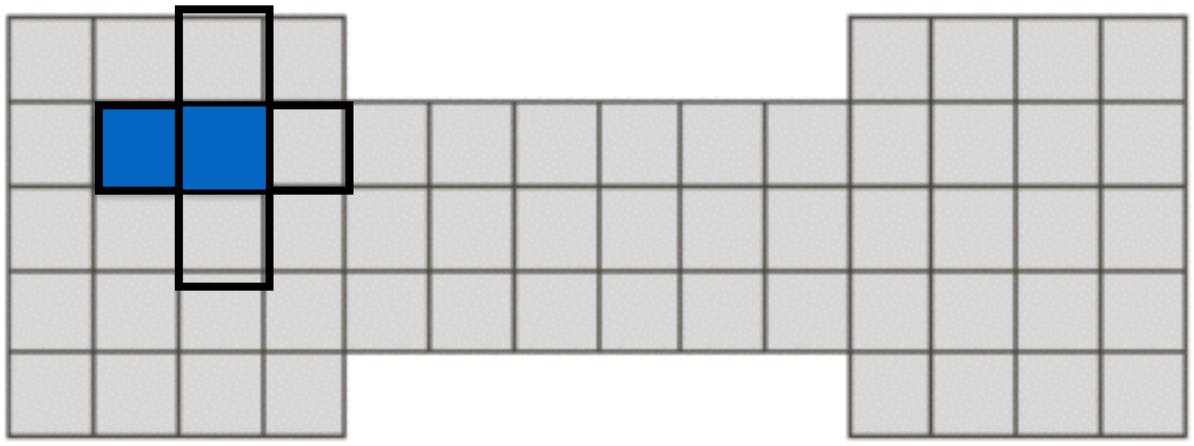

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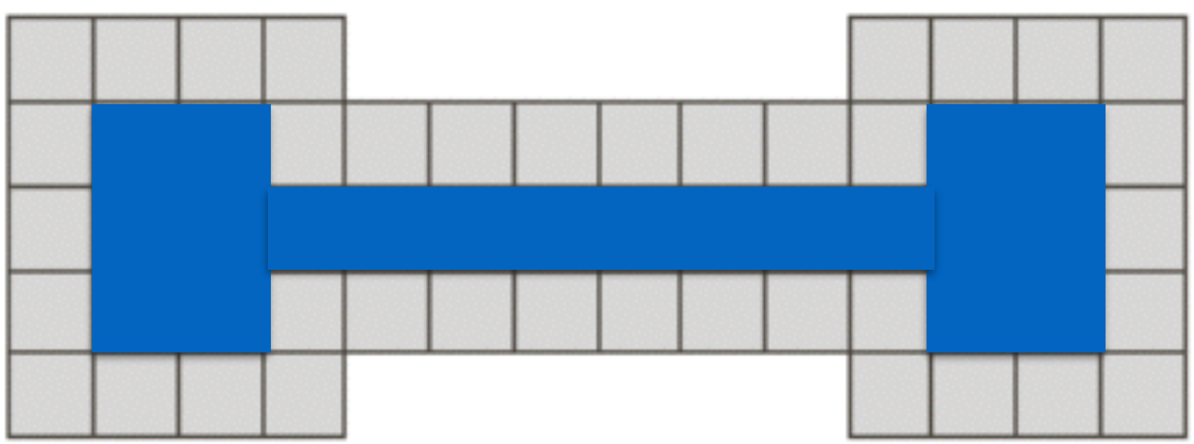
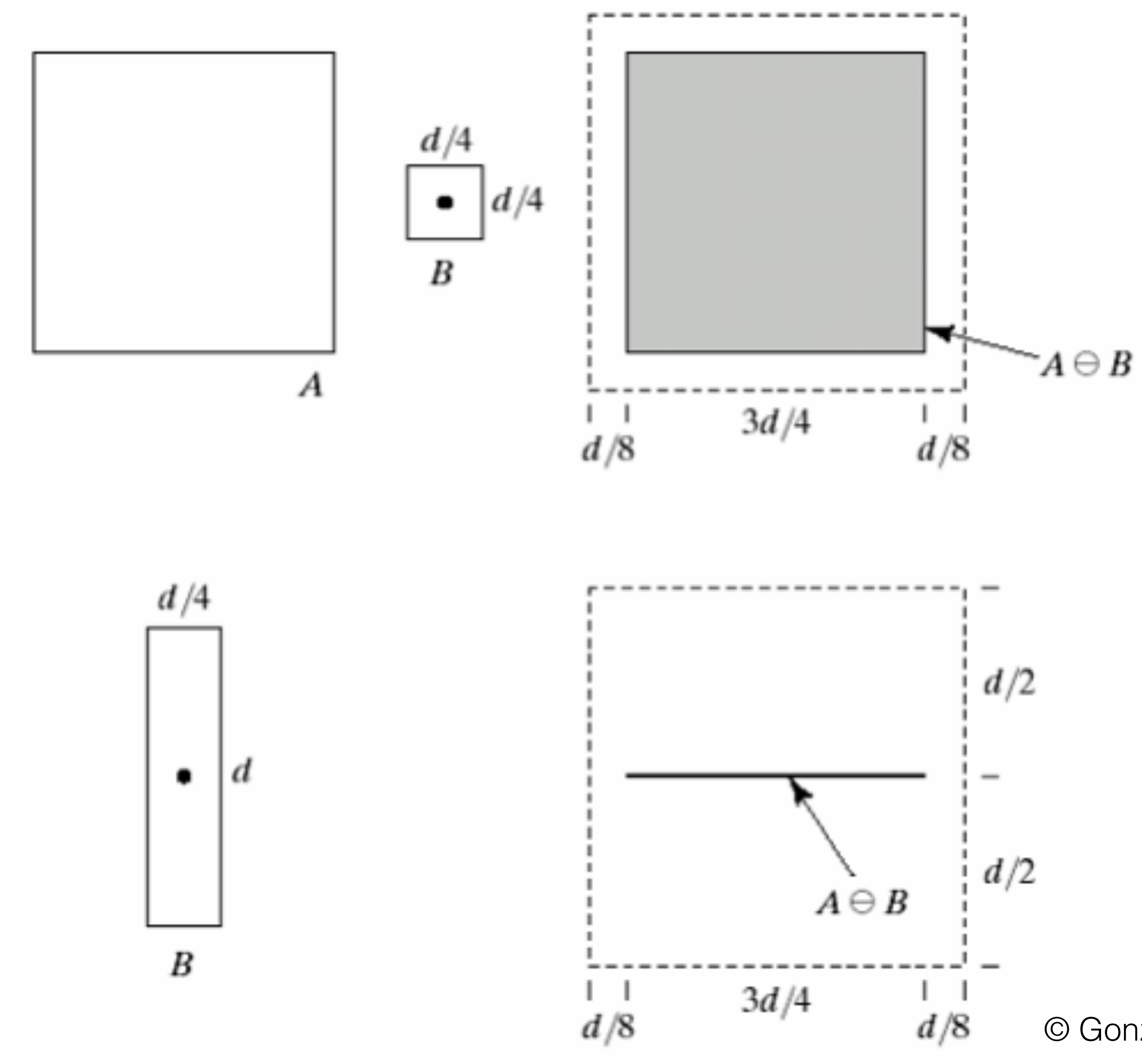


Erosion

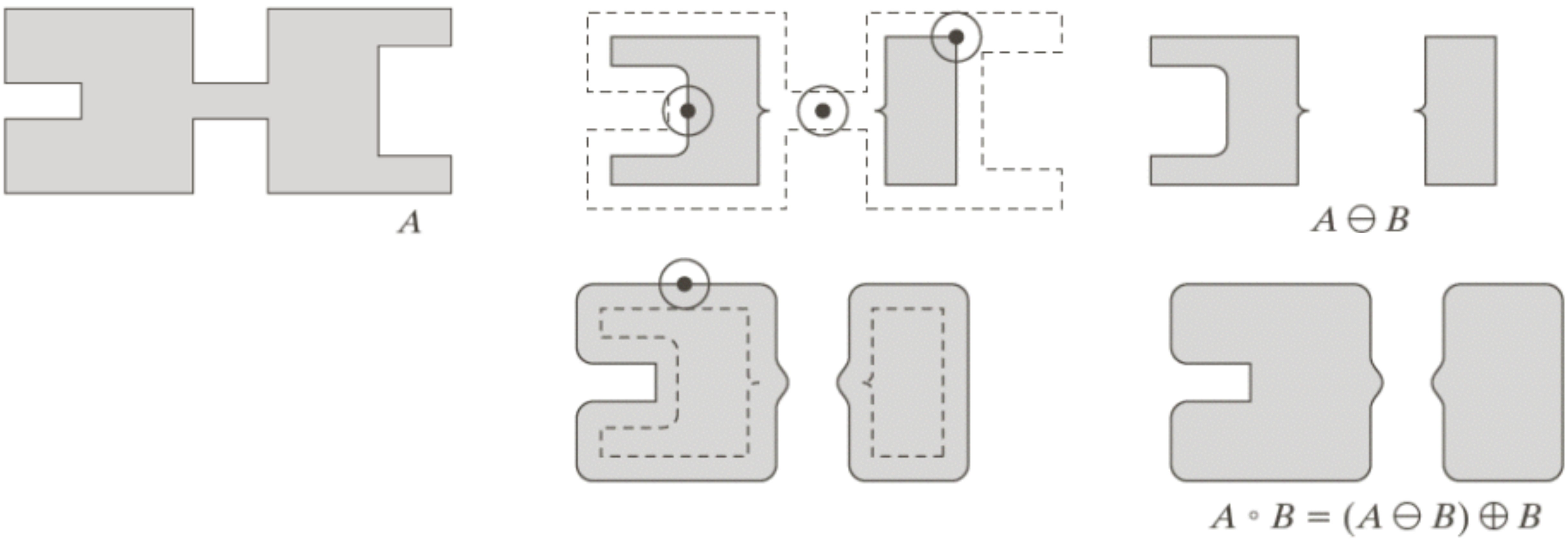
- Results can vary significantly depending on the shape of the structuring element



Opening

- Opening of ***A*** by ***B***

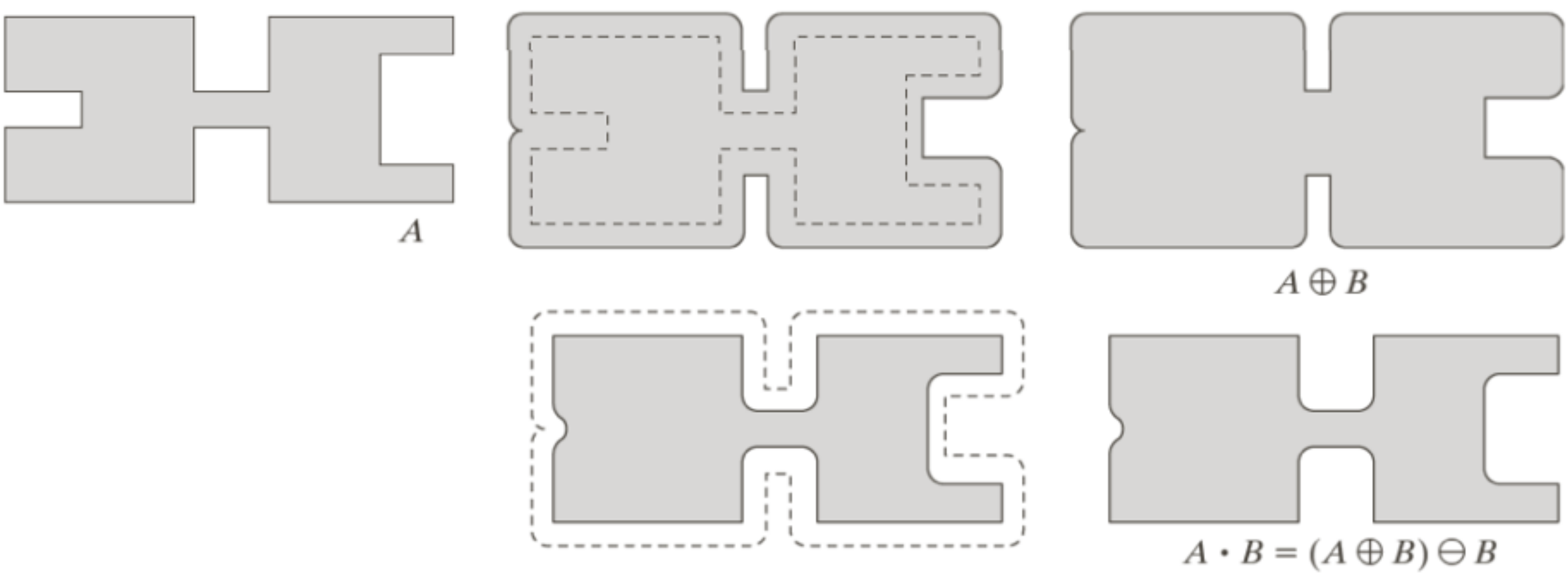
$$A \circ B = (A \ominus B) \oplus B$$



Closing

- Closing of ***A*** by ***B***

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



Opening and Closing

- **Opening:**
  - smoothes contours, breaks narrow segments in between shapes, removes sharp peaks
- **Closing:**
  - smoothes contours, fuses narrow breaks, closes holes

Duality relation

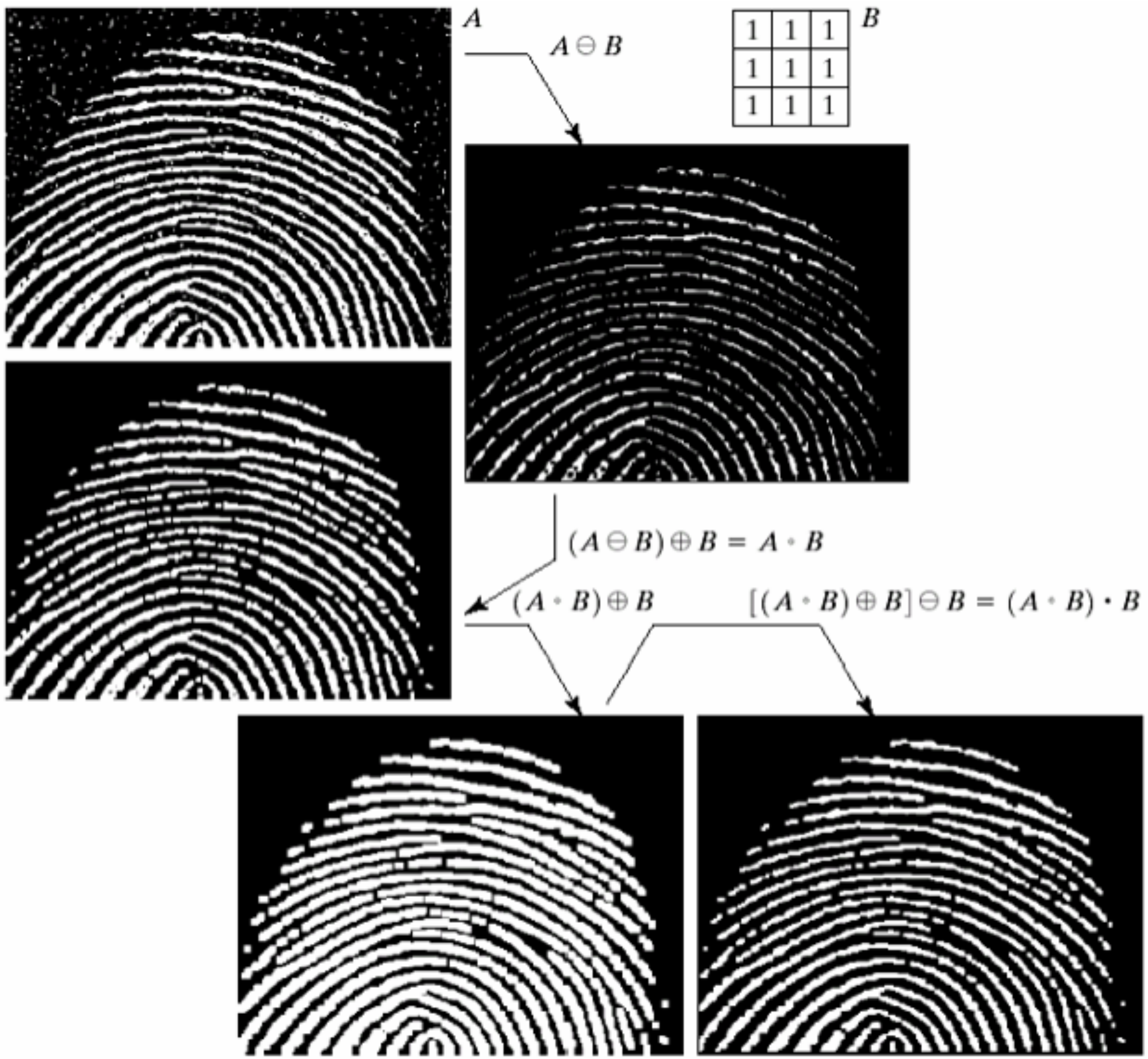
- Dilation and Erosion are dual operations

$$(A \ominus B)^c = A^c \oplus \hat{B}$$

- Opening and Closing are dual operations

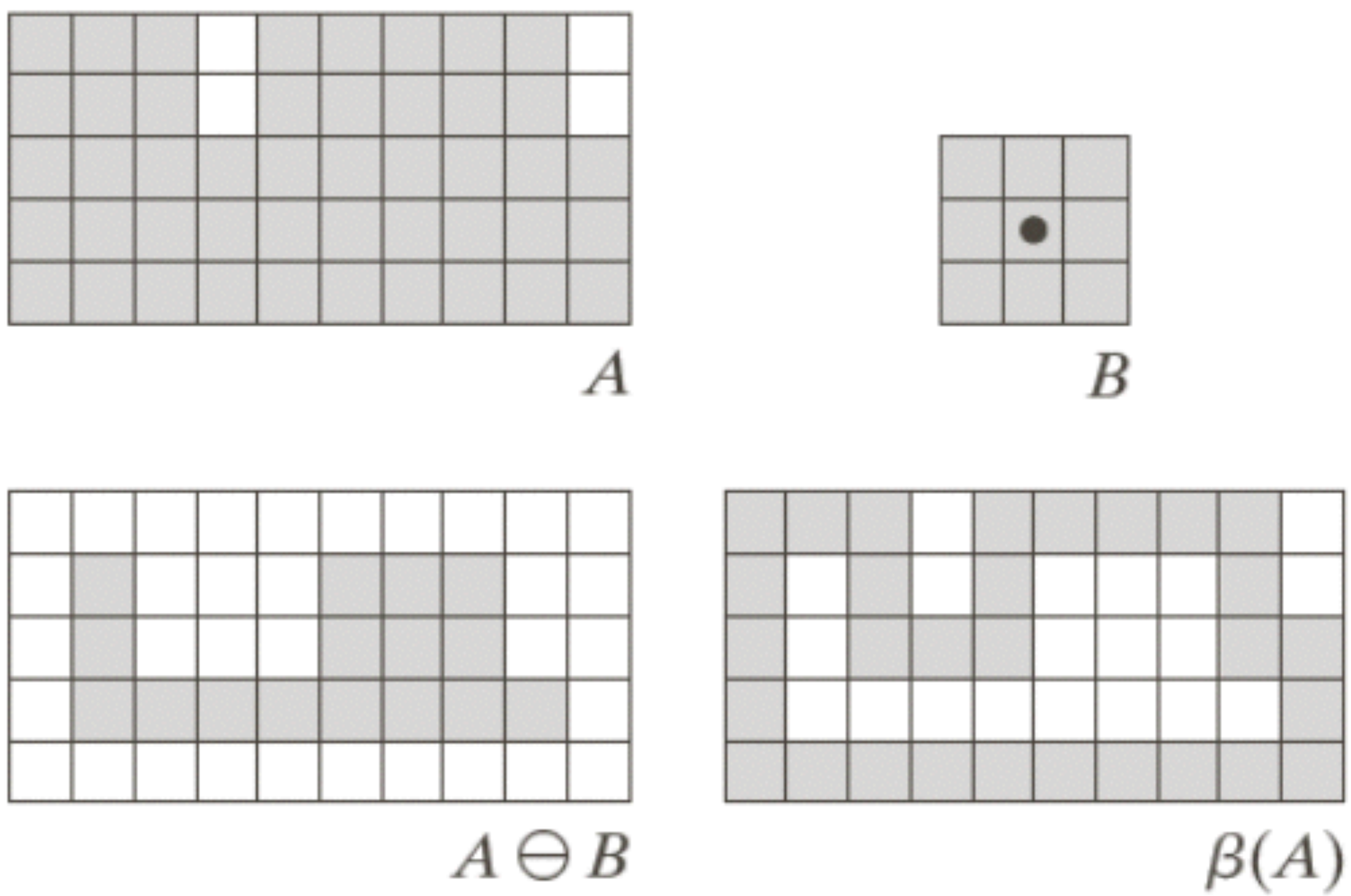
$$(A \bullet B)^C = A^C \circ \hat{B}$$

Processing pipeline



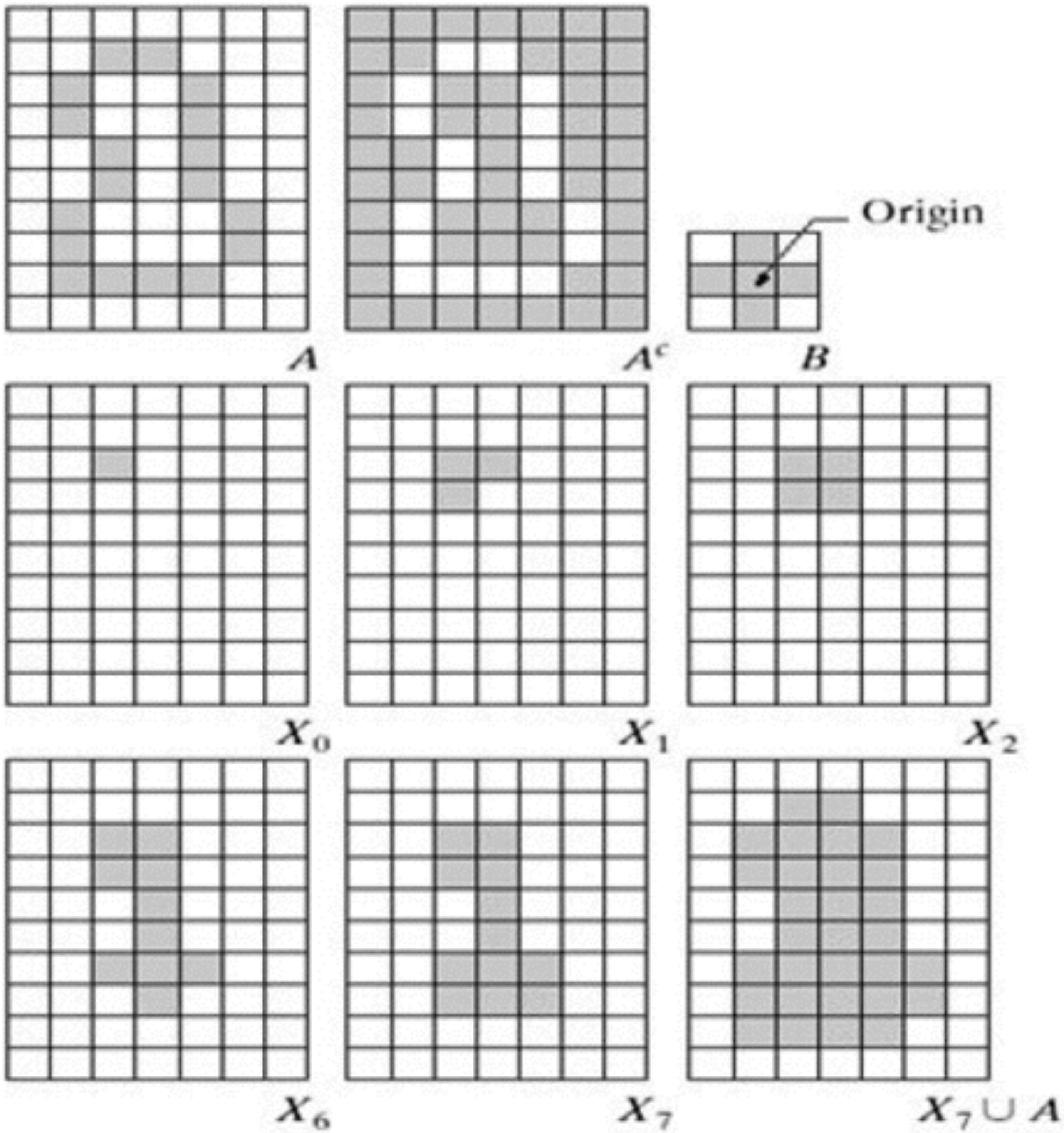
Boundary extraction

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



Region filling

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

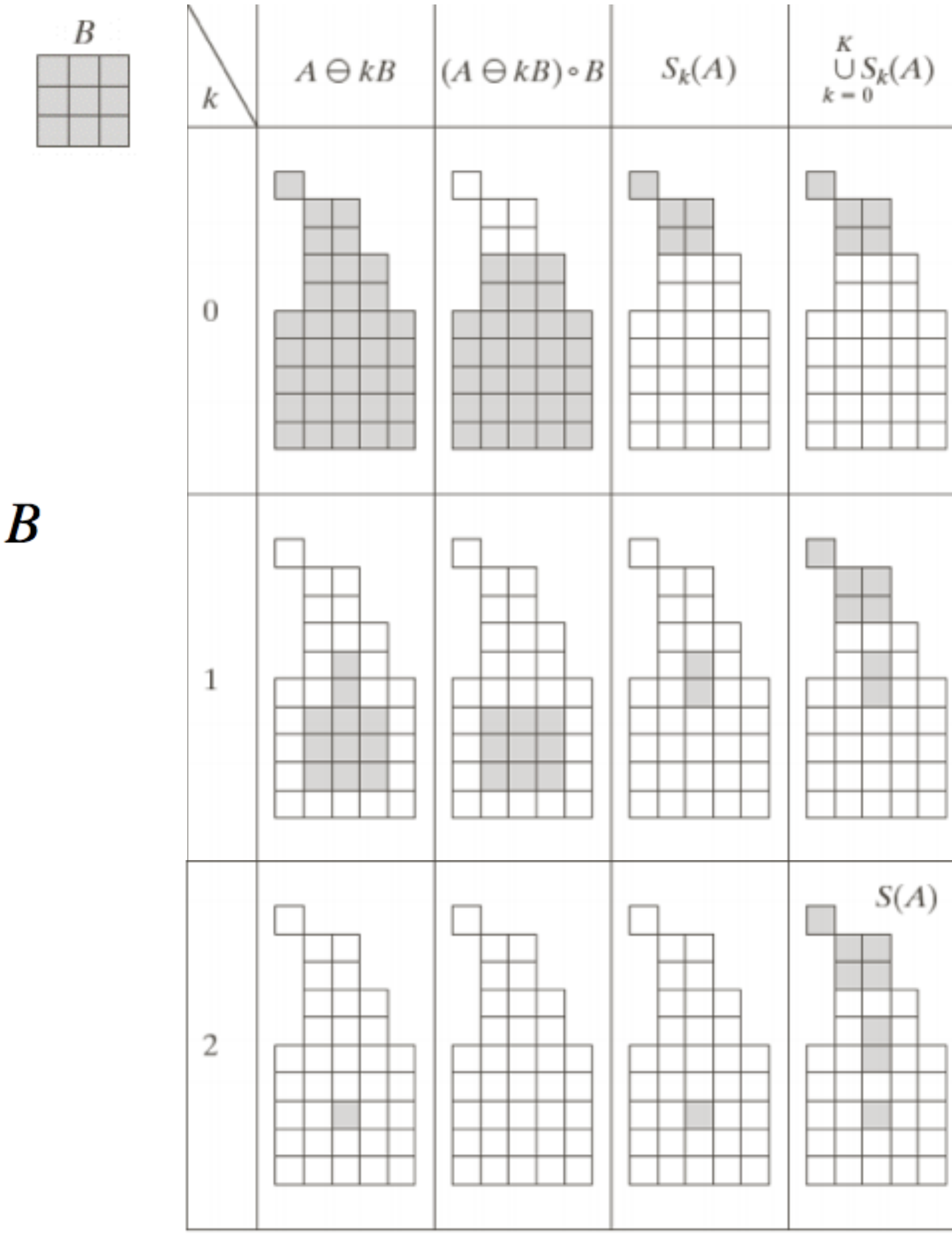


Skeletonization

$$S(A) = \bigcup_{k=0}^{K} S_k(A)$$

$$S_k(A) = (A \ominus kB) - (A \ominus kB) \circ \boldsymbol{B}$$

$$K = max\{k | (A \ominus kB) \neq \emptyset\}$$



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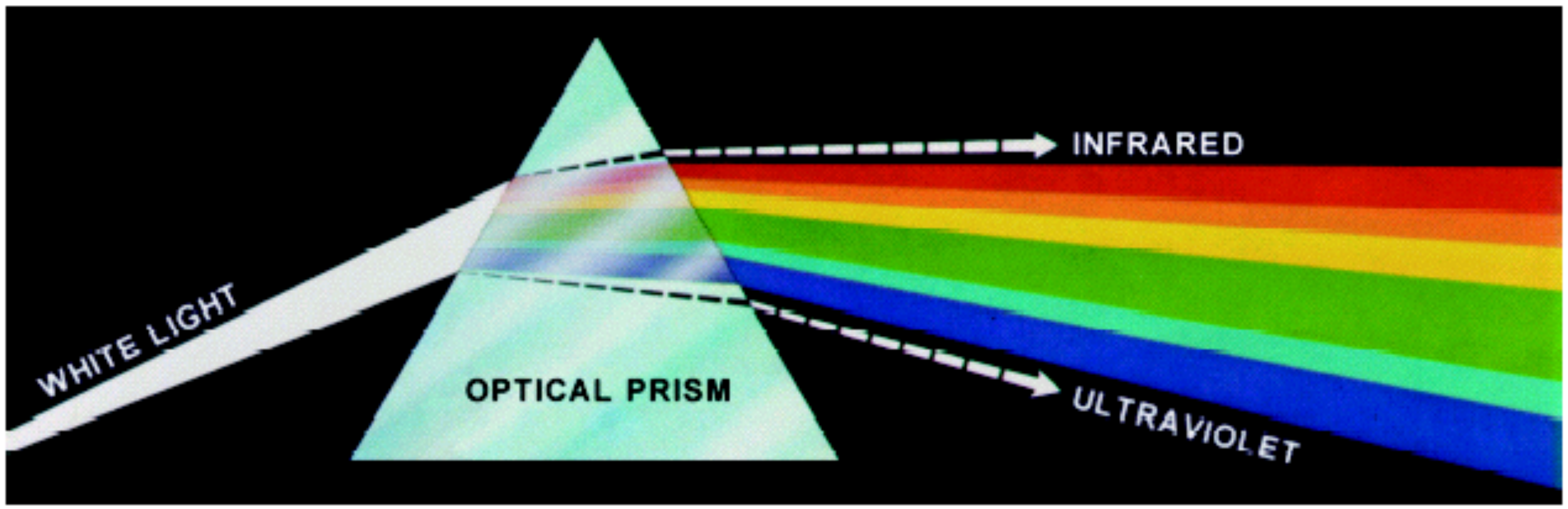
Lecture outline

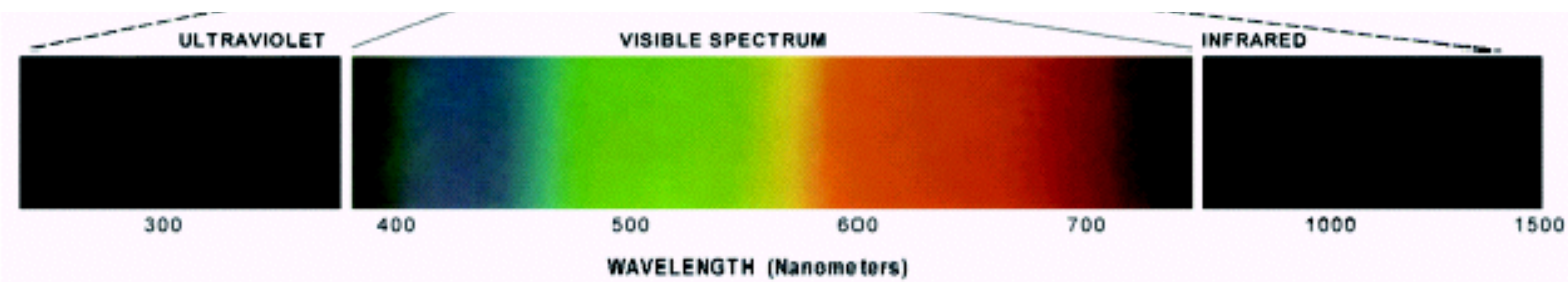
- Wiener filter
- Morphological image processing
- Color fundamentals

Why consider color?

- Color is a powerful descriptor for various tasks
  - tracking, segmentation, object detection and recognition
- Humans can distinguish thousands of color shades
  - as compared to only two dozens shades of gray

Color spectrum



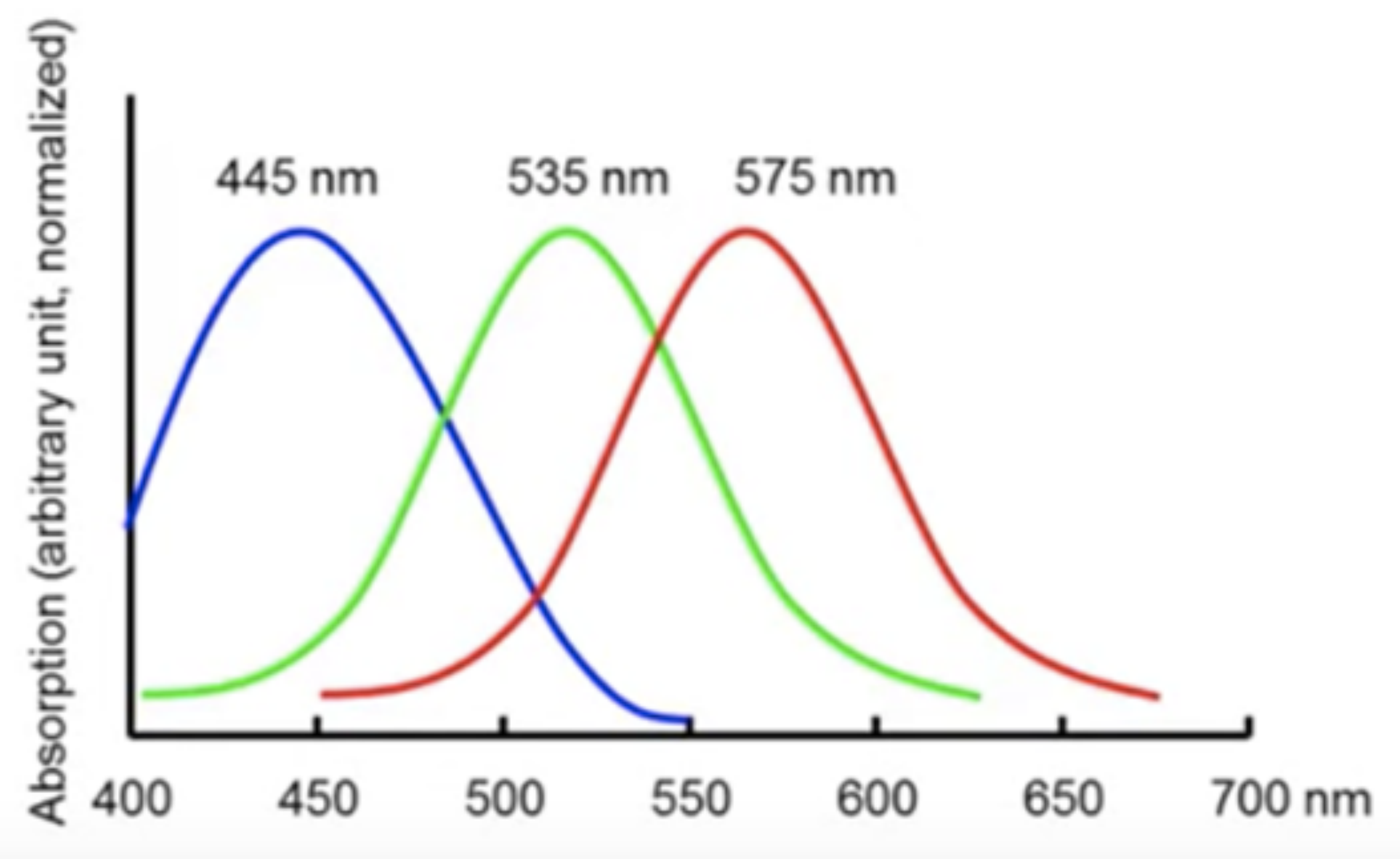


Color characterization

- **Achromatic light**
  - colorless light (intensity)
- **Chromatic light**
  - Radiance: amount of energy that flow from the light source (watts)
  - Luminance: amount of energy an observer perceives from a light source, (lumens) e.g. Far infrared light: high radiance, but 0 luminance

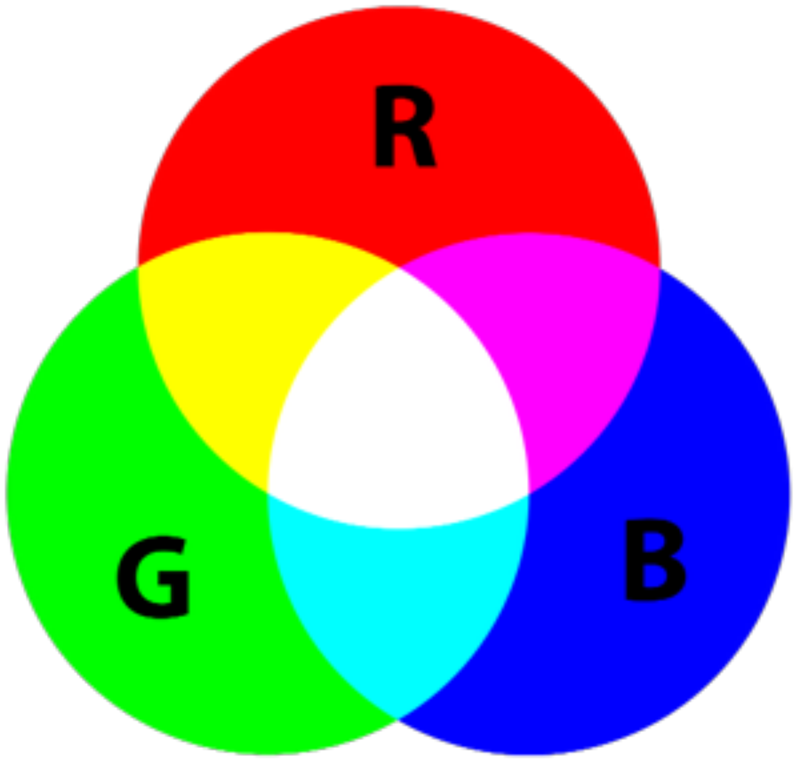
Color perception

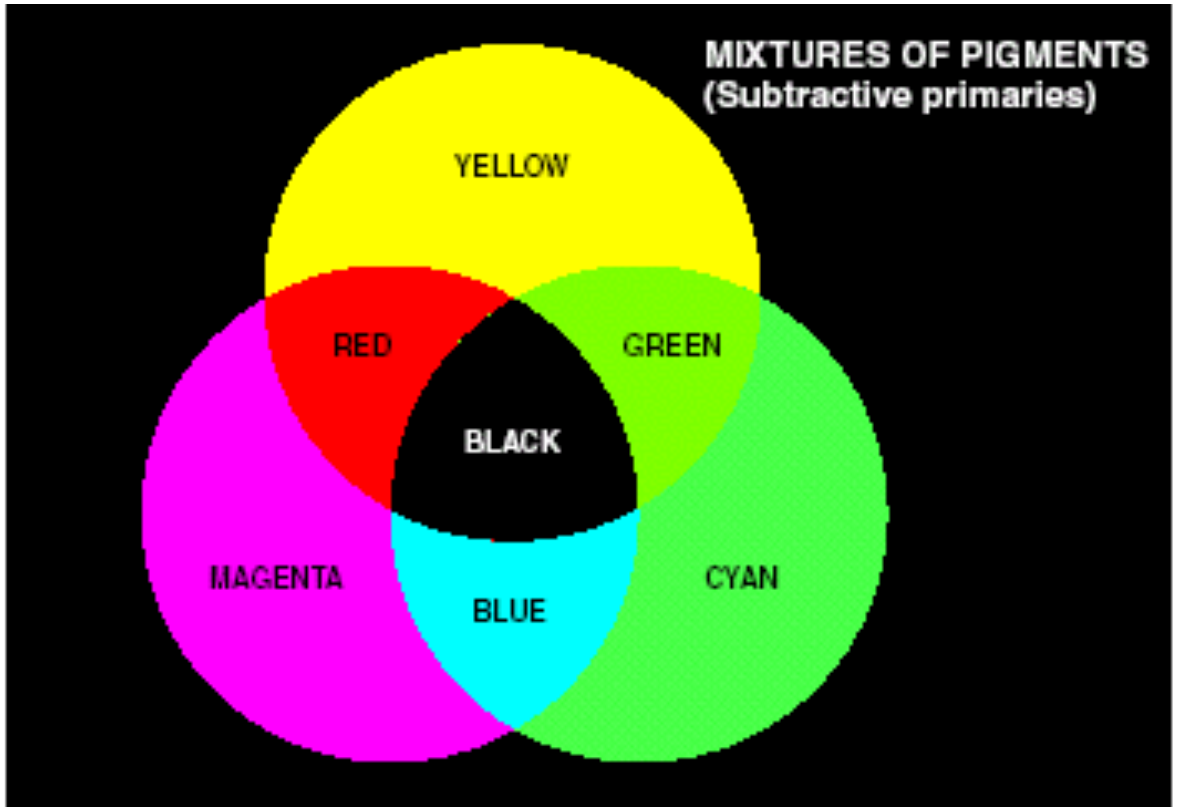
- The color of an object depends on the wavelength of the light **reflected** by it
- 6 - 7M cones => color sensors in our eyes



Primary and secondary colors

- Following the absorption trend in human eyes, colors are seen as a combination of the primary colors
  - Primary colors: Red (R), Green (G), Blue (B)
  - Secondary colors: Cyan (G+B), Yellow (R+G), Magenta (R+B)



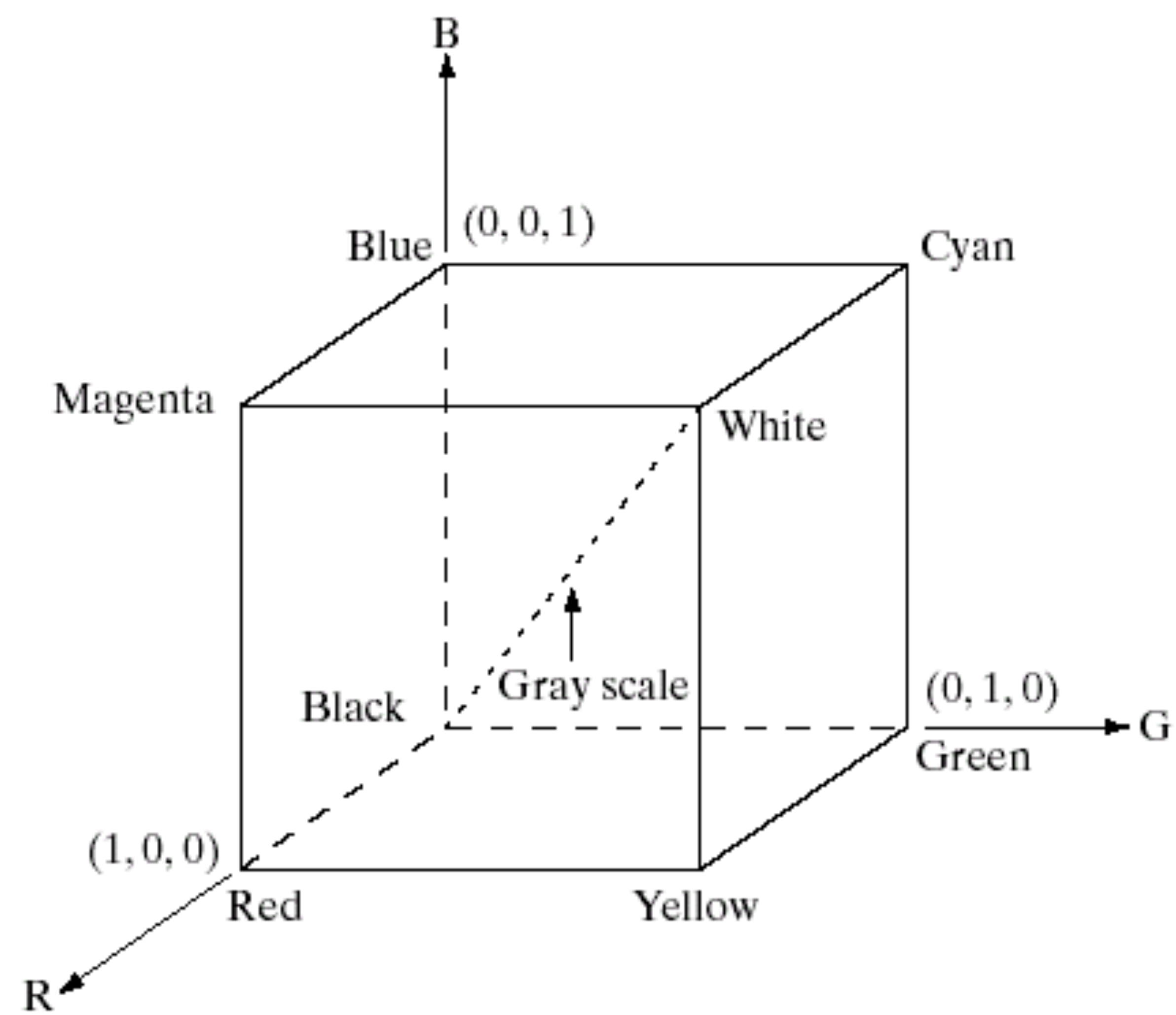


Distinguishability of colors

- **Brightness:** Intensity
- **Hue:** Indicates the dominant wavelength in a mixture of light
- **Saturation:** Purity of the dominant wavelength

Color models/spaces

- Why do we need color models?
- **RGB** color space
- 24-bit color image



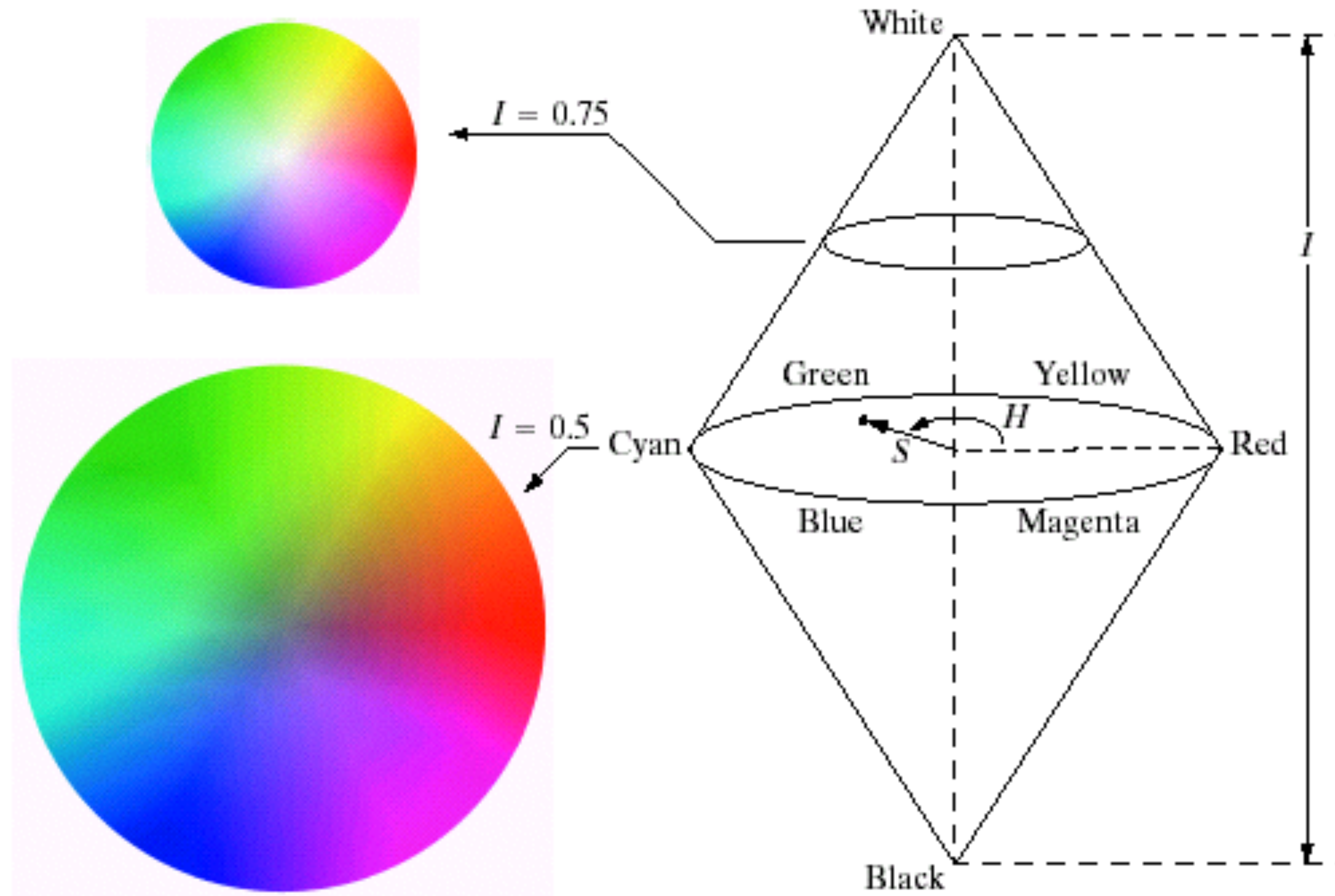
Color models/spaces

- **CMY** color space
- 1 = white
- Sometimes Black is added => CMYK
- Used in printing

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

Color models/spaces

- **HSI** color space
- Matches human description



RGB to HSI

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases}$$

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

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

$$I = \frac{1}{3}(R+G+B)$$

It is assumed that the RGB values have been normalized to the range [0,1]

Color image processing

- Most grayscale methods we studied extend to color images in a straight-forward manner

- Two main approaches of color image processing
  - treat pixel value as a vector [R G B]
  - process each channel as a grayscale image