ECE 172A: Introduction to Image Processing
Morphological Processing: Part I

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Outline

- Morphology: Introduction
- Basic Definitions
- Erosion and Dilation
- Opening and Closing
- Distance Map and Watershed
- Graylevel Morphology
- Morphological Filtering

Morphology: Introduction

What does morphology even mean?

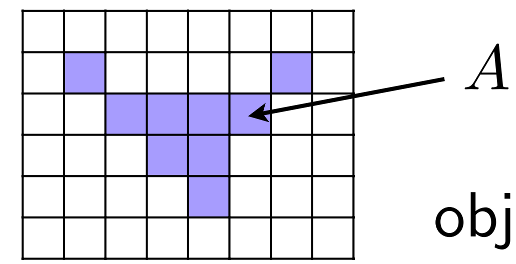
The study of shape and structure

- Language: Set Theory
  - Binary images (bitmap)

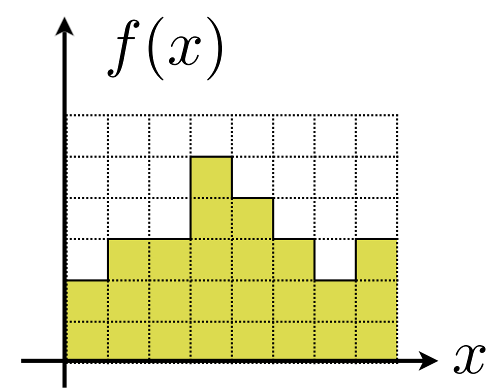
    $\Longrightarrow$ Sets of points in 2D space ($\mathbb{Z}^2$)
  - Quantized graylevel images

    $\Longrightarrow$ Sets of points in 3D space ($\mathbb{Z}^3$)

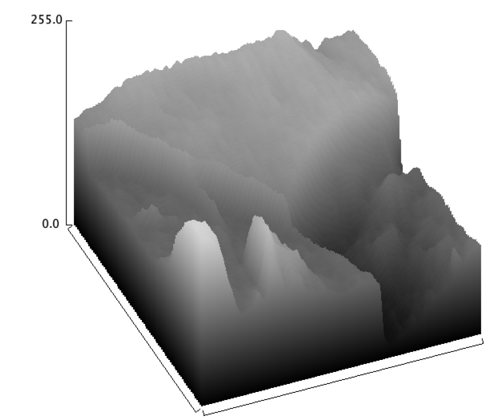
    $(x, y, Q(f(x, y))) \in \mathbb{Z}^3$



object vs. background



1D signal



2D image

- Types of transformations
  - Set-theoretic: Union, intersection, etc.
  - With a stucturing element: dilation, erosion

Morphology: Application Areas

Classification of objects or image features based on shape

- Examples
  - Extraction of objects with a specific shape
  - Extraction with a size smaller or greater than a limit
  - Contour detection
- Typical stages in an image-processing pipeline where it is useful
  - Preprocessing: noise reduction, simplification
  - Feature detection
  - Segmentation: Contour extraction
  - Postprocessing: shape cleaning and simplification
- Main application areas
  - Material sciences, mineralogy, granulometry
  - Medicine and biology: Cell counting, cytology, gel electrophoresis, microarrays
  - Robotics and machine vision

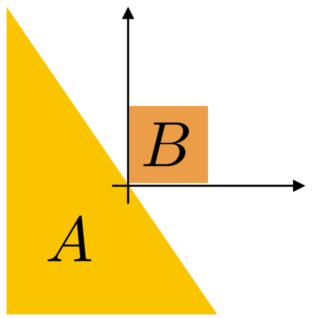
Basic Definitions

- "Universe" set

  $\mathbb{E}$ is the set of every possible element (e.g., $\mathbb{E} = \mathbb{Z}^2$ or $\mathbb{E} = \mathbb{Z}^3$ or $\mathbb{E} = \mathbb{R}^2$)

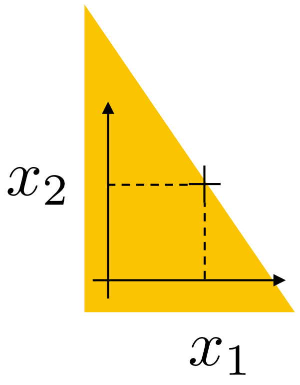
- Sets and subsets

  $A, B \subset \mathbb{E}$ Elements: $a = (a_1, a_2) \in A$, $b = (b_1, b_2) \in B$



- Translation by $x = (x_1, x_2)$

  $(A)_x = \{c \, : \, c = a + x, a \in A\}$



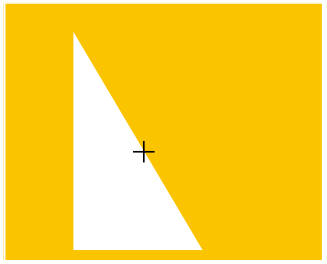
Basic Definitions (cont'd)

- Reflection or symmetry

$$A^{\mathrm{s}} = \{x \in \mathbb{E} \, : \, x = -a, a \in A\}$$

- Complement

$$A^{\mathrm{c}} = \{x \in \mathbb{E} \, : \, x \in \mathbb{E} \setminus A\}$$

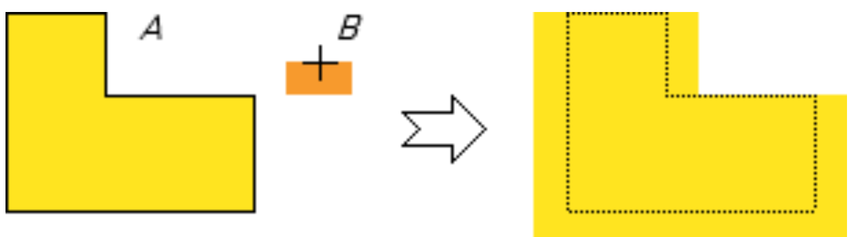


Dilation and Erosion in $\mathbb{R}^2$

- Structuring element B   B^s

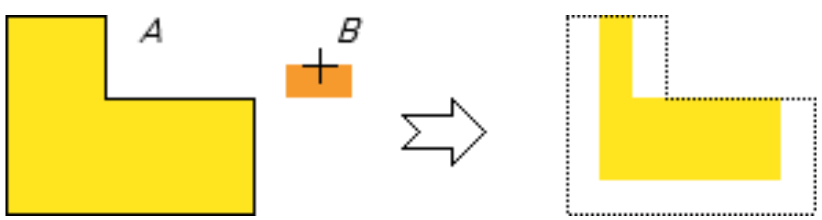
- Dilation

$$A \oplus B = \{x \in \mathbb{E} \; : \; (B^s)_x \cap A \neq \varnothing\} = \bigcup_{x \in A} (B)_x$$

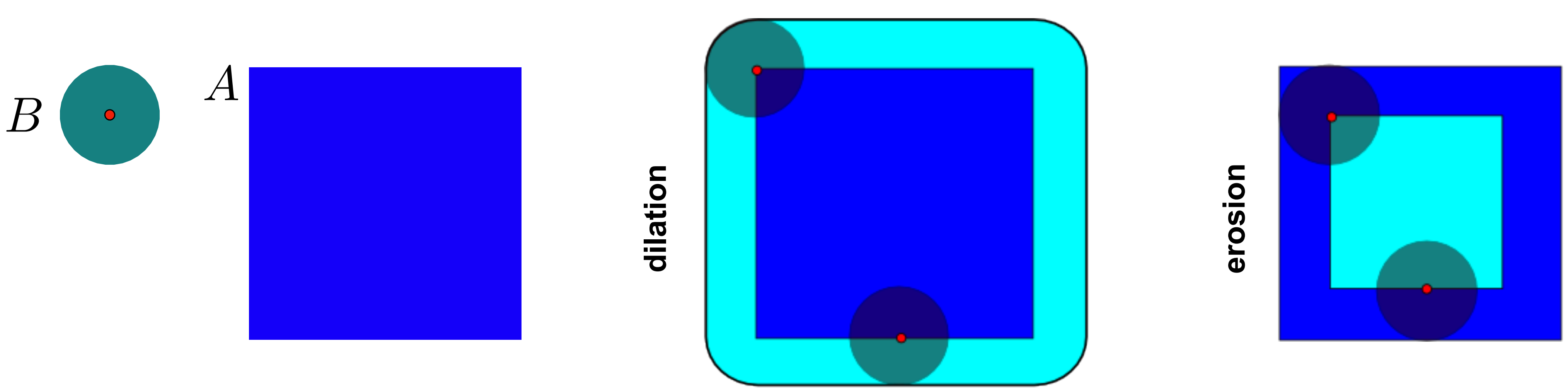


- Erosion

$$A \ominus B = \{x \in \mathbb{E} \; : \; (B)_x \subset A\} = \bigcap_{x \in B^s} (A)_x$$



- Example



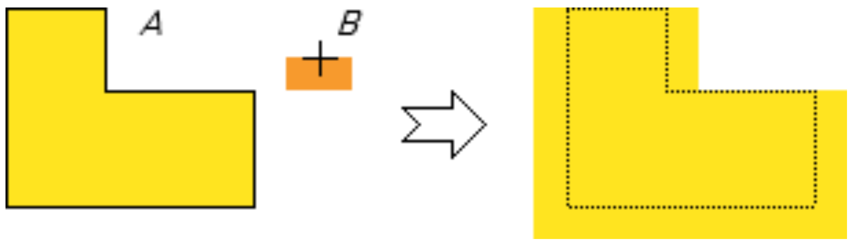
Dilation and Erosion in $\mathbb{R}^2$

- Structuring element B 

 B^{s}

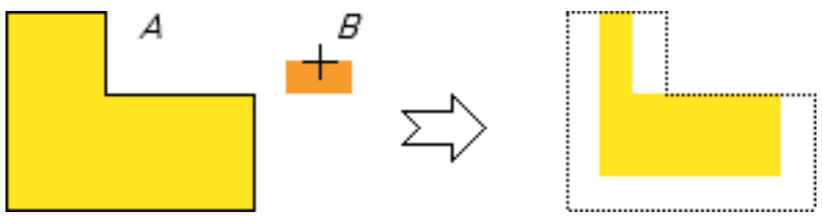
- Dilation

$$A \oplus B = \{x \in \mathbb{E} \; : \; (B^{\mathrm{s}})_x \cap A \neq \varnothing\} = \bigcup_{x \in A} (B)_x$$



- Erosion

$$A \ominus B = \{x \in \mathbb{E} \; : \; (B)_x \subset A\} = \bigcap_{x \in B^{\mathrm{s}}} (A)_x$$



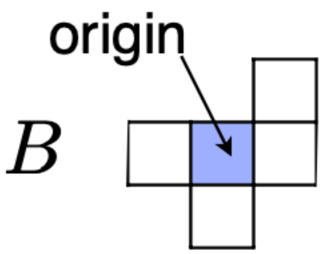
- Duality relations

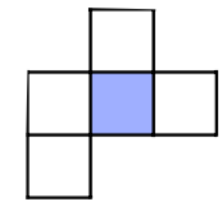
$$A \ominus B = (A^{\mathrm{c}} \oplus B^{\mathrm{s}})^{\mathrm{c}}$$ "Erosion = Dilation of complement"

$$A \oplus B = (A^{\mathrm{c}} \ominus B^{\mathrm{s}})^{\mathrm{c}}$$ "Dilation = Erosion of complement"

Dilation and Erosion in $\mathbb{Z}^2$

- Structuring element

B 

B^{s} 

- Dilation

$$A \oplus B = \{x \in \mathbb{E} \,:\, (B^{\mathrm{s}})_x \cap A \neq \varnothing\} = \bigcup_{x \in A} (B)_x$$

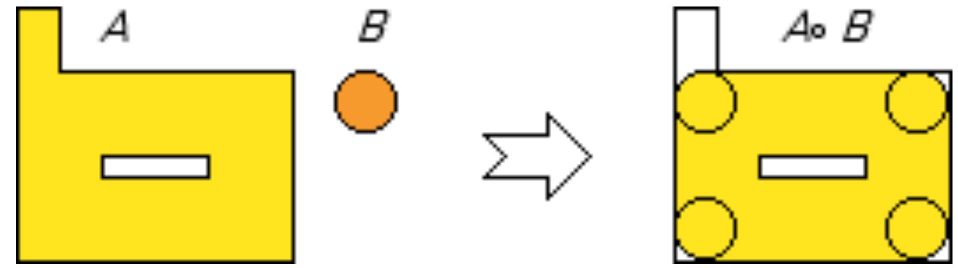
- Erosion

$$A \ominus B = \{x \in \mathbb{E} \,:\, (B)_x \subset A\} = \bigcap_{x \in B^{\mathrm{s}}} (A)_x$$

Opening

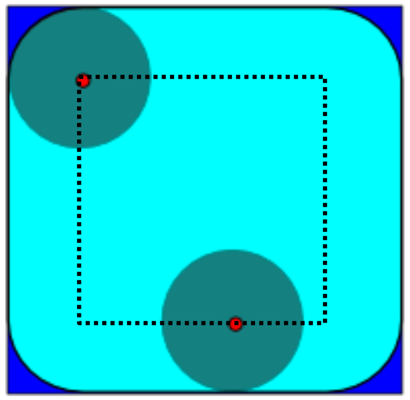
- Opening operator

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



  - Interpretation 1: "Smallest" set that contains a given erosion $A \ominus B$
  - Interpretation 2: Union of all shifted B's included in A

$$A \circ B = \bigcup_{x \in \mathbb{E}} \{(B)_x \;:\; (B)_x \subset A\}$$

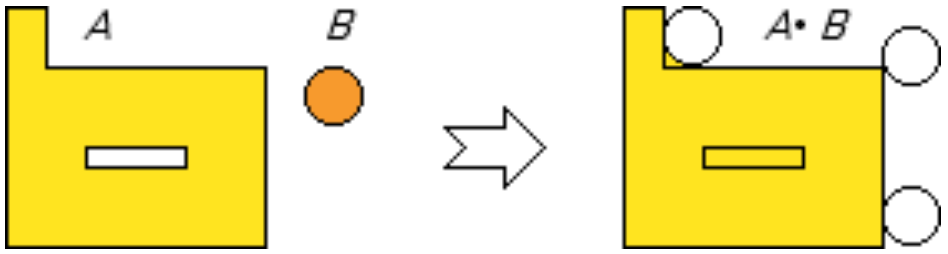


- Properties
  - Subset $\quad A \circ B \subset A$
  - Invariance to origin $\quad A \circ (B)_x = A \circ B$ for all $x \in \mathbb{E}$
  - Idempotence $\quad (A \circ B) \circ B = A \circ B$
  - Order preservation $\quad C \subset D \quad \Rightarrow \quad (C \circ B) \subset (D \circ B)$

Closing

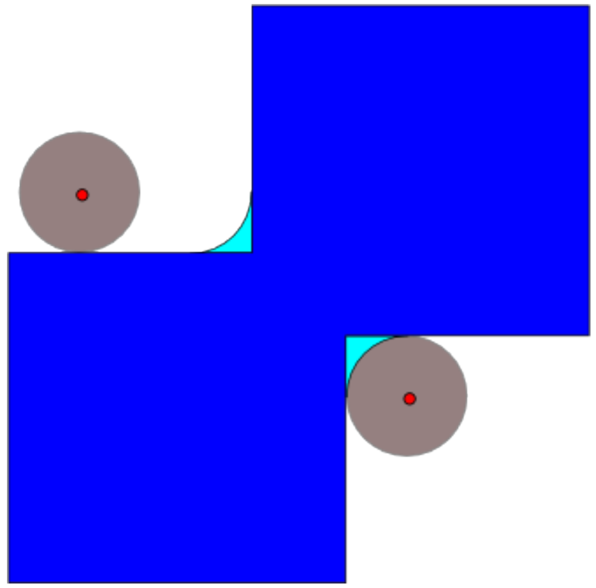
- Closing operator

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



  - Interpretation 1: "Largest" set that contains a given dilation $A \oplus B$
  - Interpretation 2: Complement of all shifted B^{s}'s included in A^{c}

  $$A \bullet B = \left(\bigcup_{x \in \mathbb{E}} \{ (B^{\mathrm{s}})_x \; : \; (B^{\mathrm{s}})_x \subset A^{\mathrm{c}} \} \right)^{\mathrm{c}}$$



- Properties
  - Superset $\quad A \bullet B \supset A$
  - Invariance to origin $\quad A \bullet (B)_x = A \bullet B$ for all $x \in \mathbb{E}$
  - Idempotence $\quad (A \bullet B) \bullet B = A \bullet B$
  - Order preservation $\quad C \subset D \quad \Rightarrow \quad (C \bullet B) \subset (D \bullet B)$

Duality Relations

- Erosion and dilation

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

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

- Opening and closing

$$A \circ B = (A^{\mathrm{c}} \bullet B^{\mathrm{s}})^{\mathrm{c}}$$

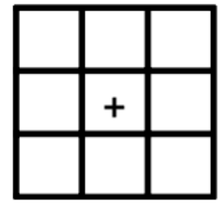
$$A \bullet B = (A^{\mathrm{c}} \circ B^{\mathrm{s}})^{\mathrm{c}}$$

Distance Map and Watershed

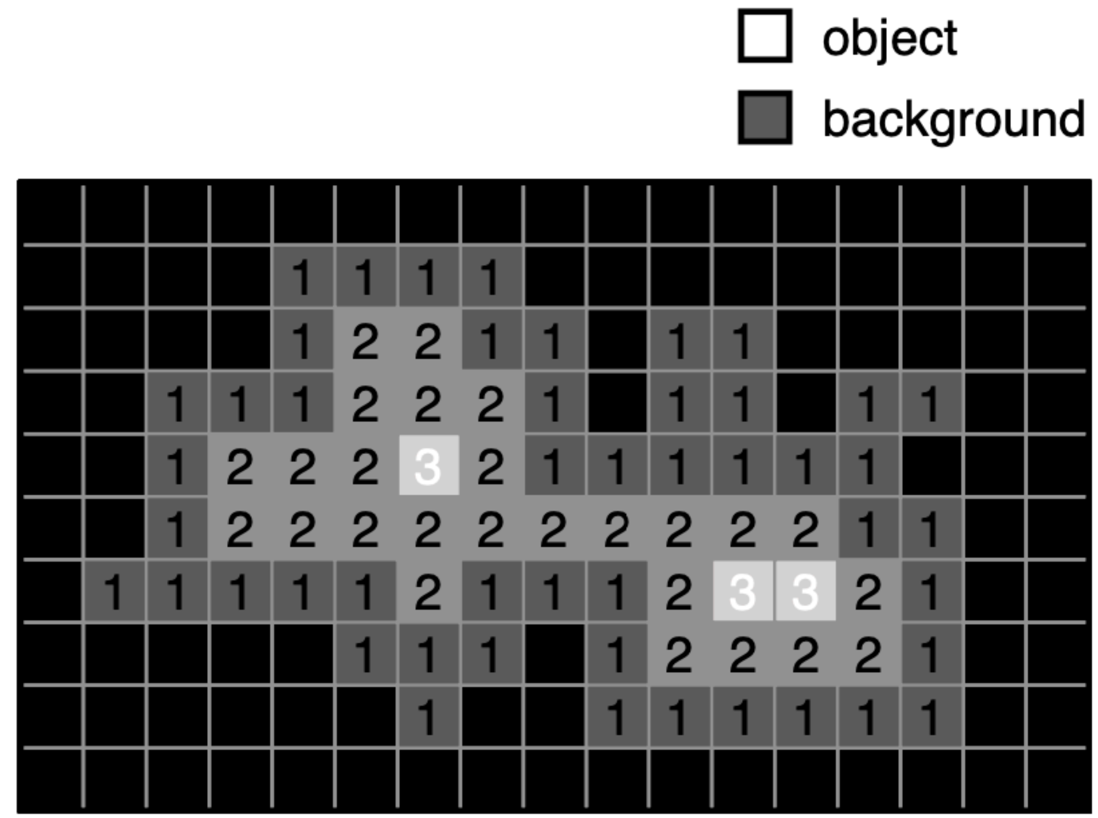
$$A_0[\mathbf{k}] = \begin{cases} 1, & \mathbf{k} \in \textbf{object} \\ 0, & \mathbf{k} \in \textbf{background} \end{cases}$$

$$n = 0$$

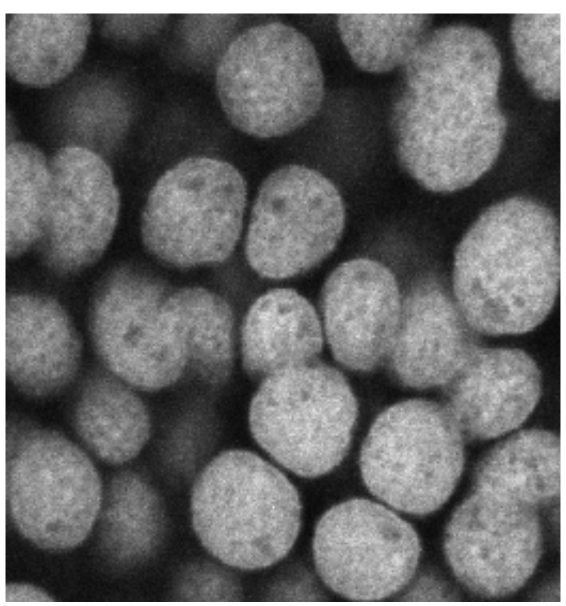
while $\max(A_n) = 1$ **do**
 $A_{n+1} = \textbf{erode}(A_n, B)$
 $D_{\text{map}} = D_{\text{map}} + (n+1)(A_n - A_{n+1})$
 $n = n + 1$



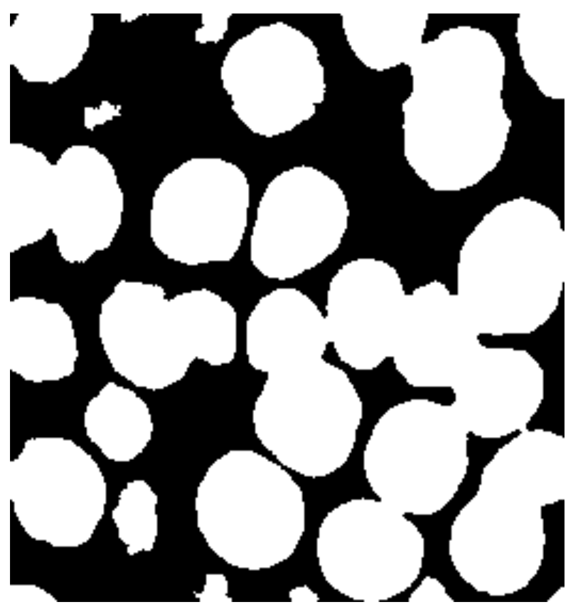
B

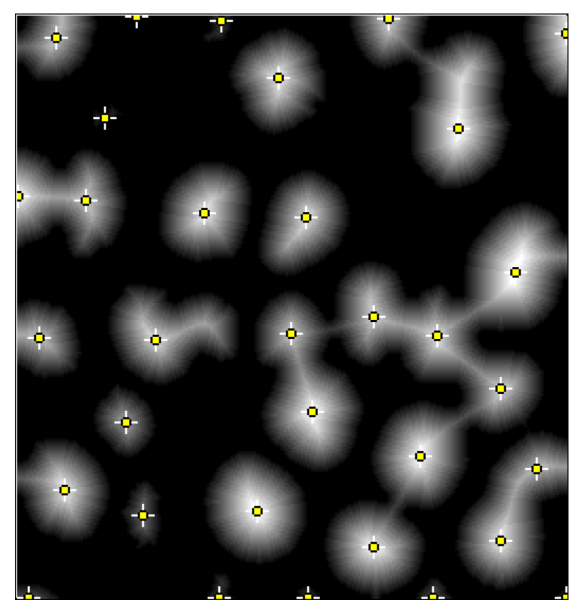


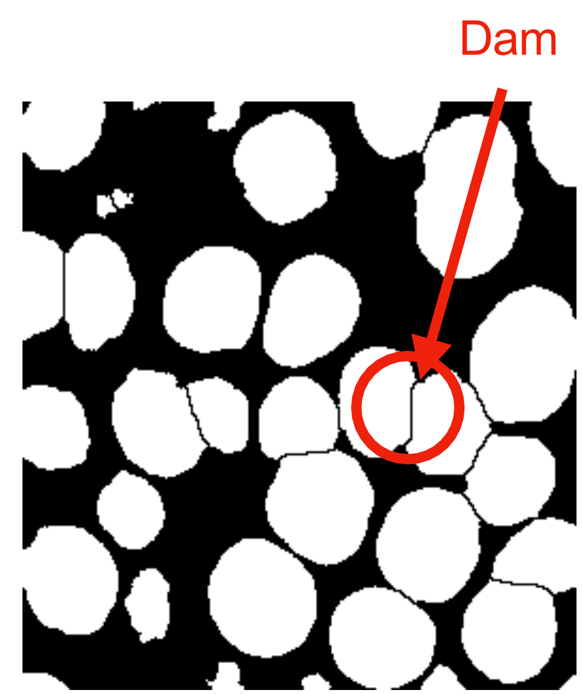
original image



thresholded image







local maxima $\Rightarrow$ seeds of watersheds