Image Preprocessing 2

KKY/USVP Lecture 3

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reg. č. CZ.02.2.69/0.0/0.0/16_015/0002287

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Frequency Analysis

Fourier series

- for periodic signals
- the periodic signal $y(t)$ with period T can be expressed as the sum of sines and cosines of frequencies that are a multiple of fundamental frequency $f = 1/T$
- $$y(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty} \left[A_n cos\left(n\frac{2\pi}{T}t \right) + B_n sin\left(n\frac{2\pi}{T}t \right) \right] \quad (1)$$

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Frequency Analysis

Fourier transform

- it always exists - it is a generalization of Fourier series to an infinite interval
- Fourier transform for two variables (2D)
- $$F(u,v) = \iint_{-\infty}^{\infty} f(x,y) \cdot e^{(-2\pi i \cdot (xu+yv))} dxdy \qquad (2)$$
- u, v ... spatial frequencies
- relation of Fourier transform and convolution
- the Fourier transform of a convolution is a product and the product is a convolution

Frequency Analysis

Discrete Fourier Transform (DFT):

- Used to calculate the Fourier transform of a sampled (discrete) function in discrete frequency points
- Discrete Fourier transform for two variables (2D)
- $$F(u,v) = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} f(n,m) \cdot e^{\left(-2\pi i \cdot \left(\frac{nu}{N} + \frac{mv}{M}\right)\right)} dxdy \quad (3)$$
- DFT is very computationally expensive
- Fast Fourier Transform (FFT): Fast algorithm for calculating the Fourier transform

Mathematical morphology

Introduction

- separate area of image analysis
- based on point set theory
- in the center of attention is the shape of the objects
  - shape identification
  - optimal reconstruction of the shape that is broken
- easy hardware implementation, faster than the classic approach
- Images are usually first preprocessed using standard techniques, and objects are found by segmentation methods $\rightarrow$ binary image

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Mathematical morphology

Application

- preprocessing (noise removal, simplification of object shape)
- emphasis on the structure of objects (skeleton, thinning, amplification, calculation of convex envelope, marking of objects)
- description of objects by numerical characteristics (area, perimeter, projection, etc.)

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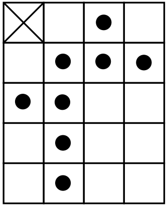
Binary image = point set

- X - objects
- X_c - background (including holes in objects)



X = { (0, 2), (1, 1), (1, 2), (1,3), (2, 0), (2, 1), (3, 1), (4, 1) }

origin (0,0) 

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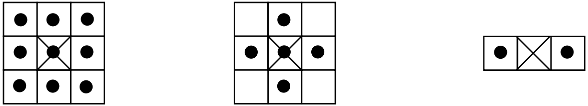
structuring element

- relation with another, smaller point set B, called structuring ELEMENT
- frequently used structuring elements



- the origin does not have to be a point of the structuring element (see right element in the figure above)
- Elements that have the same properties for different directions are called isotropic

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Properties

- We imagine the morphological transformation as if we were moving the structuring element B systematically throughout the image W. The **point of the image** that coincides with the **origin of the structuring coordinates element**, we call the **instantaneous point**. The result of the relationship between the image and the structuring element we write to the instantaneous point of the image.
- For each morphological transformation $\Phi(x)$ there is a dual transformation $\Phi^*(x)$

$$\Phi(x) = \left(\Phi^*\left(x^C\right)\right)^C \tag{4}$$

- **Basic transformations:** translation, dilation, erosion, opening, closing

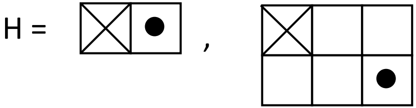
Mathematical morphology

Translation

- The translation of a point set X by a vector h is denoted by X_h

$$X_h = \left\{ d \in E^2 ; d = x + h \quad for \quad x \in X \right\} \tag{5}$$

- Example



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Dilation $\oplus$

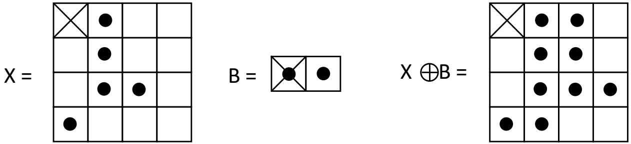
- merge two point sets using vector sum (Minkowski sum)

$$X \oplus B = \left\{ d \in E^2; d = x + b \quad for \quad x \in X, b \in B \right\} \tag{6}$$

- Example

$$X = \{(0,1),(1,1),(2,1),(2,2),(3,0)\} \qquad B = \{(0,0),(0,1)\} \tag{7}$$

$$X \oplus B = \{(0,1),(0,2),(1,1),(1,2)(2,1),(2,2),(2,3),(3,0),(3,1)\} \tag{8}$$



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Dilation $\oplus$ properties

- The most commonly used structuring element - 3x3, containing all 9 points of the eight-neighborhood
  - objects grow by one layer at the expense of the background
  - holes and bays with thickness of 2 points is filled
- Properties
  - commutative $X \oplus B = B \oplus X$
  - associative $(X \oplus B) \oplus D = X \oplus (B \oplus D)$
  - dilation can be expressed as the union of shifted point sets $X \oplus B = \bigcup_{b \in B} X_b$
  - translation is the dilation using structuring element that contains exactly one point
  - invariant with respect to displacement $X_h \oplus B = (X \oplus B)_h$

Mathematical morphology

Erosion $\ominus$

- merge two point sets using the vector subtraction
- is a dual transformation to dilation NOT INVERSE

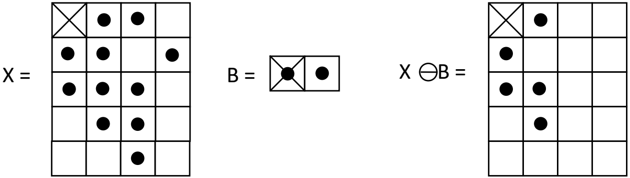
$$X \ominus B = \{d \in E^2; d + b \in X \quad \forall b \in B\} \tag{9}$$

- Example

$$X = \{(0,1),(0,2),(1,0),(1,1),(1,3),(2,0),(2,1),(2,2),(3,1),(3,2),(4,2)\} \tag{10}$$

$$B = \{(0,0),(0,1)\} \tag{11}$$

$$X \ominus B = \{(0,1),(1,0),(2,0),(2,1)(3,1)\} \tag{12}$$



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Erosion $\ominus$ properties

- The most commonly used structuring element - 3x3, containing all 9 points of the eight-neighborhood
  - objects (lines) of thickness 2 and lonely points disappear
  - objects are reduced by 1 layer
- if we subtract its erosion from the original image, we get the outlines of the object
- Properties
  - if the origin is contained in a structuring element, it is antiextensive $(0,0) \in B \Rightarrow X \ominus B \subseteq X$
  - invariant with respect to displacement $X_h \ominus B = (X \ominus B)_h$ and $X \ominus B_h = (X \ominus B)_{-h}$
  - erosion can be expressed as the intersection of shifted point sets $X \ominus B = \bigcap_{b \in B} X_{-b}$

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Dual properties of dilation and erosion

- symmetric set $B^{\sim} = \{b; -b \in B\}$
- erosion, unlike dilation, is not commutative
- dilation and intersection $(X \cap Y) \oplus B \subseteq (X \oplus B) \cap (Y \oplus B)$ and $B \oplus (X \cap Y) \subseteq (B \oplus X) \cap (B \oplus Y)$
- erosion and intersection $(X \cap Y) \ominus B \subseteq (X \ominus B) \cap (Y \ominus B)$ and $B \ominus (X \cap Y) \supseteq (B \ominus X) \cap (B \ominus Y)$
- dilation and union $B \oplus (X \cup Y) = (X \cup Y) \oplus B = (X \oplus B) \cup (Y \oplus B)$
- erosion and union $(X \cup Y) \ominus B \supseteq (X \ominus B) \cup (Y \ominus B)$ and $B \ominus (X \cup Y) \supseteq (X \ominus B) \cap (Y \ominus B)$
- if we use two structuring elements for dilation / erosion in succession, it does not matter which one we use the first

Mathematical morphology

Opening and Closing

- combination of dilatation and erosion
- the resulting image contains less detail
- **Opening** - erosion followed by dilation

$$X \circ B = (X \ominus B) \oplus B \tag{13}$$

- **Closing** - erosion followed by dilation

$$X \bullet B = (X \oplus B) \ominus B \tag{14}$$

- If the image does not change after opening/closing by structuring element B, we say that it is open/closed with respect to B.

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Opening and Closing properties

- Opening separates objects connected by a narrow neck, removes small details.
- Closing connects objects that are close to each other, filling small holes and narrow bays
- The meaning of the terms "small", "narrow", "close"depends on the size of the structuring element.
- **Closing** - erosion followed by dilation
- both opening and closing are invariant with respect to the translation
- opening is an antiextensive projection $X \circ B \subseteq X$
- closing is an extensive projection $X \subseteq X \circ B$
- both opening and closing are idempotent, i.e., repeated use of these operations does not change the result

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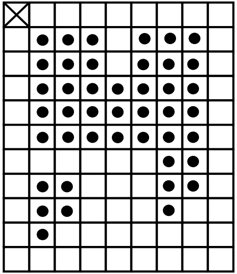
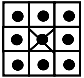
Opening and Closing Example – input image and structuring element

X =



B =



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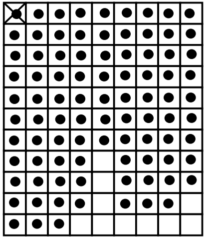
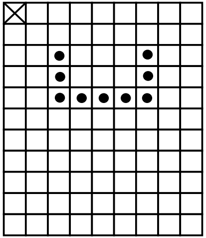
Opening and Closing Example – results of dilation and erosion

$X \oplus B =$



$X \ominus B =$



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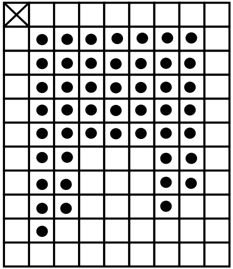
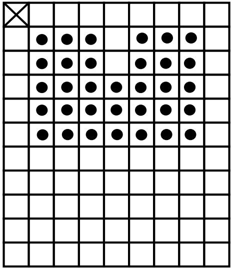
Opening and Closing Example – results of opening and closing

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



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



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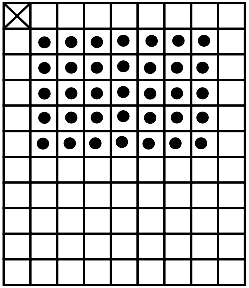
Opening and Closing Example – results of opening followed by closing (vice versa)

$$(X \bullet B) \circ B =$$



$$= (X \circ B) \bullet B$$

In this case, they are equal. (Generally not)

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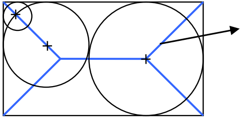
Skeleton

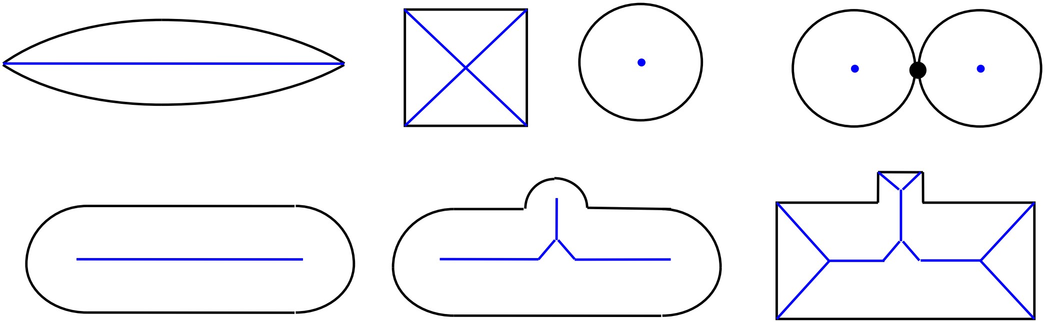
- The skeleton $S(Y)$ is a set of points - the centers of circles, which are contained in Y and touch the boundary Y at least in 2 points.



- The skeleton can be formed by erosions and dilatations, but the skeleton thus obtained can be composed of lines thicker than one point.
- Often the skeleton is replaced by a set processed by sequential homotopic processing

Mathematical morphology

Skeleton - examples



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Hit or miss transformation

- composite structuring element $B = (B_1, B_2)$
- we are looking for whether $B_1 \subset X$ and at the same time $B_2 \subset X^C$
- definition

$$X \otimes B = \{x : B_1 \subset X \wedge B_2 \subset X^C\} \tag{15}$$

- definition using dilation and erosion

$$X \otimes B = (X \ominus B_1) \cap (X^C \ominus B_2) = (X \ominus B_1) \mid (X \oplus B_2^{\sim}) \tag{16}$$

- where $\mid$ one-sided difference of sets $X \mid Y = X \cap Y^C$

Segmentation

INPUT: INTENSITY IMAGE

OUTPUT: IMAGE DIVIDED INTO AREAS RELATED TO REAL WORLD OBJECTS

Complete segmentation:

- distinguishable areas related to real world objects.
- necessary to use knowledge about solved problem.
- special case: constant objects in front of constant background of known brightness – good results without any further knowledge of the problem.

Examples: text in scanned document, blood cells, counting screws

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Partial segmentation:

- areas are homogeneous with respect to particular selected properties (brightness, color, texture, ...)
- areas can overlay each other
- necessary to use knowledge about solved problem.

Examples: scene with field and forest viewed from window – areas can not be related to real world objects

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Segmentation - Task knowledge

It is necessary to use knowledge about the problem to obtain the best results. For example:

- defined shape
- defined position and orientation
- defined start and end point of the object edge
- relation between object and other areas

Examples:

- *searching for ships on the sea (example property: color of background)*
- *searching for railways and highways in the map (example property: maximum curvature)*
- *searching for rivers in the map (example property: rivers does not intersect)*

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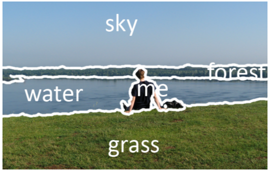
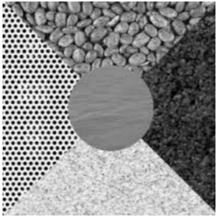
Segmentation - Segmentation approaches

- brightness approaches – thresholding
- edges based approaches
- areas based approaches





Segmentation - Thresholding

- ☺ oldest and simplest approach
- ☺ the most common approach
- ☺ low resource and computing requirements
- ☺ fastest approach – capable to run in real-time
- ☹ threshold determination – not a simple task to perform it automatically
- ☹ can be perform only on particular type of input images (objects and background are easy to distinguish)

$$g(i,j) = \begin{cases} 1 & \text{for } f(i,j) \geq T \\ 0 & \text{for } f(i,j) < T \end{cases} \tag{17}$$

T – threshold constant

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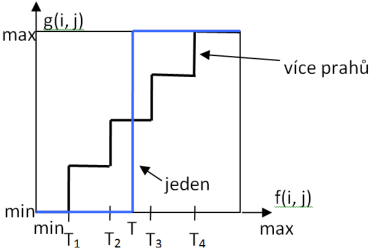
Segmentation - Thresholding

$$g(i,j) = \begin{cases} 1 & \text{pro } f(i,j) \geq T \\ 0 & \text{pro } f(i,j) < T \end{cases} \tag{18}$$

T – threshold constant



Segmentation - Thresholding

Modification: thresholding with a set of known brightness constants

$$g(i,j) = \begin{cases} 0 & \text{for } f(i,j) \in D \\ 1 & \text{otherwise} \end{cases} \tag{19}$$

where D is a set of brightness values representing background.

Examples: blood cells – cytoplasm has particular set of brightness (background is brighter, core is darker)

Modification: thresholding with multiple threshold

$$g(i,j) = \begin{cases} 1 & \text{for } f(i,j) \in D_1 \\ 2 & \text{for } f(i,j) \in D_2 \\ \vdots & \\ n & \text{for } f(i,j) \in D_n \\ 0 & \text{otherwise} \end{cases} \tag{20}$$

where $D_i \cap \; D_j = 0 \; i \neq j$

Segmentation - Thresholding

Modification: partial thresholding

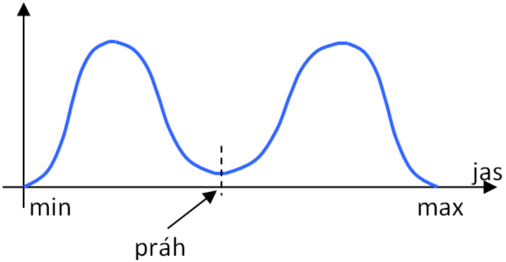
$$g(i,j) = \begin{cases} f(i,j) & \text{for } f(i,j) \in D \\ 0 & \text{otherwise} \end{cases} \tag{21}$$

where D is a set of brightness values related to e.g multiple objects.

- remove background
- preserve brightness values in objects
- $f(i,j)$ **not only** brightness function (e.g. image gradient value, texture property, depth map, color)
- *demo*

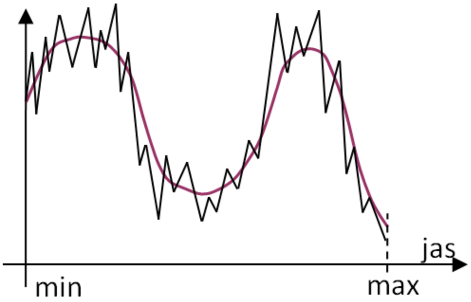
Determination of the threshold

- basic thesholding is based on known (in advance) thershold
- input information for threshold determination is usually image histogram
- how to determine the threshold **automatically**?; "trial and error"approach or;
- bimodal histogram (2 sufficiently distant maximums)
- in this case is possible to determine minimum value between masimums.



Histogram smoothing:

- we are looking for a local minimum between the two largest sufficiently distant local maxima
- but often it is not possible to decide unambiguously about the significance of local maxima and minima
- smoothing suppresses local extremes and ideally provides a bimodal histogram (local averaging - e.g. Gaussian window or median filtering, etc.)



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Percentage thresholding

- we have an a priori knowledge of what percentage of the image area is covered by objects.
- e.g. the average text coverage of the page area is around 5 %
- we set the threshold so that just as many percent of the pixels have the color of the objects, the rest the background color.
- see fig. on the next slide: cumulative histogram for 2x differently lit scene, object covers 70 %

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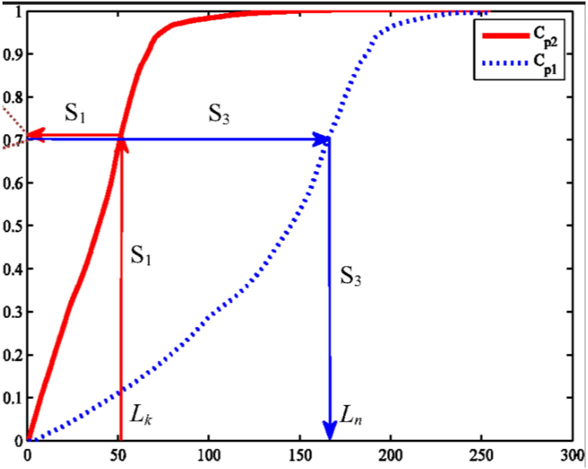
Percentage thresholding



Adaptive thresholding

- one global threshold value may not be appropriate for certain cases
- the image may have different lighting conditions in different places
- in this case the adaptive thresholding calculates the threshold for small regions of the image (sliding window)

Original Image

Global Thresholding (v = 127)

Adaptive Mean Thresholding

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Segmentation based on edge detection

Edges places of the image where there is a certain discontinuity, mostly in brightness, but also in color, texture, depth, etc.

Edge image is created by the application of an edge operator.

Border is a description of the edge of a segmented object.

- The task of segmentation in this case is to join the edges into strings that better match the course of the boundaries
- A priori information about where the edges are and what their relationships are to other parts of the picture is often used
- If a priori information is not available, the segmentation method must take into account local properties together with general knowledge specific to the application area.

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Edge image thresholding

- usually very few places in the image have zero edge size. The reason is the presence of noise
- the edge image thresholding method suppresses indistinct edges of small size and preserves only significant edges (the meaning of the words ”small”, ”significant”is related to the size of the threshold)
- the threshold value can be determined, for example, by percentage thresholding method
- sometimes post-processing of the result is applied - e.g. omitting **edges** shorter than a certain value
- see figure on the next slide

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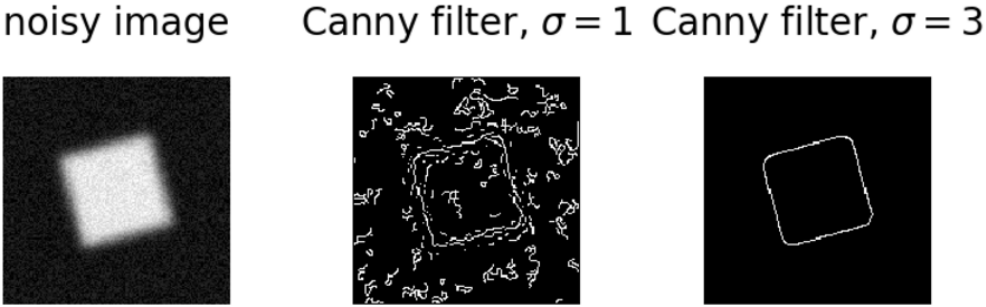
Edge image thresholding



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Determining the boundary using knowledge of its position

- We assume information about the probable **position and shape** of the border, obtained, for example, through higher-level knowledge or as a result of segmentation methods applied to a lower-resolution image.
- One possibility is to determine the position of the boundary as the position of significant edge cells, which are located near the assumed location of the boundary and which have a direction close to the assumed direction of the boundary at a given location.
- If a sufficient number of pixels meeting these conditions can be found, a suitable approximation curve is intersected by these points - *refined boundary*
- see figure on the next slide

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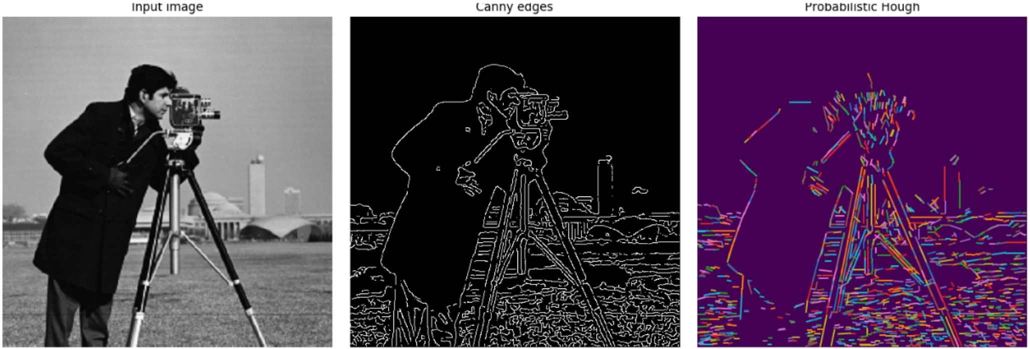
Determining the boundary using knowledge of its position



Gradual division of connectors

- We will use it if we know the endpoints of the boundary and assume little noise and little curvature of the boundary
- A possible approach is to gradually divide the connectors of already detected neighboring boundary elements and search for another boundary element on the **normal** guided by the center of this connector.
- Tte edge element that is closest to the junction of the points detected so far and has a **above-threshold** edge size is considered a new boundary element, and the iteration process is repeated.
- see the figure on the next slide

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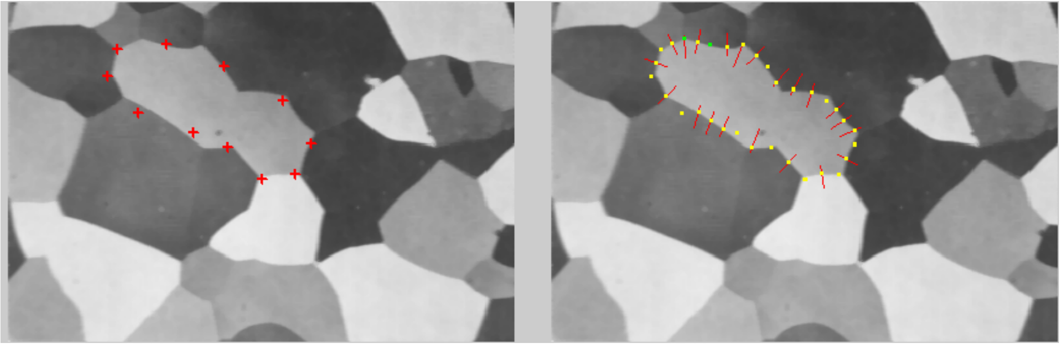
Gradual division of connectors



Region Growing

- Can be used in noise images where it is difficult to find boundaries
- An important feature is **HOMOGENITY**
- Dividing the image into maximum contiguous areas so that these areas are homogeneous in some respects.

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Region Growing

Homogeneity criterion

- based on luminance properties, more complex methods of description or even on the model of the segmented image.
- we usually require the following conditions to be met for the areas:

1. $$H(R_i) = TRUE \quad for \quad i = 1, 2, \ldots, I$$
2. $$H(R_i \cup R_j) = FALSE\ for\ i, j = 1, 2, \ldots, I\ i \neq j\ R_i\ neighbor\ R_j$$

Where: I .... number of areas R_i .... individual areas $H(R_i)$ .... the two-valued expression of the homogeneity criterion → areas must be (1) homogeneous and (2) maximal

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Region Growing - Algorithm

The most natural method of joining regions is based on an initial layout, where each pixel represents a **separate region**, which does not satisfy (2). Furthermore, we always connect two adjacent areas, if the area created by joining these two areas will meet the criterion of homogeneity.

- The result of the merging depends on the order in which the areas are presented for merging.
- The simplest methods are based on the initial segmentation of the image into 2x2, 4x4 or 8x8 areas.
- The description of homogeneity is mostly based on statistical brightness properties (eg brightness histogram in the area).
- The description of the area is compared using statistical tests with the description of the neighboring area.
  - when matched, the two areas merge and a new area is created
  - when no two areas can be merged, the process ends

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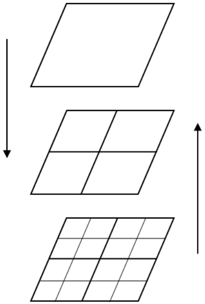
Split and Merge

- This method preserves the good properties of both approaches.
- It uses a pyramidal representation of the image.
- The areas are square and correspond to an element of a given level of the pyramidal data structure.



1. We will initially specify initial image layout.
2. If for the area R the k-th level of the pyramidal structure $H(R) = FALSE$ (the area is not homogeneous), we divide R into 4 areas $(k+1)$. levels.
3. If there are adjacent areas R_i and R_j such that $H(R_i \cup R_j) = TRUE$, we combine R_i and R_j into one area.
4. If no area can be joined or divided, the algorithm ends

Thank you for your attention!

Questions?

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