

Segmentation

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What Is Segmentation?

- The process of isolating objects of interest from the rest of the scene (Castleman, 1979)
- The process of partitioning an image into non-intersecting regions such that each region is homogeneous and the union of no two adjacent region is homogeneous (Pal, 1993).

Why Is It Useful?

- Extracts information
- Enhances contents
- Enables measurements
- Provides guidance
- Allows comparisons

Why Is It Difficult?

- Non-uniform mapping
- Inhomogeneities
- Inadequate object model
- Spurious artefacts
- Noise

Tomographic Data and Segmentation

- Many anatomically distinct objects
- High variability of object shapes
- High variability of scanner parameters
- 3D objects' nature
- High demands on the segmentation precision
- No control over the environment

Segmentation Methods

- Automatic
 - Many approaches
 - Still a problem
- Semiautomatic
 - Most popular
 - Usually hierarchical
- Manual
 - Totally subjective
 - Only for simple tasks

Segmentation Methods

- Automatic
 - Processing of numerous data sets
 - Tuning to specific tasks (brain from MRI data)
 - Special parameter settings
 - Necessity of visual verification
- Semiautomatic
 - Based on user's knowledge & experience
 - Highly precise
 - Labor-intensive
 - 2D (slice) and 3D (volume) approaches

Segmentation Methods

- 2D-techniques
 - Manual editing by paintbrush tools
 - Thresholding
 - Active contours (snakes)
 - Problems with 3D anatomy
- 3D-techniques
 - Histogram-based
 - Connected-components labeling
 - Active surfaces (balloons)
 - Problems with anatomically distinct objects

Segmentation Methods

- Image-based
 - Rely only on image properties
 - Usually multistage approach
- Knowledge-based
 - Use explicit information
 - No distinction to registration

Image-based Segmentation Methods

- Discontinuity-oriented
 - Geometric features
 - Boundary detection
 - Edge linking
- Similarity-oriented
 - Thresholding
 - Region-growing
 - Motion use

Geometric Features

- Use discontinuities in the image to isolate distinct elements:
 - Points
 - Lines
 - Edges

Point Detection

-1	-1	-1
-1	8	-1
-1	-1	-1

$$R = w_1 z_1 + w_2 z_2 + \dots + w_9 z_9 = \sum_{i=1}^9 w_i z_i$$

A point is detected if $|R| > T$ where T is a nonnegative threshold

Line Detection

-1	-1	-1	-1	-1	2	-1	2	-1	2	-1	-1
2	2	2	-1	2	-1	-1	2	-1	-1	2	-1
-1	-1	-1	2	-1	-1	-1	2	-1	-1	-1	2

The above masks can be used for detecting lines of a particular slope.

Edge Detection

- An edge is the boundary between two regions with distinct gray level properties.
- Edge-detection techniques rely on derivative operators.
- This is the most common approach for detecting meaningful discontinuities.

Gradient Vector and Magnitude

• Image: $f(x, y)$

• Gradient: $\nabla f(x, y) = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial}{\partial x} f \\ \frac{\partial}{\partial y} f \end{bmatrix}$

• Magnitude: $|\nabla f| = \sqrt{G_x^2 + G_y^2}$

Gradient Direction and Approximation

- Direction: $\alpha(x, y) = \tan^{-1}\left(\frac{G_y}{G_x}\right)$
- Approximation: $\nabla f(x, y) = |G_x| + |G_y|$

Gradient Operators



Sobel

Roberts

Gradient Operators



Prewitt

Isotropic

Sobel Operators

- Used to compute the derivatives:

-1	-2	-1
0	0	0
1	2	1

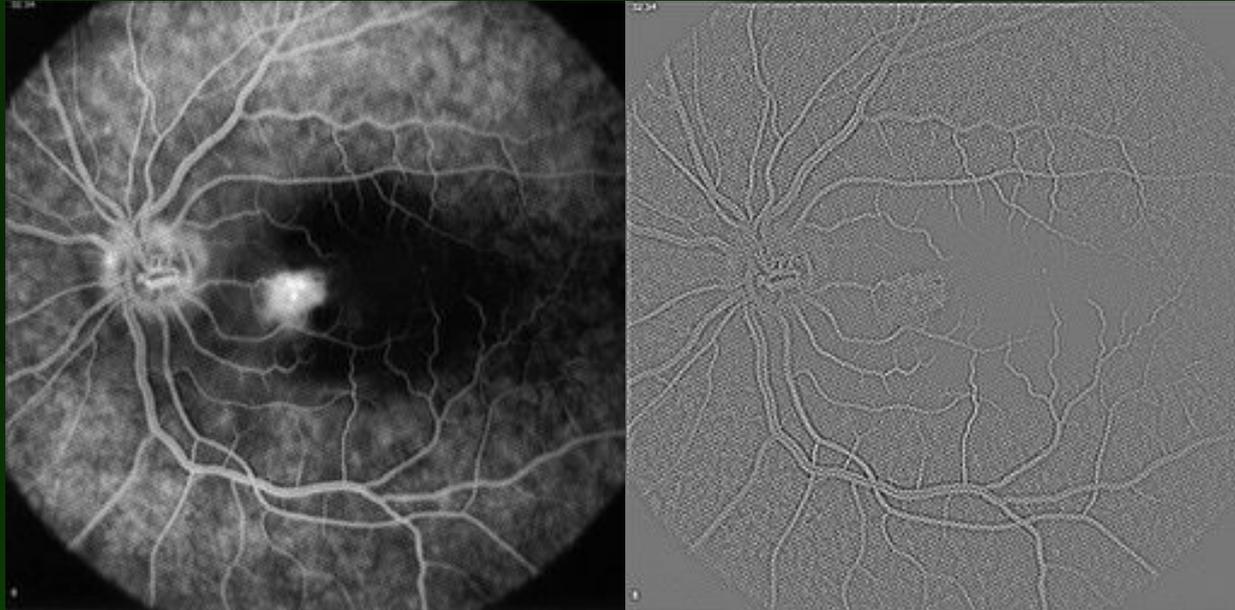
-1	0	1
-2	0	2
-1	0	1

- In formulas:

$$G_x = (z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)$$

$$G_y = (z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)$$

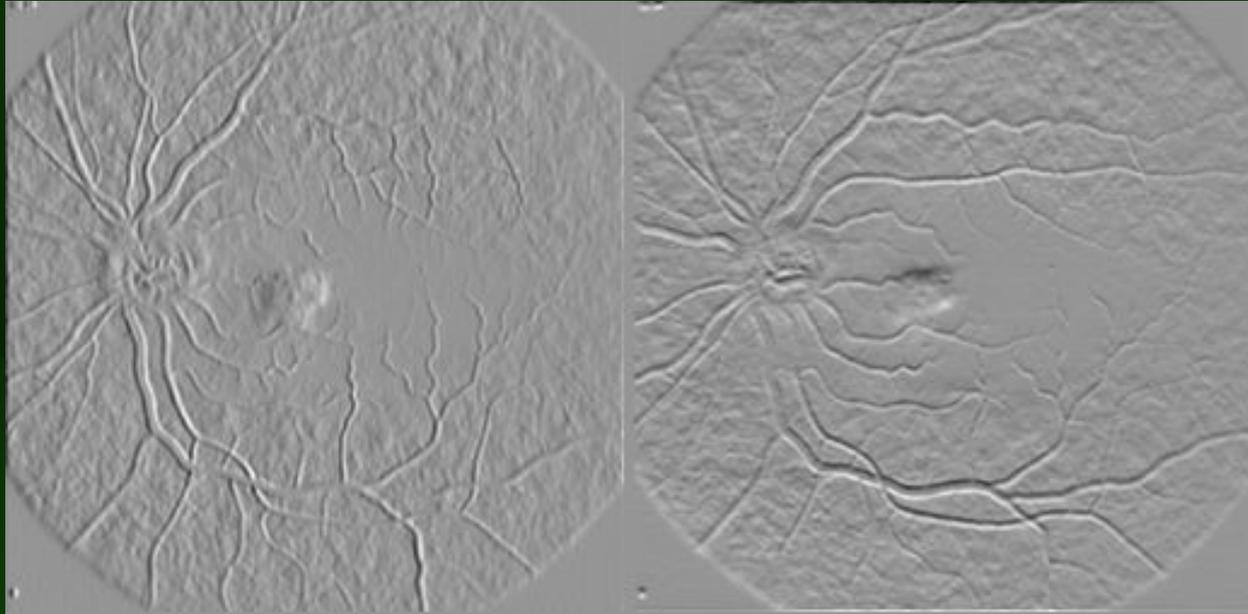
Sobel Operators



original

gradient

Sobel Operators



x-gradient

y-gradient

Edge Linking – Local Processing

- Analyze and link pixels with similar characteristics in a small neighborhood about every detected point:
 - 4-connected
 - 8-connected
 - m-connected

4-Connectivity

- Pixels p and q are *4-connected* if $q \in N_4(p)$

0	1	1
0	1	0
1	0	1

8-Connectivity

- Pixels p and q are *8-connected* if $q \in N_8(p)$

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

m-Connectivity

- Pixels p and q are m -connected if

1) $q \in N_4(p)$ or 2) $q \in N_8(p) \wedge N_4(q) \cap N_4(p) = \{ \}$

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

Edge Linking – Gradient-based

- Compare gradient strength:

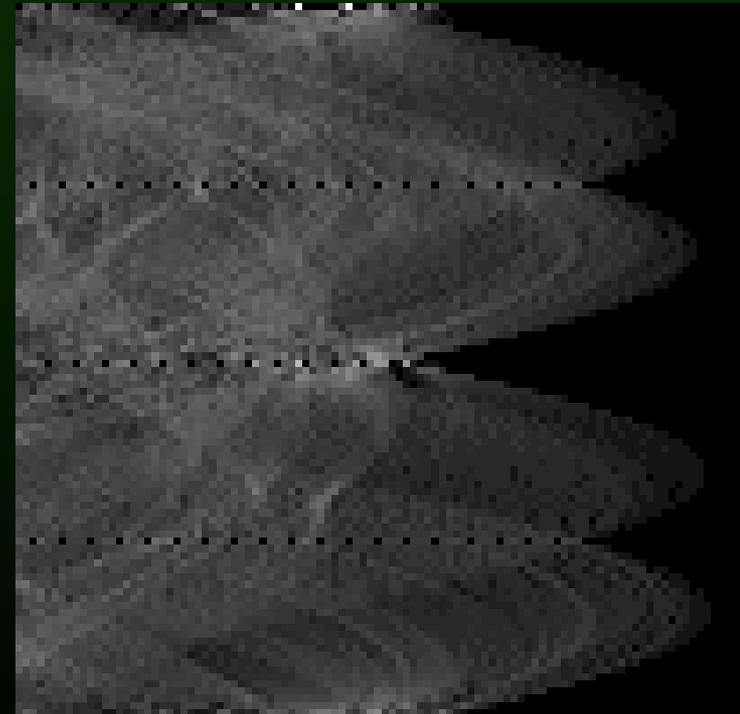
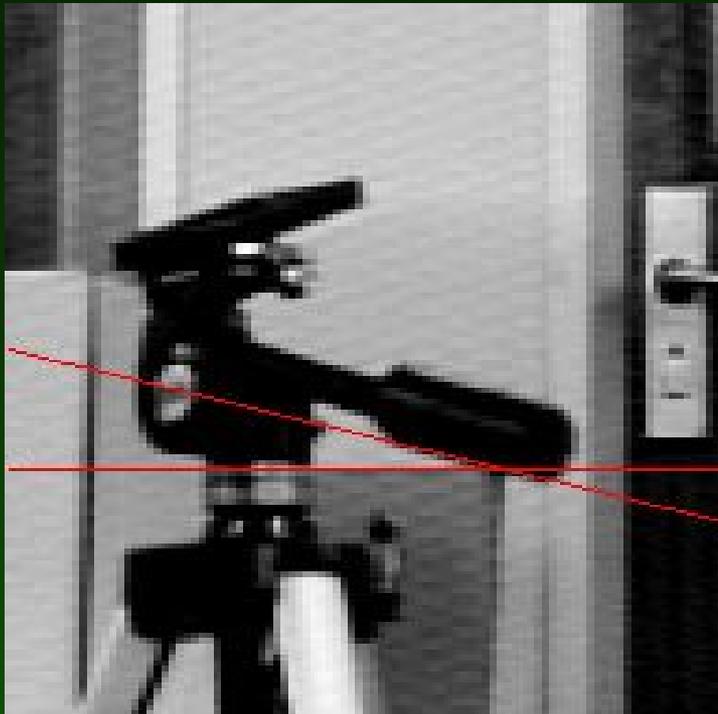
$$f(x, y) \approx f(x', y') \Leftrightarrow |\nabla f(x, y) - \nabla f(x', y')| \leq T$$

- Compare gradient angle:

$$f(x, y) \approx f(x', y') \Leftrightarrow |\alpha(x, y) - \alpha(x', y')| \leq A$$

Edge Linking – Global Processing

- Hough transform: finds pixels lying on a parameterized curve of a predefined shape



Region-oriented Segmentation

- Partition the entire image R in n subregions R_i such that:

$$1) R = \bigsqcup_{i=1}^n R_i$$

2) R_i is connected

3) $R_i \cap R_j = \{\}$ for $i \neq j$

4) $P(R_i) = \text{TRUE}$ for $i = 1, 2, \dots, n$

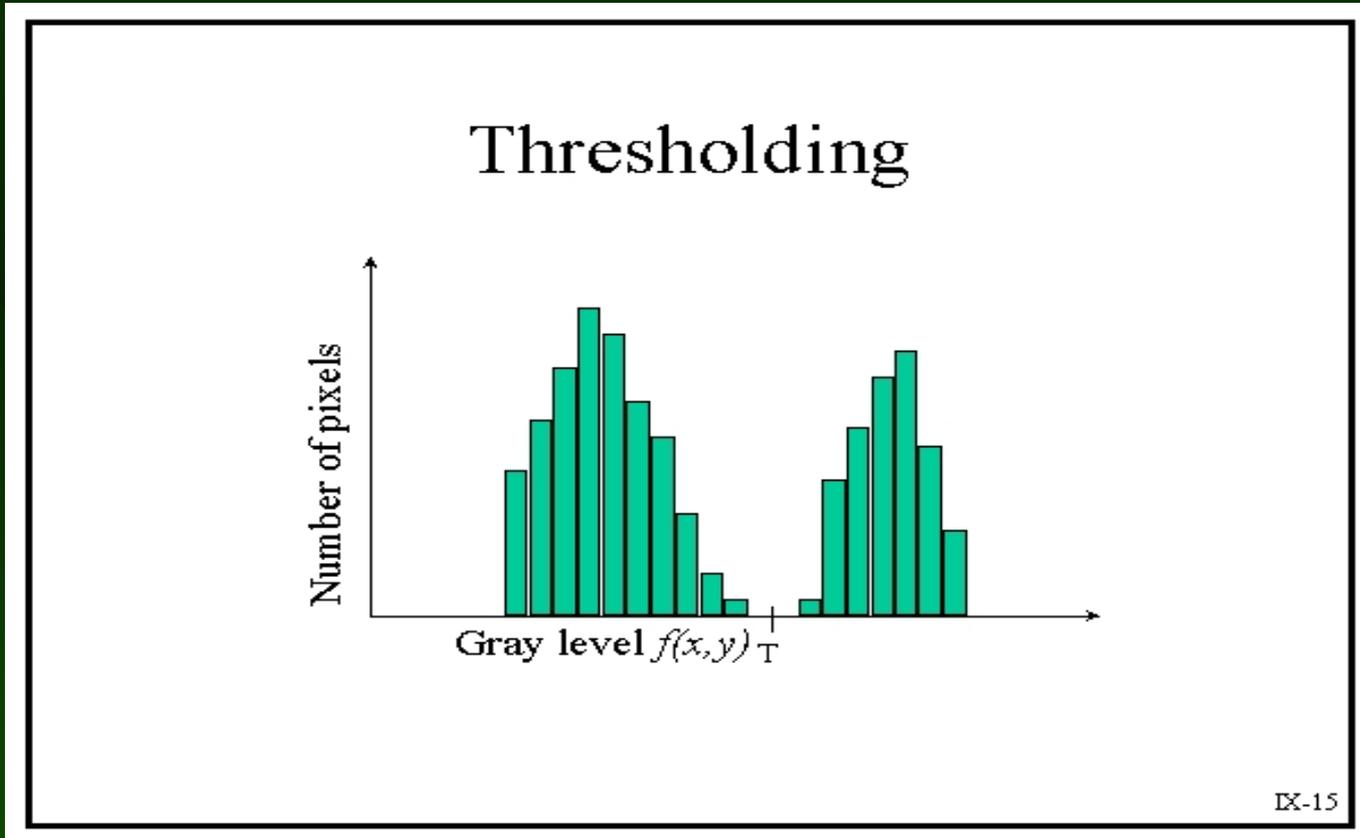
5) $P(R_i \cup R_j) = \text{FALSE}$ for $i \neq j$

$P(R_i)$ is a logical predicate

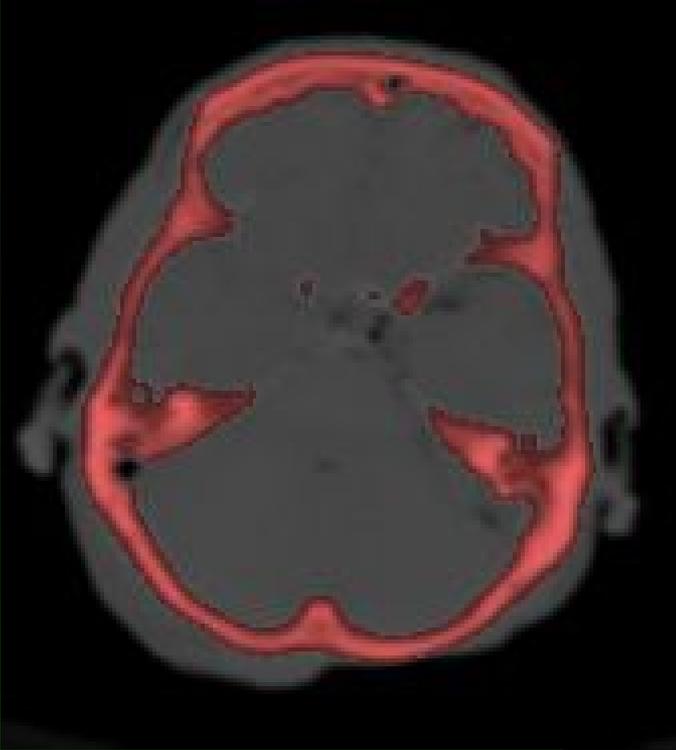
Thresholding

- Labeling operation on a gray scale image that distinguishes pixels of a higher intensity from pixels with a lower intensity value
- The output is usually a binary image.
- Works well when the image histogram is bi-modal.

Thresholding



Thresholding



CT data



MRI data

Thresholding

- Global thresholding
- Local thresholding
- Multiple thresholding
- Dynamic thresholding
- Optimal thresholding

Region Growing

- Group pixels or subregions into larger regions
 - Pixel aggregation
- Two problems:
 - Selection of initial seeds
 - Selection of suitable properties

Region Splitting and Merging

- Split into four disjointed quadrants any region R_i where $P(R_i) = \text{FALSE}$
- Merge any adjacent regions R_i and R_j for which $P(R_i, R_j) = \text{TRUE}$
- Stop when no further merging or splitting is possible

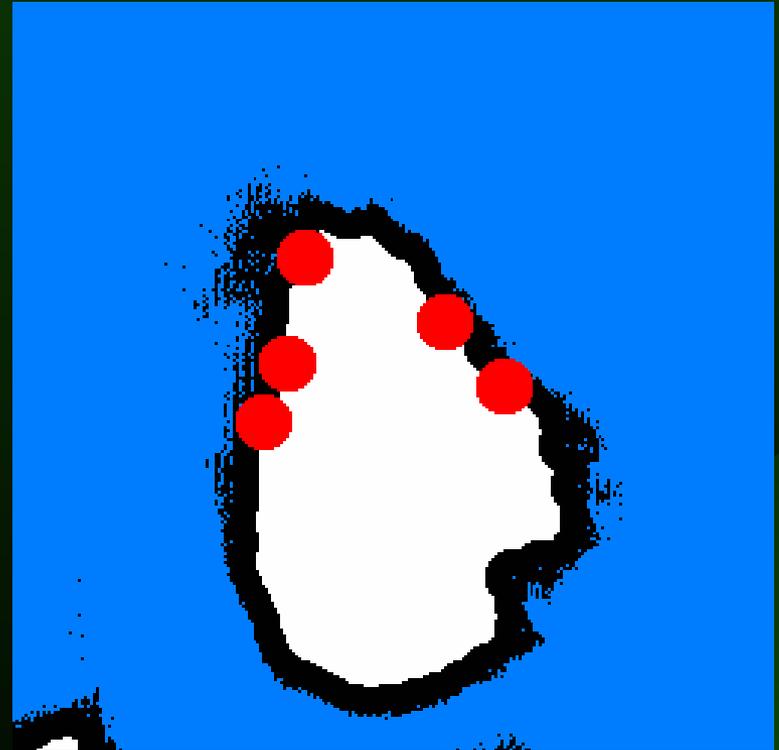
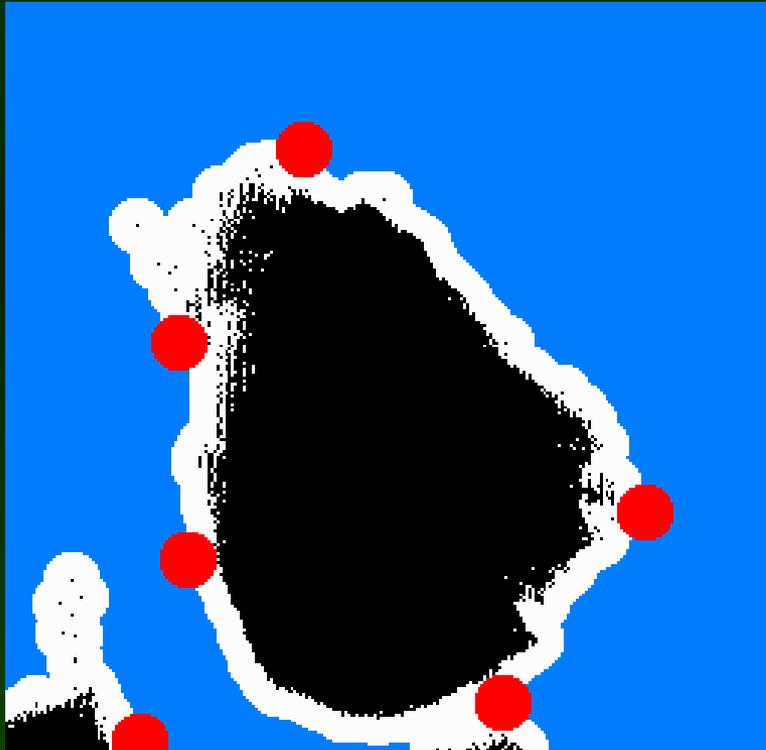
Mathematical Morphology

- Describes objects as subsets of Euclidean space, emphasising their shapes, volumes, textures, i.e. reduces them to their essentials. It classifies the objects into groups by putting them through a sequence of set transformations (J. Serra, 1982).
- It is a hybrid mixture of abstract mathematics (set theory) and reliable recipes.

Mathematical Morphology

- Describes images as sets of ordered pairs (coordinates): $A, B \subset \mathbb{Z}^2$
- Transformations are set operations:
 - Dilation: $A \oplus B = \{x \mid B_x \cap A \subseteq A\}$
 - Erosion: $A \otimes B = \{x \mid B_x \subseteq A\}$
 - Opening: $A \circ B = (A \otimes B) \oplus B$
 - Closing: $A \bullet B = (A \oplus B) \otimes B$

Dilation and Erosion



Dilation and Erosion



Opening and Closing

