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).

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Why Is It Useful?

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

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Why Is It Difficult?

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

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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

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Segmentation Methods

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

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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

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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

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Segmentation Methods

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

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Image-based Segmentation Methods

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

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Geometric Features

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

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Point Detection

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

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

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

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

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

Gradient Direction and Approximation

- Direction: $\alpha(x, y) = \tan^{-1}\left(\dfrac{G_y}{G_x}\right)$

- 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

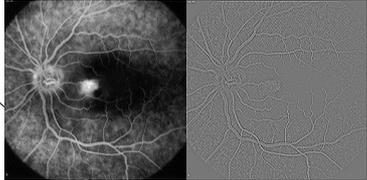| -1	0	1
-2	0	2
-1	0	1

- In formulas:

$$G_x = (z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)$$
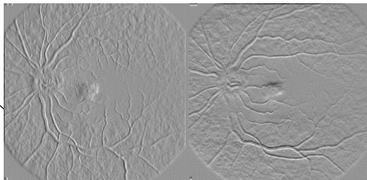$$G_y = (z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)$$

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Sobel Operators

original   gradient

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Sobel Operators

x-gradient   y-gradient

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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

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4-Connectivity

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

0	1	1
0	1	0
1	0	1

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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

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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:

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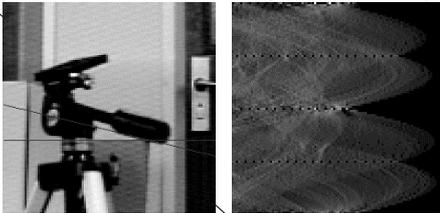
- Compare gradient angle:

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

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

2) R_i is connected

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

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

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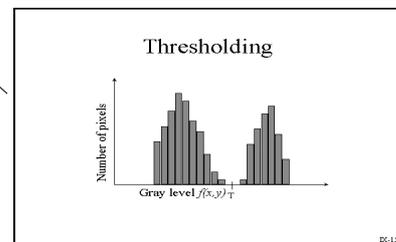
$P(R_i)$ is a logical predicate

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.
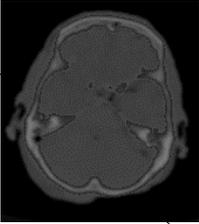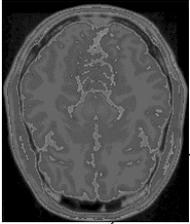
- Works well when the image histogram is bi-modal.

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 $P(R_i)$ = FALSE
- Merge any adjacent regions R_i and R_j for which $P(R_i, R_j)$ = 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): $A, B \subset Z^2$
- Transformations are set operations:
  - Dilation: $A \oplus B = \{x | B_x \cap A \subseteq A\}$
  - Erosion: $A \otimes B = \{x | B_x \subseteq A\}$
  - Opening: $A \circ B = (A \otimes B) \oplus B$
  - Closing: $A \bullet B = (A \oplus B) \otimes B$

Dilation and Erosion

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Dilation and Erosion

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Opening and Closing

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