Image Processing: Segmentation

Introduction
  objective and definition
  classification of methods
Region based segmentation
Contour based segmentation
Conclusion
Introduction

- Image segmentation aims at splitting an entire image into a set of regions
- Segmentation is useful for
  - image analysis, for which it is considered as an initial step
  - image indexing, a signature
  - image compression, since homogeneous regions can be encoded more compactly
- Regions of interest depend on the application
  - for scene analysis, segmentation should delimit objects
  - for document analysis, segmentation consists in separating text (words and characters), graphics and images
  - for image indexing, segmentation should extract uniform (colored or textured) areas
  - ...

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Definition

- There exists no general formal definition of segmentation
- In most cases, segmentation should provide a set of regions having the following properties
  - connectivity and compactness
  - regularity of boundaries
  - homogeneity in terms of color or texture
  - differentiation from neighbor regions
Difficulties

- Image segmentation is considered as a very difficult task
- The main reasons for these difficulties are
  - there is no universal definition of objects or regions
  - real images suffer from several weaknesses
    - irregular illumination, shadows and reflections
    - objects with textured surfaces
    - noisy and blurred images
    - partially occluded objects
- Segmentation results are very sensitive to parameter choices
Easily segmentable images
Hardly segmentable images
Two fundamental approaches to image segmentation

- Region based approaches
  - group together pixels with similar properties
  - combining proximity and similarity
- Contour based approaches
  - locate boundaries between regions
  - boundaries have to be joined to form complete contours

Both approaches may give very different results
Both approaches are complementary and can be combined

example from www.caip.rutgers.edu/~comanici
Classification of region based approaches

- Region based approaches rely on pixel properties such as:
  - homogeneity
  - spacial proximity
- The most used methods are:
  - thresholding
  - clustering
  - watershed
  - pixel aggregation
  - region growing
  - split and merge
Image Segmentation by Thresholding

- Pixel are classified by comparing their values (intensity or other function) with one or several thresholds.
- Thresholds are determined by histograms and can be fixed:
  - globally
  - locally
  - dynamically
- The choice of good thresholds is mandatory:
  - they exist if the histogram peaks are separated by deep valleys.
Image Segmentation by Thresholding
Image Segmentation by Thresholding

- Thresholding do not consider spatial properties such as proximity
- Thresholding can be used when
  - regions are homogeneous
  - objects and background have a strong contrast
- Thresholding is inappopriate when
  - regions have an important gradient
  - regions are strongly textured
Segmentation by Watershed

- Assumptions
  - A region is composed of regional minima and influence zone
  - Regions are divided by watershed lines

- Methods
  - Simulate immersion
  - Waterfall algorithm
Segmentation by Watershed

example from Simphiwe Mkwelo, University of Cape Town
K-Means Clustering

- **Principle**
  - given N points in feature space (for instance RGB pixel values) and K categories
  - pick randomly K points as initial centers \( m_1, \ldots, m_K \).
  - repeat the following step
    - assign each points, to the cluster with nearest \( m_i \)
    - recompute mean \( m_i \) of each cluster from its member points (make sure no cluster is empty)
  - until no mean has changed more than some \( \varepsilon \),
Image Segmentation by Clustering

- K-Means clustering with k=5,4,3

results are not always unique!
Image Segmentation by Pixel Aggregation

- The basic idea is to grow from a seed pixel
  - At a labeled pixel, check each of its neighbors
  - If its attributes are similar to those of the already labeled pixel, label the neighbor accordingly
  - Repeat until there is no more pixel that can be labeled

- A simple case
  - The attribute of a pixel is its pixel value
  - The similarity is defined as the difference between adjacent pixel values
  - If the difference is smaller than a threshold, they are assigned to the same region, otherwise not
Region growing consists of:
- starting with a very fine segmentation
- merging together similar adjacent regions

Region Adjacency Graphs are used to represent segmentation data:
- each node represents a region
- an edge exits between two nodes if the corresponding regions are adjacent
Region Growing: Homogeneity predicate

- A homogeneity predicate $H(R)$ is a function that takes a region $R$ and returns true or false according to the pixel properties.

- A segmentation result is given by a partition $\{R_1, R_2, ..., R_n\}$ such that:
  - $\forall k$ $R_k$ is connex
  - $\forall k$ $H(R_k)$ is true
  - $\forall i \neq j$ if $R_i$ is a neighbor of $R_j$ then $H(R_i \cup R_j)$ is false

- As predicates we can choose:
  - absolute intensity homogeneity
    $\forall p,q \in S \quad |I(p) - I(q)| \leq s$
  - differential intensity homogeneity
    $\forall p,q \in S$ and (p neighbor of q)
    $|I(p) - I(q)| \leq s$
Region Growing

(a) Original Image  (b) Region Growing  (c) Segmented region

from Dongsung Kim, Soongsil University
Image Segmentation by Split and merge

- Split into a quad-tree representation
- A region is split if the homogeneity predicate is not satisfied.
- This may lead to over-segmentation!
- Two adjacent regions are merged if the homogeneity predicate is satisfied.
  - this can be done by growing each region toward its neighbors.
Contour based approaches

- Contour based segmentation consists of
  - edge detection by derivative operator
  - thresholding
  - thinning and contour following
  - edge pruning and gap filling

- Alternative methods
  - active contours or "snakes"
  - ...

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Edge detection

- Edge detection by derivative operator

- Convolution
  - by Laplacian
    
    \[
    \begin{pmatrix}
    0 & 1 & 0 \\
    1 & -4 & 1 \\
    0 & 1 & 0
    \end{pmatrix}
    \begin{pmatrix}
    1 & 0 & 1 \\
    0 & -4 & 0 \\
    1 & 0 & 1
    \end{pmatrix}
    \begin{pmatrix}
    1 & 1 & 1 \\
    1 & -8 & 1 \\
    1 & 1 & 1
    \end{pmatrix}
    \begin{pmatrix}
    -1 & 2 & -1 \\
    2 & -4 & 2 \\
    -1 & 2 & -1
    \end{pmatrix}
    \]

  - or gradient operators (Prewitt, Sobel, ...)

    \[
    \begin{pmatrix}
    -1 & 0 & 1 \\
    -1 & 0 & 1 \\
    -1 & 0 & 1
    \end{pmatrix}
    \begin{pmatrix}
    -1 & -1 & -1 \\
    0 & 0 & 0 \\
    1 & 1 & 1
    \end{pmatrix}
    \begin{pmatrix}
    -1 & 0 & 1 \\
    -2 & 0 & 2 \\
    -1 & 0 & 1
    \end{pmatrix}
    \begin{pmatrix}
    -1 & -2 & -1 \\
    0 & 0 & 0 \\
    1 & 2 & 1
    \end{pmatrix}
    \]
Edge detection and thresholding
Canny edge detection

- Smooth image with a Gaussian filter
- Compute gradient magnitude and orientation with differential filters
- Apply non-maxima suppression to thin the gradient-magnitude edge image
- Track along edges starting from the point exceeding higher threshold with the edge point exceeding the lower threshold
- Apply edge linking to fill small gaps
Edge thresholding and thinning
Edge Detection, Edge Pruning and Gap Filling
Segmentation by Active Contours

- Assumption
  - Salient boundary (snake) can represent a region boundary

- Method
  - A salient curve is generated by minimizing snake energy considering
    - internal energy: curve continuity and bending
    - external energy: gradient

from http://www.tsi.enst.fr/tsi
Segmentation by Active Contours

from Dongsung Kim, Soongsil University

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Motion based image segmentation

- Segmentation of video images can use motion
  - moving objects in fixed scenes can be extracted by frame comparison
  - group together pixels with coherent motion
Conclusion

- Image segmentation is far from being solved
- Image segmentation needs perceptual and cognitive knowledge