Image Analysis
Lecture 9.1 - Segmentation

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Segmentation

- Image segmentation is the process of partitioning a digital image into multiple parts, i.e. find groups of pixels that belong together.

- The goal is to divide the image into meaningful and/or perceptually uniform regions.

- Segmentation is typically used to locate objects and boundaries of physical entities in the scene.

- The segmentation process utilize available image information (intensity, color, texture, pixel position, …).
Segmentation (2)

First step in image analysis:
- Going from pixels to objects or object parts (physical items or scene elements)
- Paves the way for object feature extraction followed by
- Object recognition (Classification)

Principles:
- Thresholding
- Edge based
- Region based
- Automatic (supervised) or interactive (unsupervised)
Color based segmentation - three categories

Original image  
Segmented image
Semantic Segmentation (meaningful regions)
Segmentation methods

- Active contours (Snakes, Scissors, Level Sets)
- Split and merge (Watershed, Divisive & agglomerative clustering, Graph-based segmentation)
- Gray level thresholding
- K-means (parametric clustering)
- Mean shift (non-parametric clustering)
- Normalized cuts
- Graph cuts

Supervised color based segmentation (region growing)
Segmentation by thresholding

Otsu’s method:
- Automatic clustering based thresholding
- Minimization of intra-class variance
- Analog to Fisher’s Discriminant Analysis

Number of pixels

Gray level

$T_1$ $T_2$ $T_3$
Thresholding with Otsu’s method

3 thresholds

4 classes
Binary segmentation – foreground vs. background

Threshold between two populations

Threshold at given percentile
Binary thresholding – Object detection

Thermal image

Thresholded image (Otsu’s method)

Global threshold selection → threshold too low for detection of the object of interest
Manual thresholding

Medium threshold

High threshold
Local thresholding

Threshold computed from gray level statistics in selected window (Otsu’s method)
Local thresholding using edge information

Edge image (Canny edge detector applied to selected window)

Threshold = average gray level along edges

Thresholded window
Object detection in video sequences (visible light)

- Change detection
- Absolute difference image (Current image - time averaged background image)
- Thresholding of difference image, i.e. Otsu’s method
- Requires fixed camera (or registration of images)

Daylight video frame                     Thresholded difference image
Segmentation by clustering

Original image

Pixels represented as points in feature space

Segmented image
K-means (parametric) clustering

1. Select K points (for example randomly) as initial cluster centers
2. Assign each sample to nearest cluster center
3. Compute new cluster centers (i.e. sample means)
4. Repeat steps 2 and 3 until no further re-assignments are possible.
K-means clustering

Initial cluster centers (red, green and blue points)

Samples assigned to nearest cluster center
K-means clustering

Re-computed cluster centers

Samples re-assigned to new cluster centers
K-means clustering

Re-computed cluster centers

Final clustering
K-means clustering using color

Original image

Clustered image – 10 clusters
Mean shift (non-parametric) segmentation

- Segmentation by clustering of the pixels in the image (e.g. using color and position)
- Non-parametric method (using the so called Parzen window technique) to find modes (i.e. peaks) in the density function
- All pixels climbing to the same peak are assigned to the same region.

(Szeliski: Computer Vision – Algorithms and Applications)
Mean shift segmentation

Original image

Plot of $a$ vs. $b$ for each pixel in Lab transformed image
Parzen Method

Density estimate (smoothing of point cloud):

$$f(x) = \frac{1}{nh^d} \sum_{i=1}^{n} \varphi \left(\frac{x - x_i}{h}\right)$$

Window (kernel) function: $\varphi(u)$

Example:

$$\varphi(u) = \frac{1}{(2\pi)^{d/2}} e^{-\frac{1}{2} |u|^2}$$
Mean shift segmentation

Gradient ascent (hill climbing)

Labeled point cloud

Segmented image
Mean Shift Segmentation - example

Original image

Segmented in five categories
Active contours

Fitting of curves to object boundaries:
- Snakes (fitting of spline curves to strong edges)
- Intelligent scissors (interactive specification of curves clinging to object boundaries)
- Level set techniques (evolving boundaries as the zero set of a characteristic function).

These methods iteratively move towards a final solution.

(Szeliski: Computer Vision – Algorithms and Applications)
Active Contours - example

Original image

Segmented image
Split and merge methods

Principles:
- Region based methods
- Recursive splitting of the image based on region statistics
- Hierarchical merging of pixels and regions
- Combined splitting and merging

Methods:
- Watershed segmentation
- Region splitting (divisive clustering)
- Region merging (agglomerative clustering)
- Graph-based segmentation

(Szeliski: Computer Vision – Algorithms and Applications)
Agglomerative clustering

Dendrogram

Distance measures

Distance measures

$\hat{c} = 6$
$\hat{c} = 5$
$\hat{c} = 4$
$\hat{c} = 3$
$\hat{c} = 2$
$\hat{c} = 1$
Normalized cuts

Separation of groups with weak affinities (similarities) between nearby pixels

(Szeliski: Computer Vision – Algorithms and Applications)
Graph cuts

Energy-based methods for binary segmentation:
- Grouping of pixels with similar statistics
- Minimization of pixel-based energy function
- Region-based and boundary-based energy terms
- Image represented as a graph
- Cutting of weak edges, i.e. low similarity between corresponding pixels.

(Szeliski: Computer Vision – Algorithms and Applications)
Graph cuts - example

Original image

Segmented image
Morphological operations

- Non-linear filtering
- Typically used to clean up binary images
- Erosion: replace pixel value with minimum in local neighborhood
- Dilation: replace pixel value with maximum in local neighborhood
- Structuring element used to define the local neighborhood:

```
0 1 0
1 1 1
1 1 0
0 1 0
```

A shape (in blue) and its morphological dilation (in green) and erosion (in yellow) by a diamond-shaped structuring element.

(Renato Keshet 2008)
Morphological operations - Erosion

Structuring element (disk shaped)
Morphological operations - Dilation

Structuring element (disk shaped)
Opening = Erosion + Dilation
Closing = Dilation + Erosion
Opening - example

Segmented image (Active Contours)  

Result of opening
Closing - example

Segmented image

Result of closing
Summary

Image Segmentation:
- Thresholding techniques
- Clustering methods for segmentation
- Morphological operations

More information:
Szeliski 3.3.2 and 5.1 - 5.5