HA NOI UNIVERSITY OF SCIENCE AND TECHNOLOGY
SCHOOL OF INFORMATION AND COMMUNICATION TECHNOLOGY

Computer Vision

Chapter 5: Image segmentation

1

Chapter 5 - Content

- Introduction to image segmentation
- Pixel based approach: Segmentation based on pixel classification
  - Thresholding
  - Clustering techniques
- Region based segmentation
  - Region growing algorithm,
  - Split and merge algorithm
- Edge based segmentation

2

Introduction

- Purpose:
  - to partition an image into meaningful regions with respect to a particular application
- Goal:
  - to cluster pixels into salient image regions, i.e., regions corresponding to individual surfaces, objects, or natural parts of objects.
- The segmentation is based on the feature measurements taken from the image:
  - grey level, color, texture, depth or motion…

3

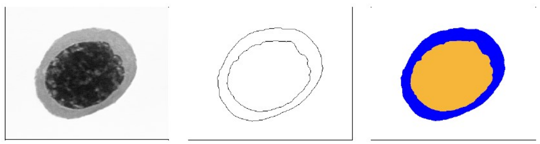
General approaches for image segmentation

- Segmentation is usually based on:
  - discontinuities: edges
    - sudden changes, borders (frontiers) between regions…
  - homogeneous zones: regions
    - same color, texture, intensity, …

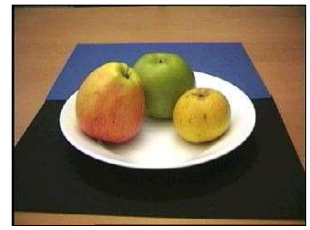
4

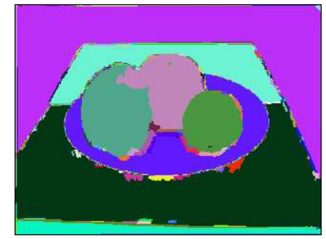
Approaches for image segmentation

- Pixel-based approach
- Region-based approach:
  - look for homogeneous areas in the image
- Edge-based approach :
  - look for discontinuities in the image
  - A closed edge is equivalent to a region
- Hybrid (Dual) approach (region + edge)



Introduction: Example





Source : Jean-Christophe Baillie, ENSTA, uei.ensta.fr/baillie/assets/ES322%20-%20Segmentation.ppt

Introduction: Example

- Entity can be extracted from images using mask

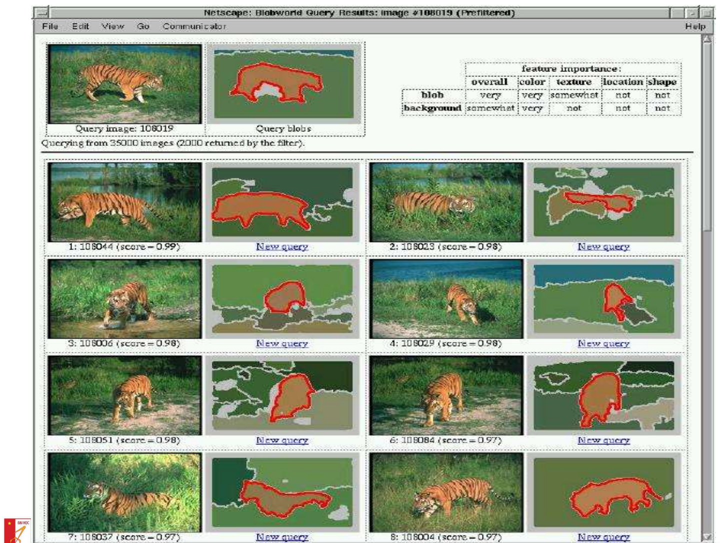
Source : Pascal Bertolino, Cours de Traitement d'images. LIS, INPG (France)

Descriptive definition segmentation

- Segmentation operators partition an image into *nonoverlapping regions*, each of which is homogeneous in one or more features and maximal in criterion of *homogeneity*
- Segmentation subdivides an image into its constituent regions or objects, it partitions an image into distinct regions that are meant to correlate strongly with objects or features of interest in the image.
- Region based segmentation is the process that partitions the image pixels into non-overlapping regions such that:
  - Each region is homogeneous i.e., uniform in terms of the pixel attributes such as intensity (gray level, color, range, or texture, etc.) and connected.
  - The union of adjacent regions is not homogeneous.

Applications

- **Image segmentation**
  - is usually an initial and vital step in a series of processes aimed at overall image understanding of computer vision
- **Segmentation applications**:
  - Object recognition;
  - Image retrieval;
  - Medical image analysis;
  - Boundary estimation within motion or stereo systems;
  - Tracking of objects in a video;
  - Classification of terrains visible in satellite images
  - …



Examples

Original images — Segmented images

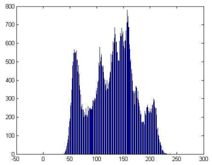


Pixel-based approach

- Segmentation based on pixel classification
  - Thresholding
  - Clustering, classification
- It is not a region segmentation technique
  - But we often in segmentation looking for regions
  - Need some post-processing

Thresholding

- Finding histogram of gray level intensity.



✓Basic Global Thresholding
✓Otsu's Method
✓Multiple Threshold
✓Variable Thresholding

Thresholding

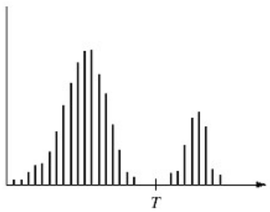
- Thesholding is a *simple and popular* method for object segmentation in digital images
- Thresholding can be
  - *Global:* one threshold for the whole image
  - *Local*: one threshold for a part of the image
  - *Adaptive:* one threshold ajusted according to each image or each image part

Basic global thresholding

- Basic thresholding (2 classes) – main idea :
  - IF value(pixel) >= threshold THEN value(pixel) = 1 (or 255)
  - IF value(pixel) < threshold THEN value(pixel) = 0
- The result is a binary image
- It is also possible to use *n thresholds* to split the image in n+1 classes
- Problem: choosing the threshold(s)!

Basic global thresholding using histogram

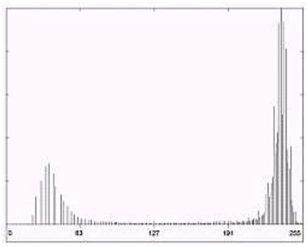
- Find the threshold on histogram of gray level intensity (histogram thresholding)

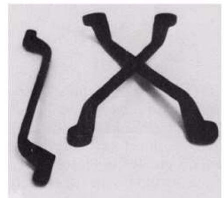


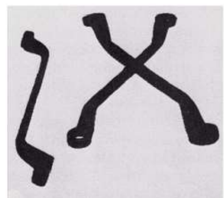
$$g(x,y) = \begin{cases} 0, & f(x,y) < T \\ 1, & f(x,y) \geq T \end{cases}$$

Basic global thresholding

- Threshold value: not difficile if
  - Controled environment
  - Industrial applications





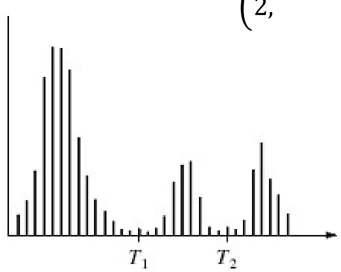


Multi-thresholds

- n thresholds to split the image in n+1 classes:
  - IF value(pixel) < threshold_1
    - THEN value(pixel) = 0
  - IF value(pixel) >= threshold_1 && value(pixel) < threshold_2
    - THEN value(pixel) = 1
  - …
  - IF value(pixel) >= threshold_n
    - THEN value(pixel) = n
- Problems: How many thresholds?

Multi-thresholds

$$g(x,y) = \begin{cases} 0, & f(x,y) < T1 \\ 1, & T2 > f(x,y) \geq T1 \\ 2, & f(x,y) \geq T2 \end{cases}$$

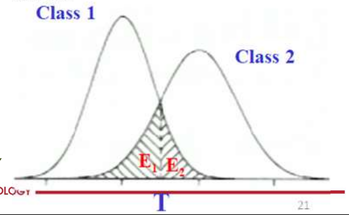


Threshold value

- Global thresholding: How to find the value of the threshold **T** ?
  - Value obtained by tests
  - The mean value of gray values
  - The median value between the min gray level and the max one
  - One value balancing both sections of the histogram
    - automatic thresholding

Choice of thresholds (optimal)

- 2 surfaces (background and object) in an image
  - We suppose mathematical models for distributions (gaussians, etc.)
  - We determine the probability of error in the classes 1 and 2 (surfaces 1 et 2)
  - We search for a threshold T resulting in a minimum error
    - Several methods for achieving this



Source : www.iro.umontreal.ca/~dift2730/

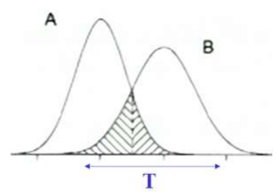
Example: Global automatic thresholding

- One possible algorithm:
  - Choose an initial value for the threshold T (mean, median, …)
  - We obtain 2 groups of pixels
    - G1 where f(x,y) >= T and G2 where f(x,y) < T
  - Compute the gray level means for G1 and G2 -> µ1 and µ2
  - Compute a new value for T
    - T = 1/2 (µ1 + µ2)
  - Repeat until T is ~ constant
- There exist many other global automatic methods
  - Otsu, Kittler, K-means, …
  - No solution on which one to use
  - Must be tested for each new application

Example: Otsu algorithm

- Sweep all possible threshold value for **T**
- For **each value of T**:
  - Compute the mean and variance for each class
  - We look for the intraclass variance
    - Means: μ_1, μ_2
    - Variances: σ_1^2, σ_2^2
    - Intra-class variance:

    $\sigma_w^2 = P_1 * \sigma_1^2 + P_2 * \sigma_2^2$
- The optimal threshold is the one with the minimum value for σ_w^2
- It is based on the idea that classes are well defined and well grouped



$$\sigma_1^2 = \frac{1}{T}\sum_{i=0}^{T-1}\left(h(i) - \mu_1\right)^2$$

$$\sigma_2^2 = \frac{1}{256-T}\sum_{i=T}^{255}\left(h(i) - \mu_2\right)^2$$

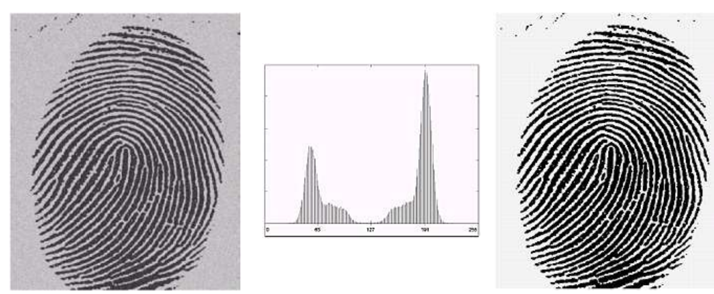
$$\mu_1 = \frac{1}{T}\sum_{i=0}^{T-1} h(i) \quad P_1 = \frac{1}{N \cdot M}\sum_{i=0}^{T-1} h(i)$$

$$\mu_2 = \frac{1}{256-T}\sum_{i=T}^{255} h(i) \quad P_2 = \frac{1}{N \cdot M}\sum_{i=T}^{255} h(i)$$

Source : www.iro.umontreal.ca/~dift2730/

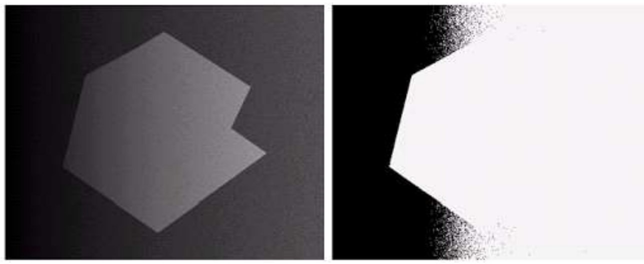
Example: Otsu algorithm

- Threshold found by the algorithm:
  - T = 125



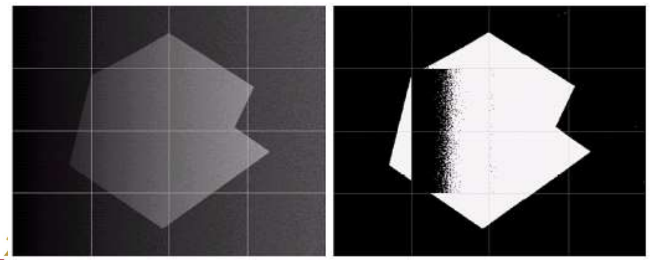
Global threshold: problem

- Problem:
  - Global thresholding cannot be used in that case
  - Solution: adaptive local thresholding

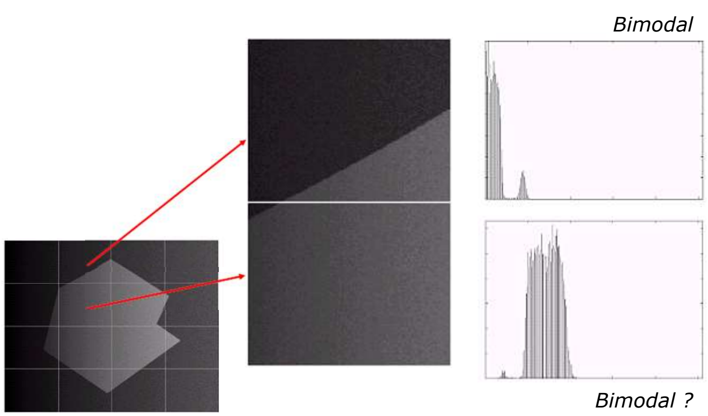


Example of adaptive thresholding

- Split the image in sub-images and process each sub-image with its own threshold
- The main decision is to choose the size of the sub-images
- Before processing each sub-image, check the variance to make sure that the sub-image contains two regions, and not only one.
  - Example: no thresholding for a sub-image if variance<100



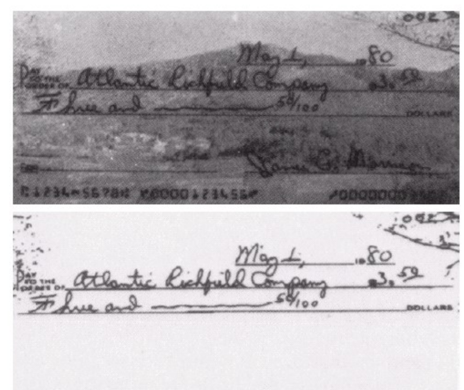
Example of adaptive thresholding



Example of adaptive thresholding

a
b

FIGURE 10.37 (a) Original image. (b) Image segmented by local thresholding. (Courtesy of IBM Corporation.)



Pixel clustering-based segmentation

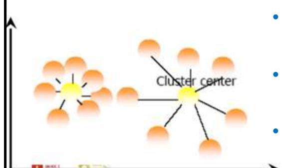
- Image is considered as a set of N image pixels.
- Attributes (property) of the pixels
  - gray level of single-band gray tone images,
  - color values of three-band color images: (r, g, b)
  - values of multi-band images, …
- Based on the similar attribute, pixels classification operators partition an image into homogeneous regions.
  - Clustering provides a grouping of the pixels that is dependent on their values in the image but not necessarily on their locations in the image unless location is a specified property
  - Classifier provide the pixel classes which should be homogeneous regions.

Clustering algorithms

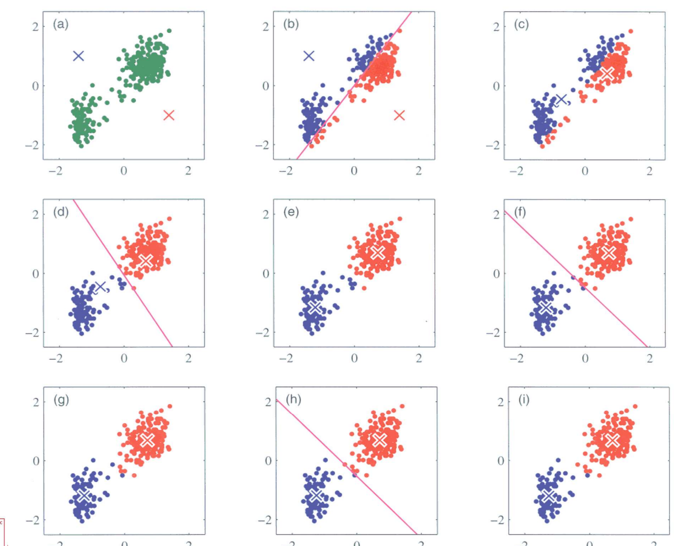
- **Image segmentation approaches including**:
  - Feature space clustering approaches
  - Graph-based approaches
- **Clustering algorithms**:
  - K-Means clustering
  - Mean-Shift Clustering
  - Expectation-Maximization Clustering
  - Watershed Segmentation
  - Graph Cuts (Spectral clustering)
  - Normalized cuts
  - …

K-means Clustering

- Let X = {$p_1, \ldots, p_N$} be a set of N image pixels:
  - $V(p_i)$: the property vector associated with pixel p_i
  - The clustering algorithm is to partition the image into K clusters (K regions)
- **The K-means algorithm**:
  - Initialization step: An initial property vector of each class C_k is chosen randomly from the set of all property vector, note $\mu_k(0)$
  - Interactive step: Assignment of image pixels to K clusters



  - Pixel p_i is assigned to the closest cluster, using a distance between 2 property vectors.
  - Update the property vector of each class: $\mu_k(t)$ is computed as the mean of {$V(p_i)$ | $x_i \in C_k$}.
  - 2 Steps above are repeated until algorithm convergence. each class C_k should be a region R_k



K-means Clustering

Input image

K-means on gray level

K-means on color

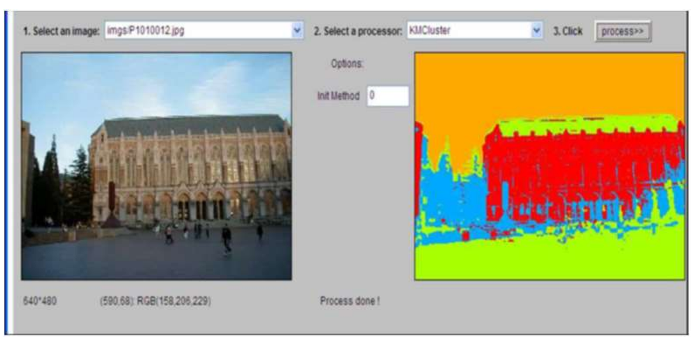
Source : D.A. Forsyth and J. Ponce. Computer Vision : A Modern Approach. Prentice-Hall, 2002.

K-means Clustering

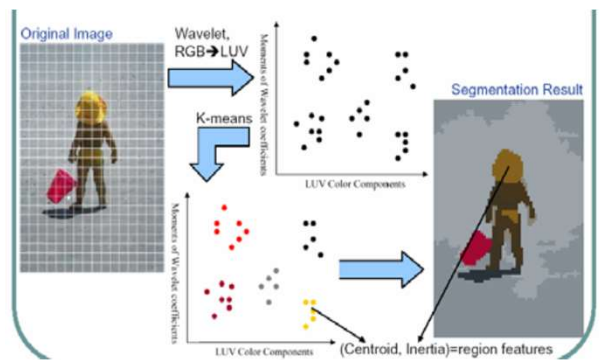
K-means on color for 11 groups

Source : D.A. Forsyth and J. Ponce. Computer Vision : A Modern Approach. Prentice-Hall, 2002.

Example



Example



Pixel-based approach: Pros & cons

- Pros
  - Simple, fast
- Cons: thresholding is mainly an operation on pixels
  - It does not give connected regions ➔ can add more features
  - we need to « clean » the results
    - erase lonely pixels, keep regions
- Other segmentation methods exist
  - that can keep the integrity of regions (connected pixels)

Features for segmentation

- Intensity, Color?
- Position
- Texture
- …

➢ Segmentation as pixel clustering, pixel classification

Segmentation as pixel clustering, classification

Depending on what we choose as the *feature space*, we can group pixels in different ways.

Grouping pixels based on **intensity** similarity

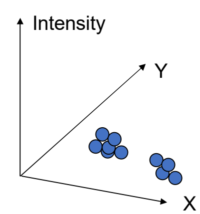
Feature space: intensity value (1-d)

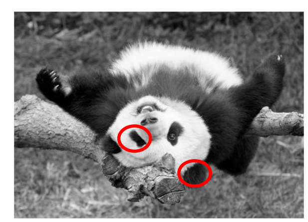
Slide credit: Kristen Grauman

Segmentation as clustering

Depending on what we choose as the *feature space*, we can group pixels in different ways.

Grouping pixels based on **intensity+position** similarity





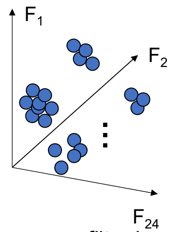
Both regions are black, but if we also include **position (x,y),** then we could group the two into distinct segments; way to encode both ***similarity & proximity.***

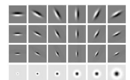
Slide credit: Kristen Grauman

Segmentation as clustering

Depending on what we choose as the *feature space*, we can group pixels in different ways.

Grouping pixels based on **texture** similarity



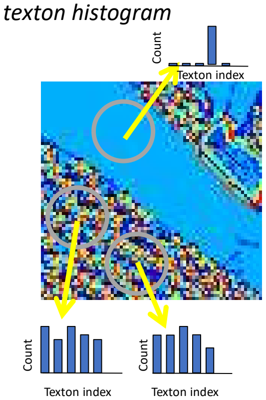


Feature space: filter bank responses (e.g., 24-d)

Slide credit: Kristen Grauman

Segmentation with texture features

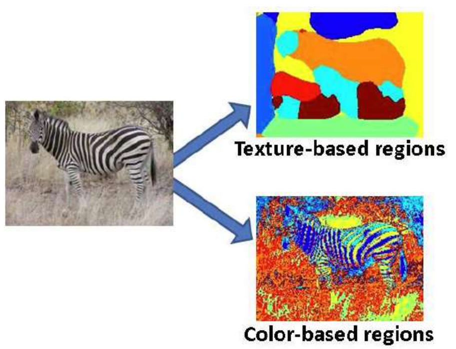
- Find "textons" by **clustering** vectors of filter bank outputs
- Describe texture in a window based on *texton histogram*



Malik, Belongie, Leung and Shi. IJCV 2001.

Adapted from Lana Lazebnik

Image segmentation example



Slide credit: Kristen Grauman

Region based segmentation

- Finding region based on the criterion of homogeneity and connectivity of pixels (region)
  - Each region is homogeneous (i.e., uniform in terms of the pixel attributes such as intensity, color, range, or texture, etc.)
  - and connected
- **Algorithms**:
  - Region growing
  - Split and merge algorithm
  - Hierarchical clustering
  - …

Region-based segmentation

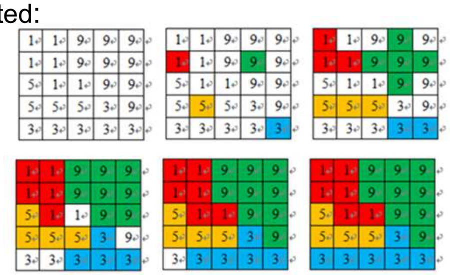
- Region-based approaches provide :
  - All pixels must be assigned to regions
  - Each pixel must belong to a single region only
  - Each region must be uniform
  - Any merged pair of adjacent regions must be non-uniform
  - Each region must be a connected set of pixels
- Region-based approaches:
  - Different methods
  - Common point: **homogeneity criteria**

Region growing

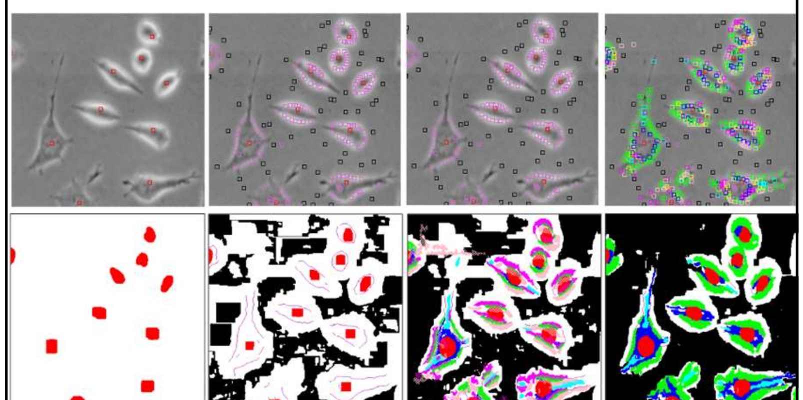
- Start from a point (seed) and add neighbor pixels following a given criteria
- The seeds can be manually or automatically chosen
  - automatic seeds in very homogeneous zones for example

Region growing algorithm

- Algorithm:
  - Choose K random pixels in K regions
  - Use 8-connected and threshold to determine
  - Repeat a and b until almost points are K classified.
- Example illustrated:



Region growing with multi-seeds

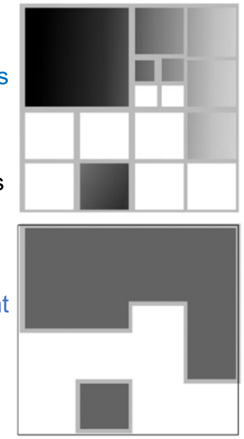


Example

Simulation of region growing (90% pixels)

Split and merge

- Split (step 1)
  - Recursively split all non-homogeneous regions following a given criteria
    - variance, max-min, …
  - Dividing one region gives 4 subregions
  - Subregion attributes are re-computed
- Merge (step 2)
  - Group all homogeneous adjacent regions following a given criteria



Split-and-merge: split

0	1	0	0	7	7	7	7
1	0	2	2	7	7	7	7
0	2	2	2	7	7	7	7
4	4	2	2	7	7	7	7
0	0	1	1	3	3	7	7
1	1	2	2	3	7	7	7
2	4	3	0	5	7	7	7
2	3	3	5	5	0	7	7

Image initiale

0	1	0	0	7	7	7	7
1	0	2	2	7	7	7	7
0	2	2	2	7	7	7	7
4	4	2	2	7	7	7	7
0	0	1	1	3	3	7	7
1	1	2	2	3	7	7	7
2	4	3	0	5	7	7	7
2	3	3	5	5	0	7	7

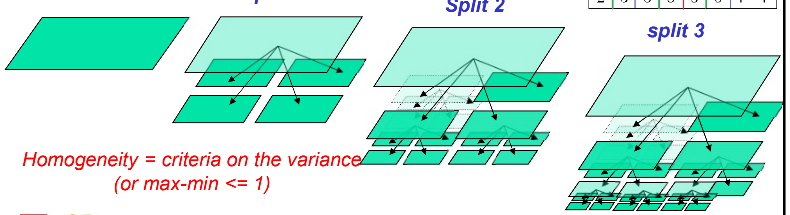
Split1

0	1	0	0	7	7	7	7
1	0	2	2	7	7	7	7
0	2	2	2	7	7	7	7
4	4	2	2	7	7	7	7
0	0	1	1	3	3	7	7
1	1	2	2	3	7	7	7
2	4	3	0	5	7	7	7
2	3	3	5	5	0	7	7

Split 2

0	1	0	0	7	7	7	7
1	0	2	2	7	7	7	7
0	2	2	2	7	7	7	7
4	4	2	2	7	7	7	7
0	0	1	1	3	3	7	7
1	1	2	2	3	7	7	7
2	4	3	0	5	7	7	7
2	3	3	5	5	0	7	7

split 3

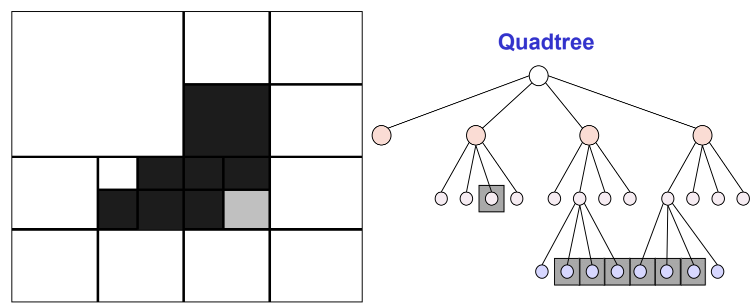


Homogeneity = criteria on the variance (or max-min <= 1)

Source : Jean-Christophe Baillie. Cours de segmentation. ENSTA ParisTech (France).

Split-and-merge: merge

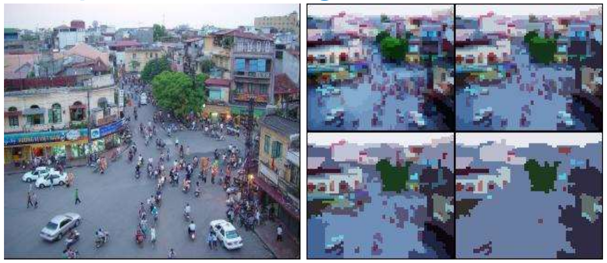
Phase 1: Create homogeneous zones (split)
Phase 2: Group homogeneous zone (merge)



Connect homogeneous adjacent regions

Source : Jean-Christophe Baillie. Cours de segmentation. ENSTA ParisTech (France)

Split-and-merge



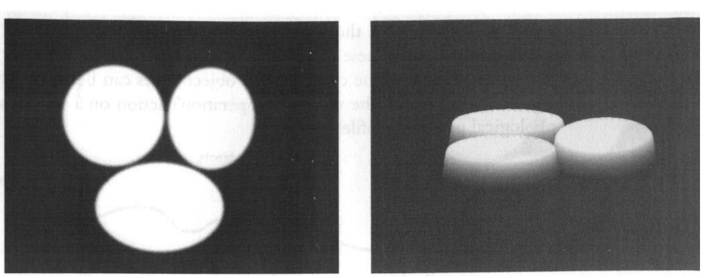
Edge based segmentation

- Finding region based on edges

- **Algorithms**:
  - Basic Edge Detection
  - The Marr-Hildreth edge detector (LoG)
  - Short response Hilbert transform (SRHLT)
  - Watersheds

Watershed segmentation

- We consider the image as a 3D shape using the gray level as the third dimension

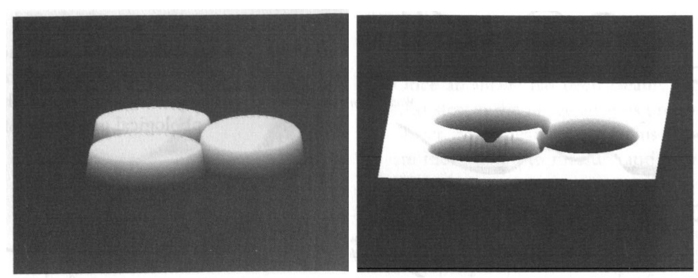


2D image Visualization in 3D

Source : http://www.gpa.etsmtl.ca/cours/gpa669/

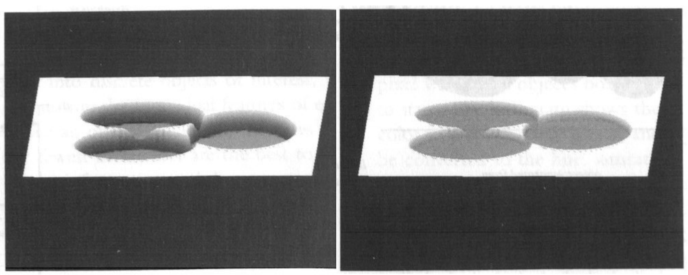
Watershed segmentation

- After we reverse (upside down) the values to create « holes » in the shape

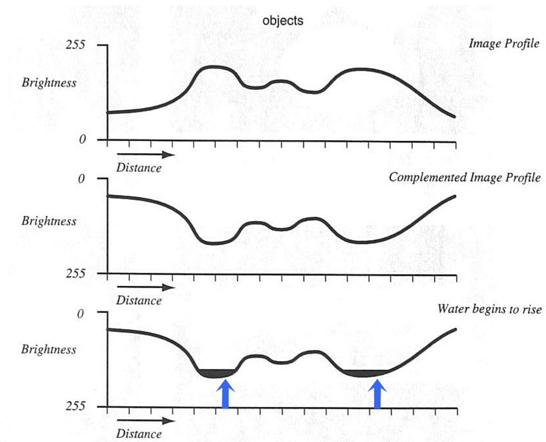


Watershed segmentation

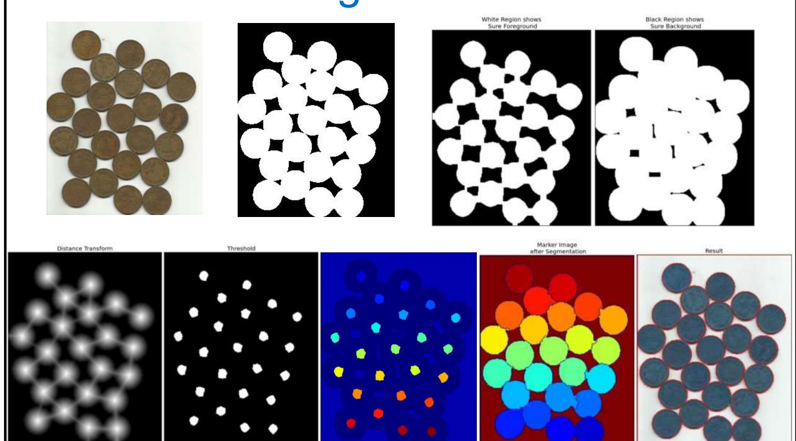
- Next we fill in the holes with water



Watershed segmentation

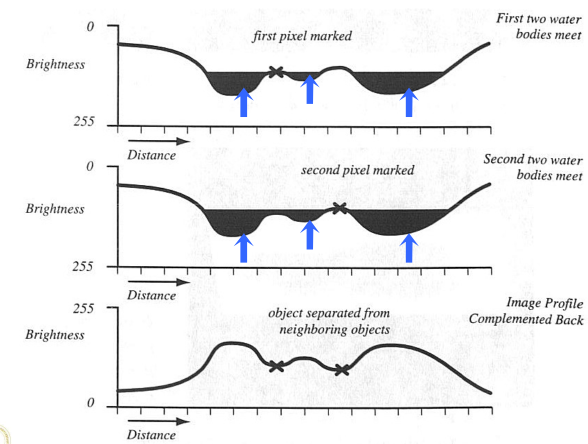


Watershed segmentation



https://docs.opencv.org/master/d3/db4/tutorial_py_watershed.html

Watershed segmentation



Segmentation – advices

- Image segmentation
  - No method works for all images
  - No miracle, no warranty!
- One of the main problem is to define the goal of segmentation:
  - What exactly are we looking for in the image?
    - Global regions or small details?
    - Presence or not of persons details in the face?
- It is good to think in advance what we will do with this segmentation results
  - This helps to define the level of precision needed

Segmentation – advices

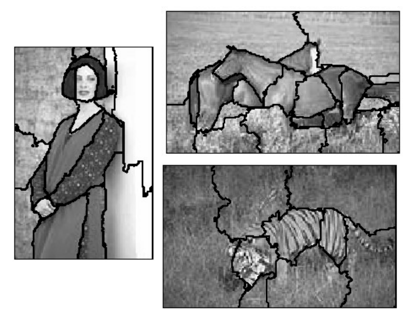
- Image Pre-processing:
  - good selection of sensors and energy source, and controled image acquisition conditions help to make segmentation easier and more efficient
- For some applications, we realize today that we can avoid to segment the image. It is often better like this.

Limits of segmentation

Image segmentation alone cannot find all image objects as we can interpret them

Segmentation vs. grouping

- Term 'segmentation' :
  - less used
  - segmentation, which let think about an exact image splitting into regions
- 'Pixel grouping'
  - which refers only to a notion of similarity between pixels without relation on the content of regions.



Source : [Malik 2001].

Motion segmentation

A.Barbu, S.C. Zhu. Generalizing Swendsen-Wang to sampling arbitrary posterior probabilities, *IEEE Trans. PAMI,* August 2005.

Credit: Kristen Grauman, UT Austin

Active contours-based segmentation

- Segmentation to find object boundaries or mid-level regions, tokens.
- Problem: Fitting an arbitrary shape with "active" deformable contours
- Deformable contours:
  - Representation of the contours
  - Defining the energy functions
  - External
  - Internal
  - Minimizing the energy function
- Extensions and applications:
  - Interactive segmentation
  - Tracking in video

Adapted from S. Seitz

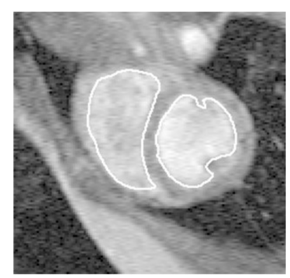
Active contours

- Deformable shapes and active contours are useful for:
  - Segmentation: fit or "snap" to boundary in image
  - Tracking: previous frame's estimate serves to initialize the next
- Fitting active contours:
  - Define terms to encourage certain shapes, smoothness, low curvature, push/pulls, …
  - Use weights to control relative influence of each component cost
  - Can optimize 2d snakes with Viterbi algorithm.
- Image structure (esp. gradients) can act as attraction force for interactive segmentation methods.

Adapted from S. Seitz

Application: Tracking via deformable contours

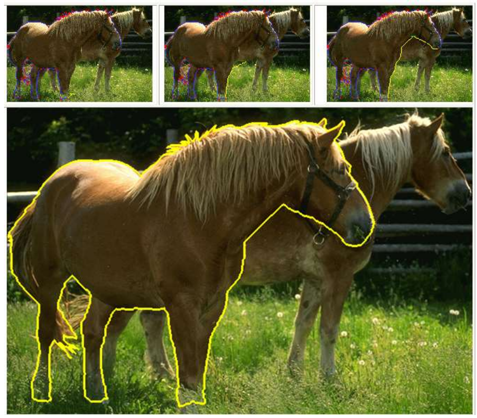
1. Use final contour/model extracted at frame *t* as an initial solution for frame *t+1*
2. Evolve initial contour to fit exact object boundary at frame *t+1*
3. Repeat, initializing with most recent frame.



Tracking Heart Ventricles (multiple frames)

Adapted from S. Seitz

Intelligent scissors



http://rivit.cs.byu.edu/Eric/Eric.html

69

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70