Lecture 21:
Segmentation I:
Thresholding, Region Growing, Region Merging

Contents

1. Introduction
2. Thresholding
3. Double Thresholding
4. Region Growing
5. Region Merging

Introduction

What is Segmentation?

- Partition of the image domain Ω into connected regions $\Omega_1, \dots, \Omega_n$.
- In the ideal case, every region Ω_i represents an object in the real world.
- The notion of segmentation is not uniform in the literature:
  - Sometimes already edge detection is regarded as segmentation.
    In this case, the contours need not to be closed.
  - We always require closed contours.
- Segmentation is one of the most difficult areas in image analysis. It may suffer from
  - inhomogeneous illumination conditions
  - occlusions
  - texture
  - lack of a priori knowledge
- No method works well in all situations.

Introduction (2)

Many books distinguish two different general strategies:

- **Region-Based Segmentation**
  - The grey values within the same segment should not have a large variance.
  - This is a global criterion that is often fairly stable (due to integration).
  - However, it may give unpleasant boundaries.

- **Edge-Based Segmentation**
  - Between two adjacent segments, there is a jump in the grey values.
  - This is a local decision that may be less stable (due to differentiation).
  - However, it can produce nicer boundaries.
  - Example: Zero crossings of the Laplacian (Lecture 13).
    Gives edge-based segmentation with closed contours as segment boundaries.

This distinction is somewhat artificial and focuses only on the extreme cases.
Thus, we do not consider it further.

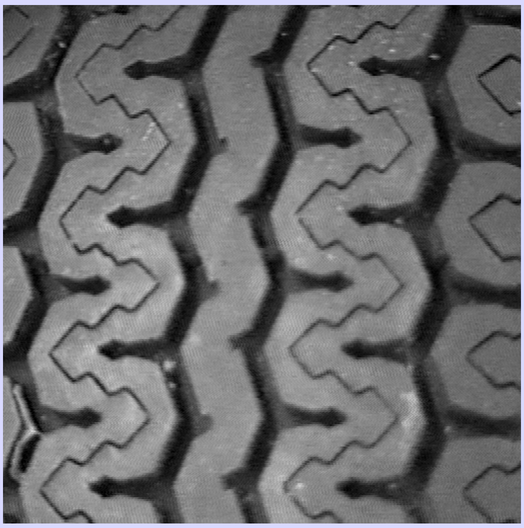
Introduction (3)

What About Texture?

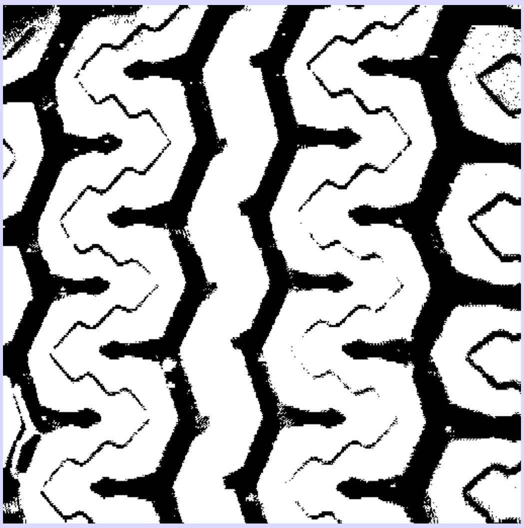
- Segmenting textures requires a preprocessing step:
  - Apply one or multiple texture descriptors, e.g. central moments averaged within some neighbourhood (cf. Lecture 20).
  - This creates an image with one or multiple feature channels.
    The averaging gives fairly homogeneous results within one segment.
- Afterwards some standard segmentation method for scalar- or vector-valued images can be applied.

Thresholding (Schwellwertbildung, Binarisierung)

- simplest segmentation method (cf. Lecture 10)
- creates a binary image:
  Grey values at one side of the threshold are assigned to one class,
  while the ones on the other side belong to the other.
- Problems:
  - selection of the threshold parameter T
  - ignores spatial context



original image, 256 greyscales



binarised at $T = 87$

Example of a segmentation by thresholding. Author: J. Weickert.

Thresholding (3)

Quantile Method for Computing the Threshold Parameter

- The p *quantile* of a histogram is the smallest grey value r such that the fraction p of all pixels has grey values $\leq r$.
- Example:
  - 70 % of all grey values are smaller than or equal to the 70 % quantile ($p = 0.7$).
- Application:
  - In optical character recognition, one knows typical quantiles for separating characters from the background.
  - This knowledge allows to select the threshold parameter automatically.
- Does not really solve the parameter selection problem, but eases it: Replaces one parameter (threshold T) by a more robust one (quantile q).

Thresholding (4)

Otsu's Method for Automatic Threshold Selection (1979)

- parameter-free
- Idea: Find a threshold that gives best separation between fore- and background.
- A threshold T decomposes the domain of an image $\boldsymbol{f} = (f_{i,j})$ into two classes $C_0(T)$ and $C_1(T)$, with grey values $\leq T$ resp. $> T$.
- Let us consider 256 grey levels $0,\ldots,255$. Let p_k denote the probability of grey value k in the image $\boldsymbol{f}$.
- Then the probabilites of the class occurences $C_0(T)$ and $C_1(T)$ are given by

$$
\begin{aligned}
P(C_0(T)) &= \sum_{k=0}^{T} p_k \;=:\; \omega(T), \\
P(C_1(T)) &= \sum_{k=T+1}^{255} p_k \;=\; 1 - \omega(T),
\end{aligned}
$$

where $\omega(T)$ denotes the *cumulative probability.*

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Thresholding (5)

- Let $\mu(T) := \sum_{k=0}^{T} k\, p_k$ be the *cumulative mean.*

  and $\mu_{\text{tot}} := \sum_{k=0}^{255} k\, p_k$ the *(total) mean.*

- Then the *class mean levels* of C_0 and C_1 are given by

$$\mu_0(T) \;:=\; \frac{\sum_{k=0}^{T} k\, p_k}{\sum_{k=0}^{T} p_k} \;=\; \frac{\mu(T)}{\omega(T)},$$

$$\mu_1(T) \;:=\; \frac{\sum_{k=T+1}^{255} k\, p_k}{\sum_{k=T+1}^{255} p_k} \;=\; \frac{\mu_{\text{tot}} - \mu(T)}{1-\omega(T)}.$$

- Otsu wanted to obtain the best separation between the two classes.
  Thus, he searched for the threshold T that maximises the *between class variance*

$$\sigma_B^2(T) \;:=\; \omega(T)\,\big(\mu_0(T)-\mu_{\text{tot}}\big)^2 \;+\; (1-\omega(T))\,\big(\mu_1(T)-\mu_{\text{tot}}\big)^2.$$

Thresholding (6)

Efficient Implementation of Otsu's Method

- We want to evaluate the between class variance $\sigma_B^2(T)$ effiently for $T = 1,\ldots,255$.

- In an assignment you will show that it can be computed via

$$\sigma_B^2(T) \;=\; \frac{(\mu_{\text{tot}}\,\omega(T) - \mu(T))^2}{\omega(T)\,(1-\omega(T))}.$$

- Here the total mean μ_{tot} is computed once:

$$\mu_{\text{tot}} \;=\; \sum_{k=0}^{255} k\, p_k\,.$$

- One obtains the cumulative probability $\omega(T)$ and the cumulative mean $\mu(T)$ iteratively from $\omega(T-1)$ and $\mu(T-1)$:

$$\omega(T) \;=\; \omega(T-1) + p_T\,,$$
$$\mu(T) \;=\; \mu(T-1) + T p_T\,.$$

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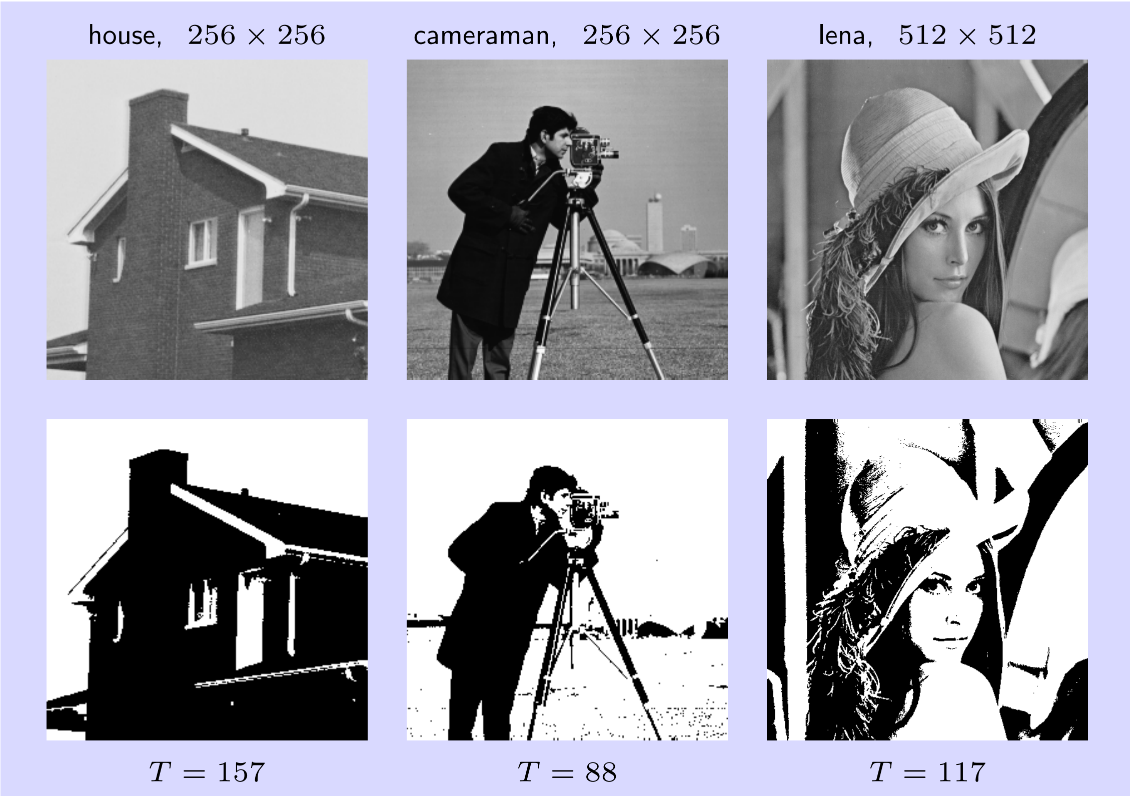

Automatic Otsu threshold selection for three popular test images. Author: J. Weickert.

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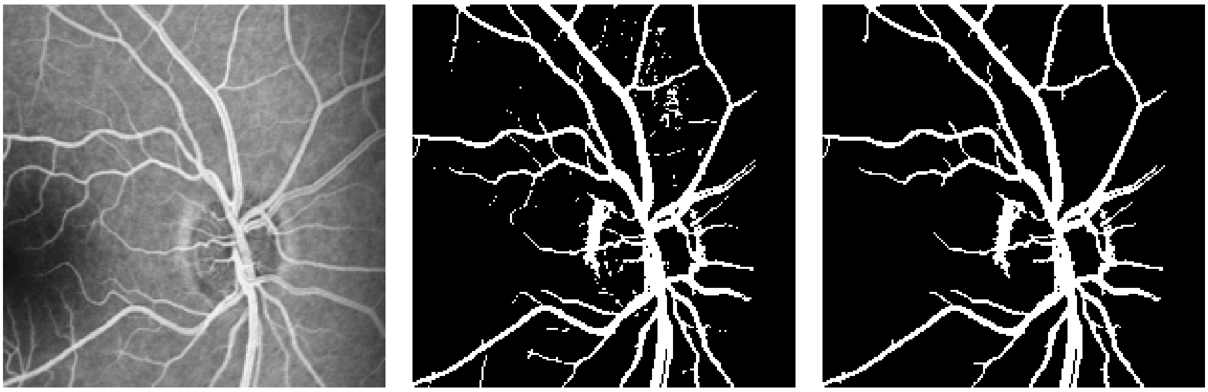
Double Thresholding

- used e.g. in the Canny edge detector (hysteresis thresholding, Lecture 13)
- A larger threshold T_2 yields “seeds” of the segmentation.
  Grey values above T_2 are accepted in all cases.
- These seed regions may grow in all directions:
  - Neigbbour pixels are added if their grey values exceed a smaller threshold T_1.
  - One proceeds iteratively until the process terminates.
- Double thesholding takes into account the spatial context of pixels,
  while single thresholding does not.
- Often it performs better than a single threshold.

Double Thresholding (2)



Single thresholding versus double thresholding. **Left:** Original image of the eye background, 200×200 pixels. **Middle:** Binarisation with a single threshold $T = 160$. **Right:** Double thresholding with $T_1 = 160$ and $T_2 = 210$. Author: J. Weickert.

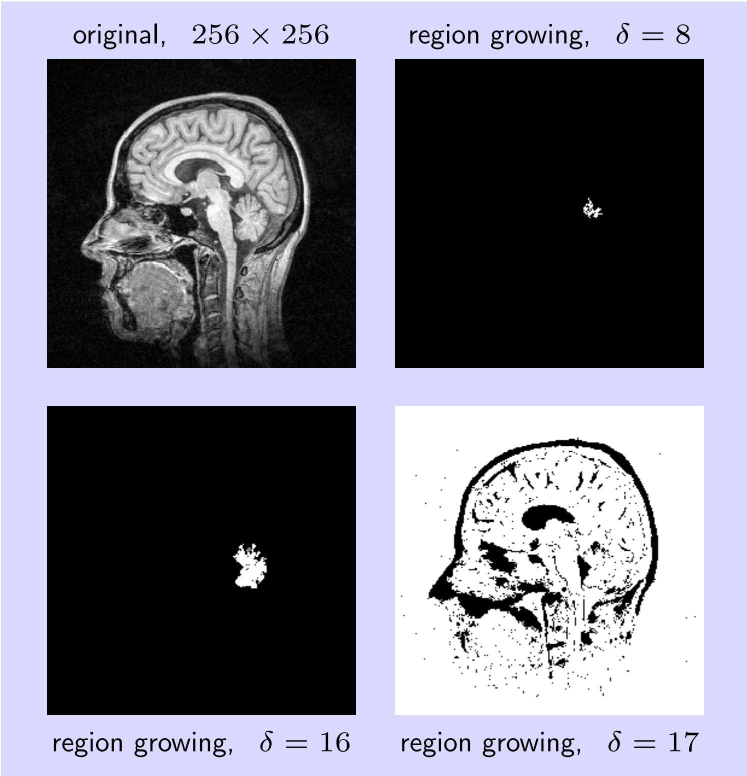
Region Growing (1)

Region Growing (Regionenwachstum)

Basic Idea

- method for separating a *single* object from its background
- Start with a manually marked seed within the structure to be segmented.
- Let this seed grow into its neighbourhood,
  as long as the grey value of a neighbour differs by less then some specified value δ.

Region Growing (2)



Region growing of an MR image with a pixel inside the cerebellum as seed. While the cerebellum is well segmented for $\delta = 16$, the segmentation for $\delta = 17$ is useless. Author: J. Weickert.

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Region Growing (3)

Advantages

- uses spatial context
- interactive: loved by clinicians
- robust within its segment: any seed inside the segment yields same segmentation

Disadvantages

- may not be robust w.r.t. the parameter δ
- requires an object that clearly differs from its background:
  unsharp boundaries can lead to undesirable growth
  (no mechanism to control the size of segments)
- sensitive w.r.t. noise

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Region Merging (Regionenverschmelzen)

Basic Idea

- merge all pixels with their neighbours if the grey values differ by less than δ
- similar to region growing, but
  - does not need a seed
  - creates a segmentation that may contain *many* segments

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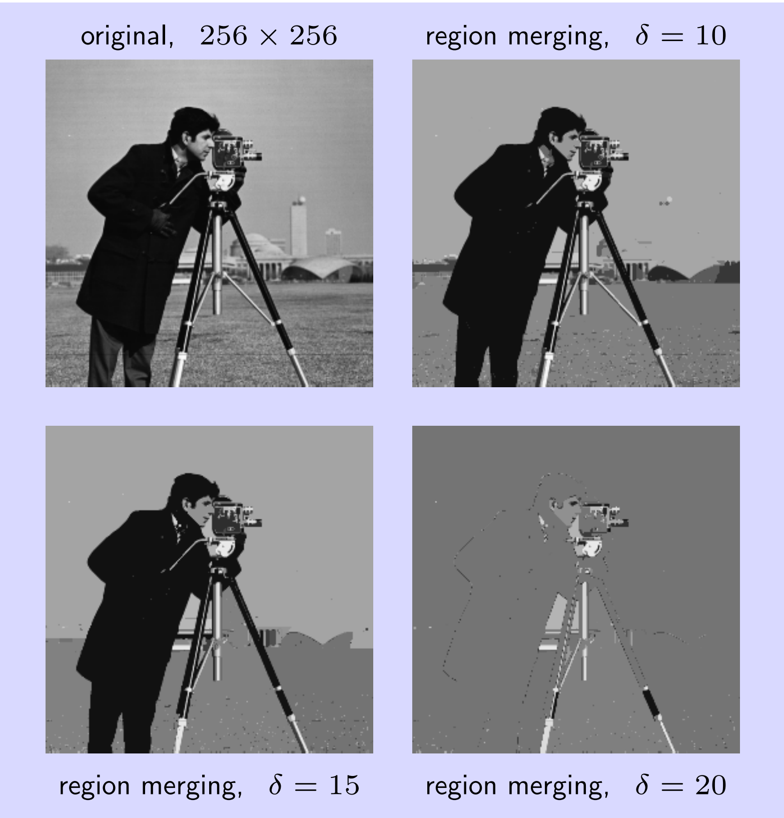

Sensitivity of the region merging result w.r.t. the merging parameter δ. Author: J. Weickert.

Region Merging (3)

Advantages

- uses spatial context
- hierarchical segmentation:
  increasing δ merges more and more segments

Disadvantages

Region merging has similar problems as region growing:

- difficulty of finding a good parameter δ that works well for the entire image
- ignores size of objects:
  - large object merges with background if local contrast is too small
  - small segment (and noise) survives if contrast is too high

Summary

Summary

- Segmentation belongs to the most difficult problems in image analysis.
- Thresholding is the simplest segmentation method.
  It does not take into account the spatial context.
- The threshold parameter can be determined automatically using Otsu's method.
  It maximises the between class variance.
- Double thresholding may perform better then regular thresholding.
  It incorporates spatial context.
- Region growing and region merging also exploit the spatial context.
  However, their standard implementations rarely perform very well.

References

- K. D. Tönnies: *Grundlagen der Bildverarbeitung*. Pearson, München, 2005.
  (Chapter 8 gives an introduction to simple segmentation approaches.)
- R. Jain, R. Kasturi, B. G. Schunck: *Machine Vision*, Mc Graw-Hill, New York, 1995.
  (for thresholding, region growing, region merging)
- N. Otsu: A threshold selection method from gray-level histograms. *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 9, No. 1, 62–66, Jan. 1979.
  (original paper describing Otsu's method).