Week02 • Semester 2 • 2018

Morphological Image Processing

Appendix

- ❑ Morphological filters and algorithms
- ❑ Morphological watersheds
- ❑ Computer vision applications

Appendix

Morphological Filters

- In practical image processing applications, dilation, erosion, opening, and closing are used most often in various combinations.
- Morphological operations can be used to construct filters similar to the spatial filters.

combinations of morphological operations

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Morphological Filters

Appendix

EXAMPLE_ fingerprint image enhancement with morphological filters

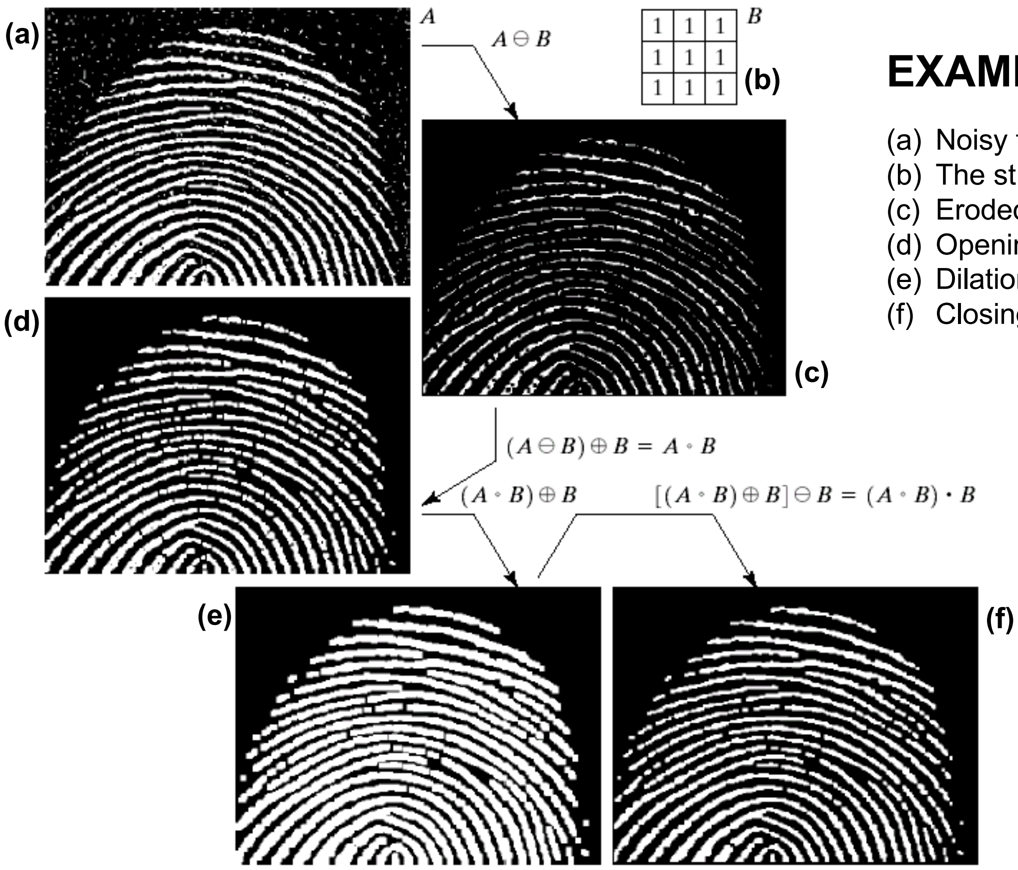
The original noisy fingerprint image

The enhanced fingerprint image
with background noise removing

Appendix

EXAMPLE_

(a) Noisy fingerprint image
(b) The structuring element
(c) Eroded image
(d) Opening of A
(e) Dilation of the opening
(f) Closing of the opening



EXAMPLE_ fingerprint image enhancement with morphological filters

- The binary image shown in Fig.(a) (previous slide) shows a section of a fingerprint corrupted by noise. Here the noise manifests itself as light elements on a dark background and as dark elements on the light components of the fingerprint. The objective is to eliminate the noise and its effects on the print while distorting it as little as possible. A morphological filter consisting of opening followed by closing can be used to accomplish this objective.
- The structuring element used is shown in Fig.(b). The rest of figure shows a step-by-step sequence of the filtering operation. Fig.(c) shows the result of eroding *A* with the structuring element. The background noise was completely eliminated in the erosion stage of opening because in this case all noise components are physically smaller than the structuring element. The size of the noise elements (dark spots) contained within the fingerprint actually increased in size. The reason is that these elements actually are inner boundaries that should increase in size as the object is eroded. This enlargement is countered by performing dilation on Fig.(c). Fig.(d) shows the result. The noise components contained in the fingerprint were reduced in size or deleted completely.
- The two operations just described constitute the opening of *A* by *B*. We note in Fig.(d) that the net effect of opening was to eliminate virtually all noise components in both the background and the fingerprint itself. However, new gaps between the fingerprint ridges were created. To counter this undesirable effect, we perform a dilation on the opening, as shown in Fig.(e). Most of the breaks were restored, but the ridges were thickened, a condition that can be remedied by erosion. The result, shown in Fig.(f) , constitutes the closing of the opening in Fig.(d). This final result is remarkably clean of noise specks, but it has the disadvantage that some of the print ridges were not fully repaired, and thus contain breaks. This is not totally unexpected, because no conditions were built into the procedure for maintaining connectivity.

Basic Morphological Algorithms

- When dealing with binary images, one of the principal applications of morphology is in extracting image components that are useful in the representation and description of shape.
- In particular, we consider morphological algorithms for extracting boundaries, connected components, and the skeleton of a region.
- Some basic morphological algorithms such as boundary extraction, region filling, thinning, thickening, and pruning are used frequently as image pre- or post-processing steps.

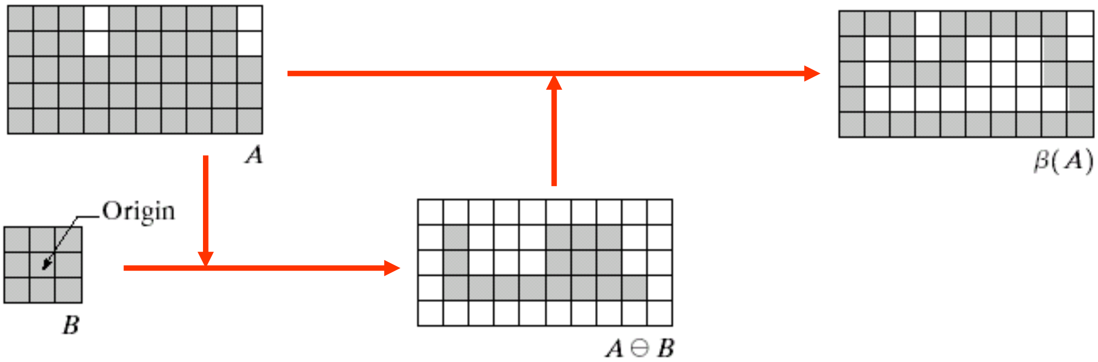
Appendix

Boundary Extraction

- The **boundary** of a set A, denoted by $\beta(A)$, can be obtained by first eroding A by B and then performing the set difference between A and its erosion. That is,

$$\beta(A) = A - (A \ominus B)$$

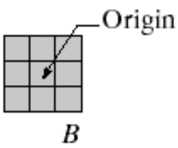
where B is a suitable structuring element.

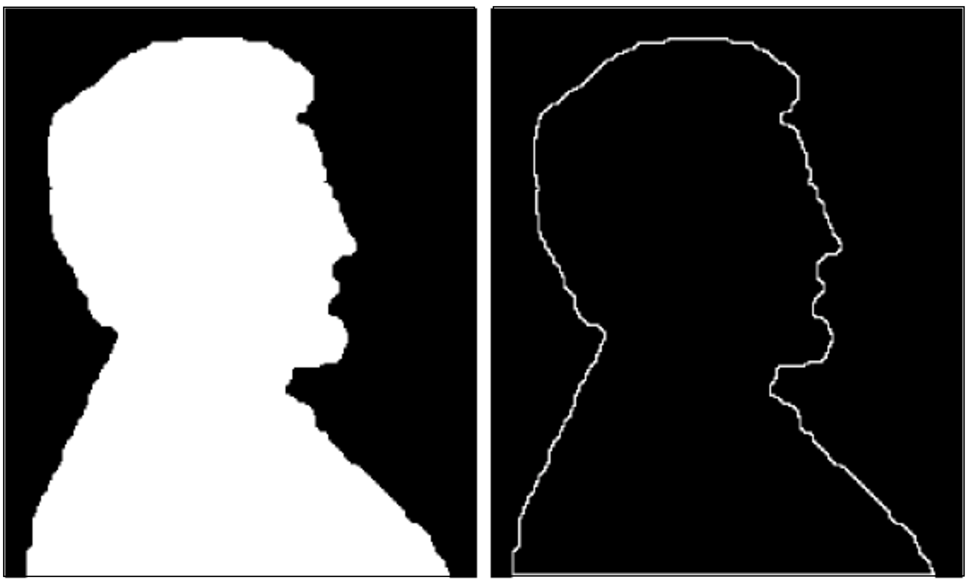


Appendix

Boundary Extraction

Example_

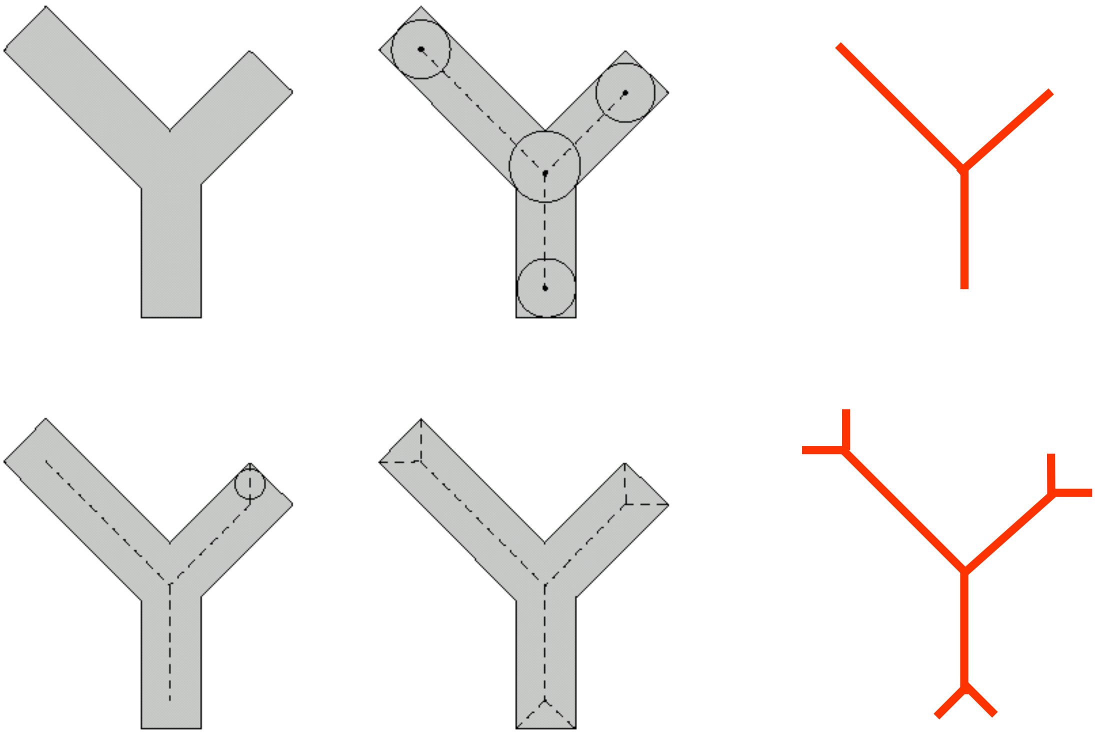




(a) (b)

Appendix

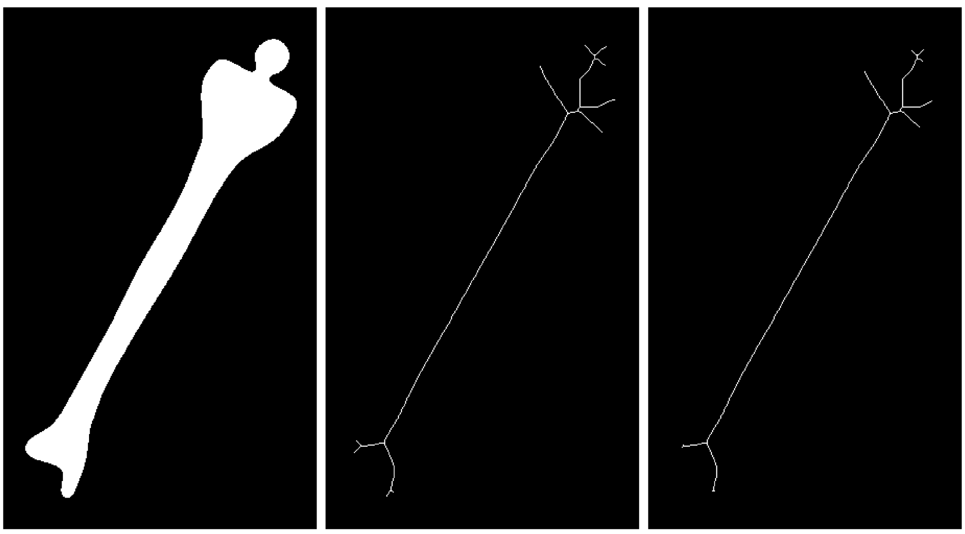
Extracting the Skeleton of a Region



Appendix

Extracting the Skeleton of a Region

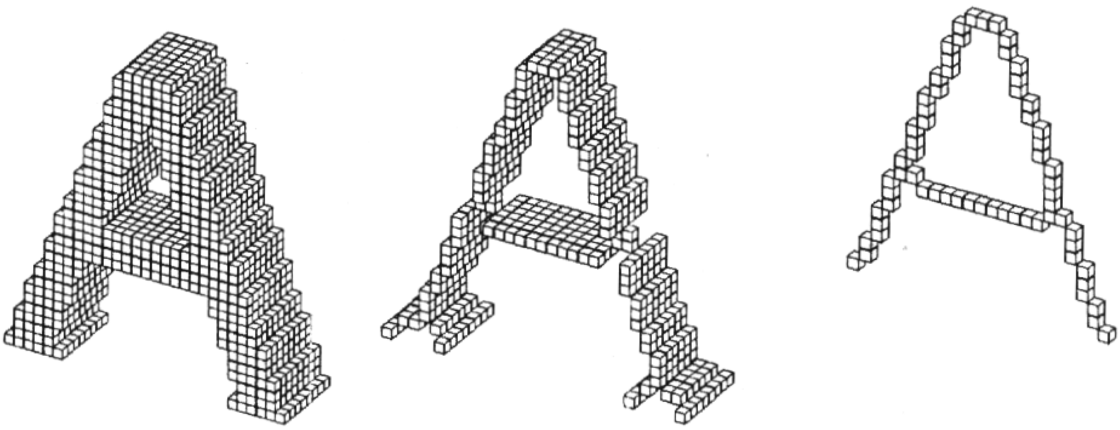
Example



Human leg bone and skeletons of the region with different structuring elements

Appendix

Morphological Thinning for 3D Skeleton Segmentation



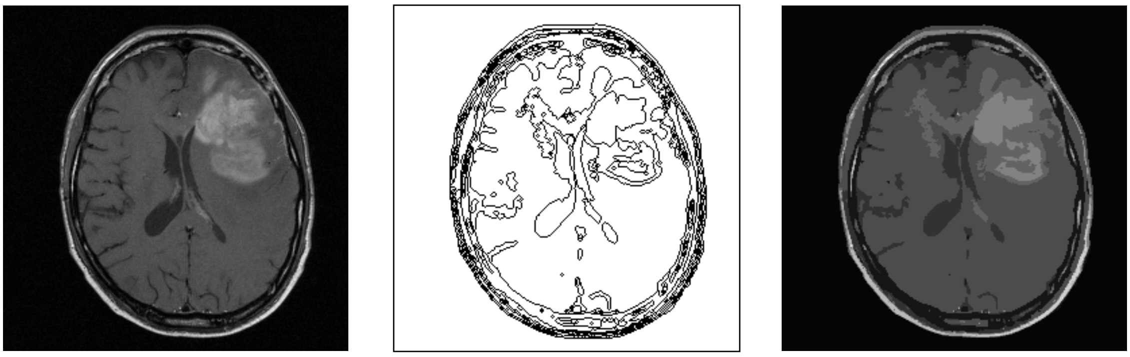
(a) (b) (c)

Application – Analysis of 3D computer tomography images

Appendix

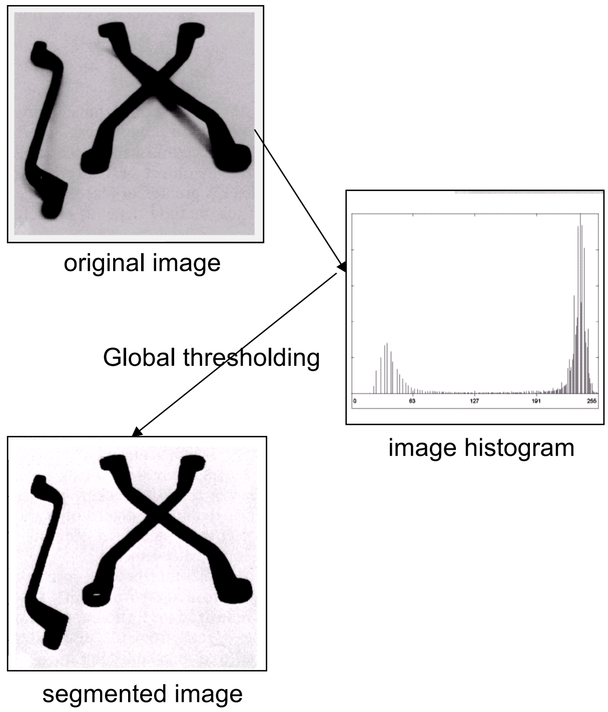
Image Segmentation

- Segmentation subdivides an image into its constituent regions.
- The level to which the subdivision is carried depends on the problem being solved. That is, segmentation should stop when the objects of interest in an application have been isolated.
- Segmentation of nontrivial images is one of the most difficult tasks in image processing.



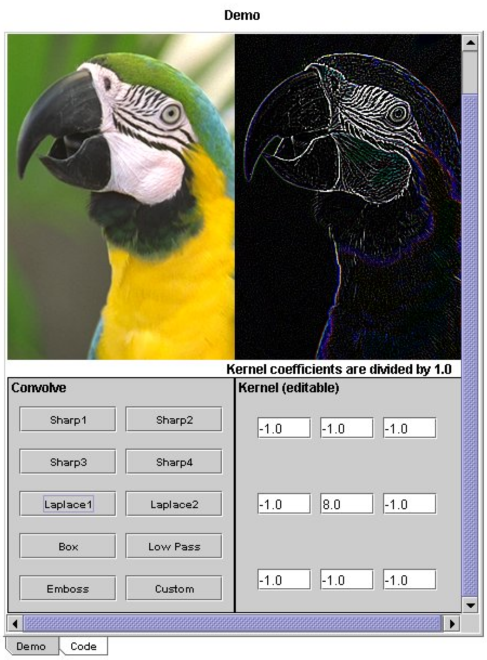
Appendix

Image Segmentation



Appendix

Image Segmentation



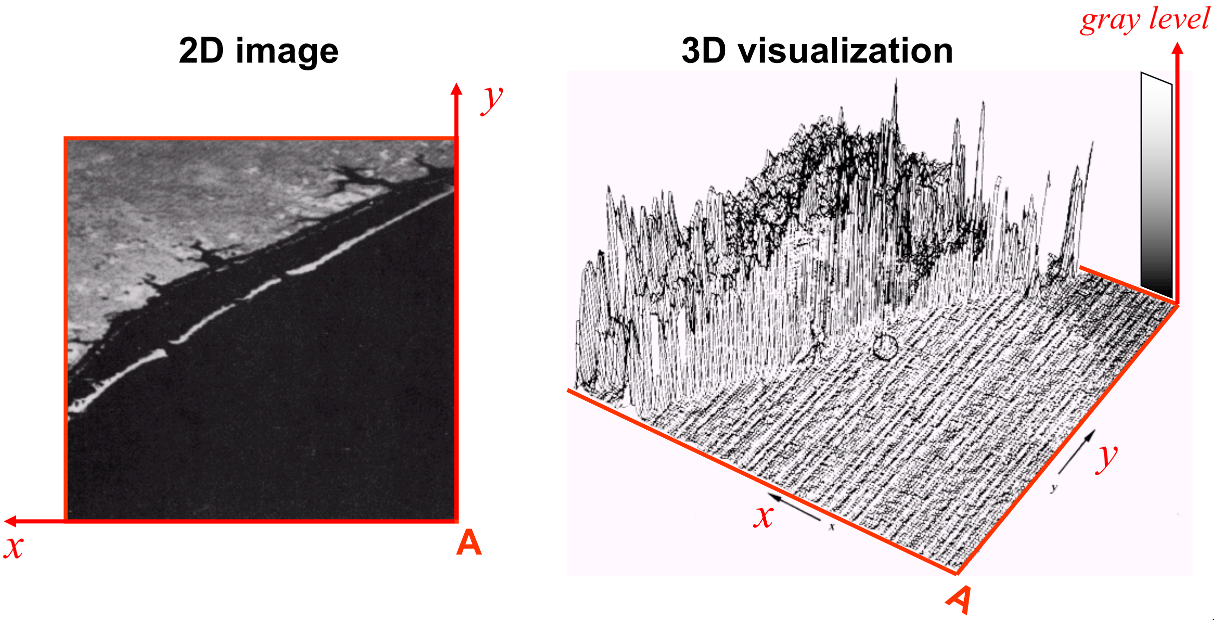
- Problem:
  discontinuous segmentation boundaries

- Disadvantage:
  the need for post-processing, such as edge linking, in methods based on detecting discontinuities in gray levels

Appendix

Segmentation by Morphological Watersheds

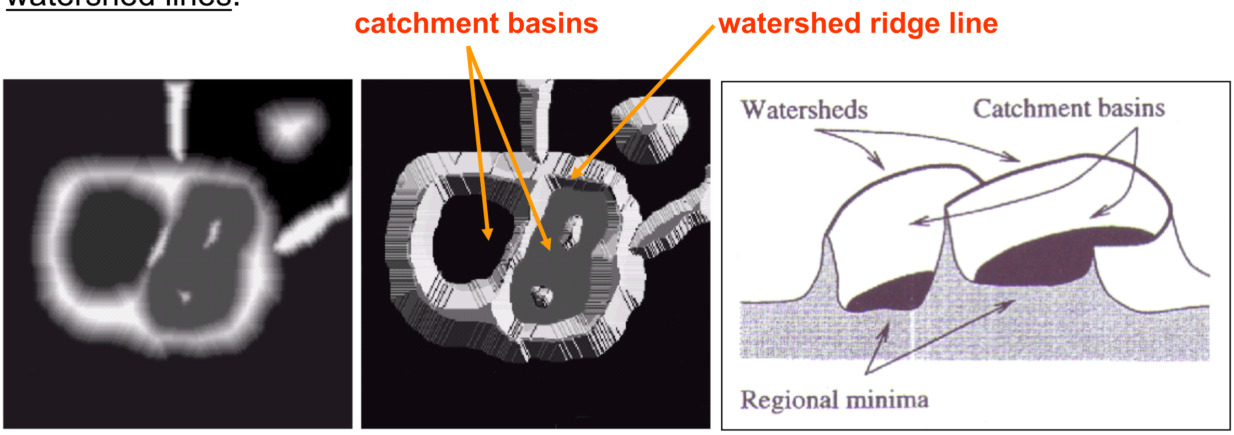
- The concept of watersheds is based on visualizing an image in three dimensions: two spatial coordinates versus gray levels.



Appendix

Segmentation by Morphological Watersheds

- In such a "topographic" interpretation, we consider three types of points: (a) points belonging to a regional minimum; (b) points at which a drop of water, if placed at the location of any of those points, would fall with certainty to a single minimum; and (c) points at which water would be equally likely to fall to more than one such minimum.
- For a particular regional minimum, the set of points satisfying condition (b) is called the **catchment basin** or **watershed** of that minimum. The points satisfying condition (c) form crest lines on the topographic surface and are termed divide lines or watershed lines.

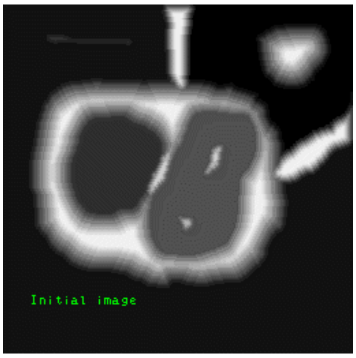


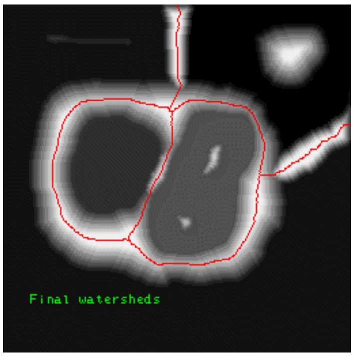
original image topographic view 3D landscape view

Segmentation by Morphological Watersheds

Appendix

- The principal objective of segmentation algorithms based on these concepts is to find the watershed lines.





- The basic idea is simple: Suppose that a hole is punched in each regional minimum and that the entire topography is flooded from below by letting water rise through the holes at a uniform rate. When rising water in distinct catchment basins is about to merge, a dam is built to prevent the merging. The flooding will eventually reach a stage when only the tops of the dams are visible above the water line. These dam boundaries correspond to the divide lines of the watersheds. Therefore, they are the (continuous) boundaries extracted by a watershed segmentation algorithm.

Segmentation by Morphological Watersheds

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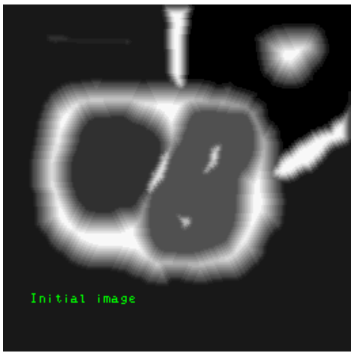
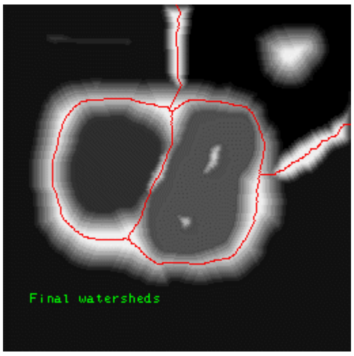
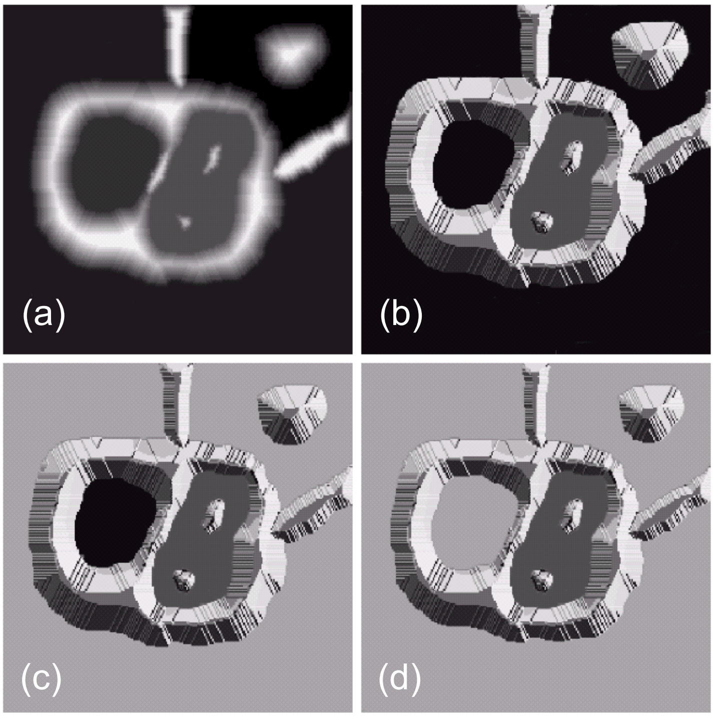


step-by-step



Segmentation by Morphological Watersheds



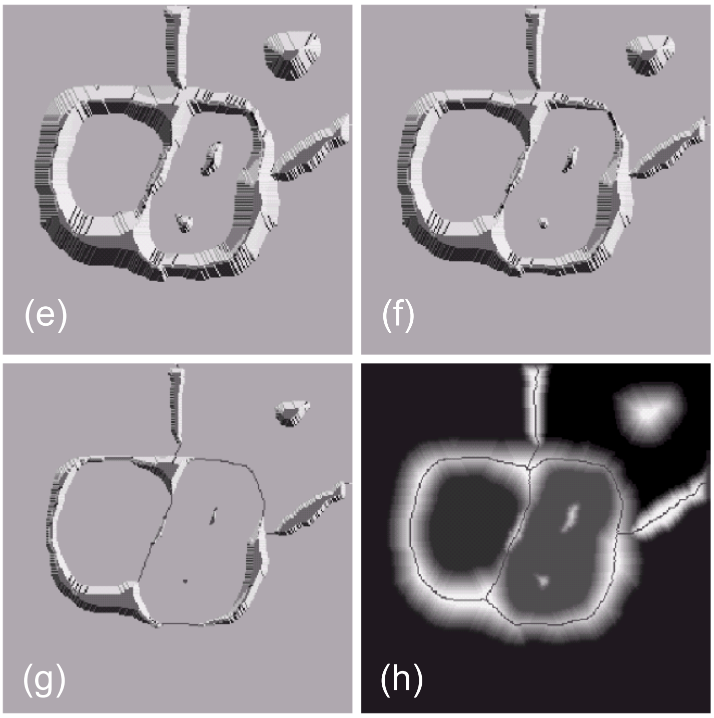
(a) Original image

(b) Topographic view

(c) The first stage of flooding

(d) The second stage of flooding

Segmentation by Morphological Watersheds



(e) Result of further flooding

(f) Beginning of merging of water from two catchment basins (a short dam was built between them)

(g) Longer dams

(h) Final watershed (segmentation) lines

Segmentation by Morphological Watersheds

Appendix

- Figure (a) in the previous slide shows a simple gray-scale image and Fig. (b) is a topographic view, in which the height of the “mountains” is proportional to gray-level values in the input image. Fore ease of interpretation, the backsides of structures are shaded. This is not to be confused with gray-level values; only the general topography of the three-dimensional representation is of interest. In order to prevent the rising water from spilling out through the edges of the structure, we imagine the perimeter of the entire topography (image) being enclosed by dams of height greater than the highest possible mountain, whose value is determined by the highest possible gray-level value in the input image.
- Suppose that a hole is punched in each regional minimum [shown as dark areas in Fig. (b)] and that the entire topography is flooded from below by letting water rise through the holes at a uniform rate. Figure (c) shows the first stage of flooding, where the “water”, shown in light gray, has covered only areas that correspond to the very dark background in the image. (Cont’)

Segmentation by Morphological Watersheds

Appendix

- In Figs. (d) and (e) we see that the water now has risen into the first and second catchment basins, respectively. As the water continues to rise, it will eventually overflow from one catchment basin into another. The first indication of this is shown in (f). Here, water from the left basin actually overflowed into the basin on the right and a short “dam” (consisting of single pixels) was built to prevent water from merging at that level of flooding. The effect is more pronounced as water continues to rise, as shown in (g). This figure shows a longer dam between the two catchment basins and another dam in the top part of the fight basin. The latter dam was built to prevent merging of water from that basin with water from areas corresponding to the background. This process is continued until the maximum level of flooding (corresponding to the highest gray-level value in the image) is reached. The final dams correspond to the watershed lines, which are the desired segmentation result. The result for this example is shown in (h) as a dark, one-pixel-thick path superimposed on the original image. Note the important property that the watershed lines form a connected path, thus giving continuous boundaries between regions.

Appendix

Segmentation by Morphological Watersheds

- One of the principal applications of watershed segmentation is in the extraction of nearly uniform (bloblike) objects from the background.
- Regions characterized by small variations in gray levels have small **gradient** values.
- Thus, in practice, we often see watershed segmentation applied to the gradient of an image, rather than to the image itself.

Appendix

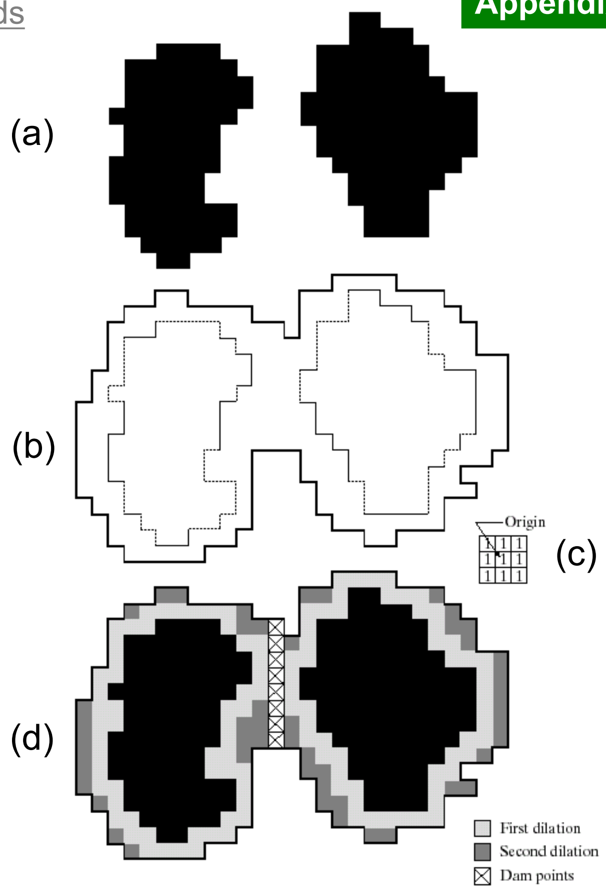
Dam Construction by Morphological Dilation

(a) Two partially flooded catchment basins at stage n-1 of flooding

(b) Flooding at stage n, showing that water has spilled between basins (for clarity, water is shown in white rather than black)

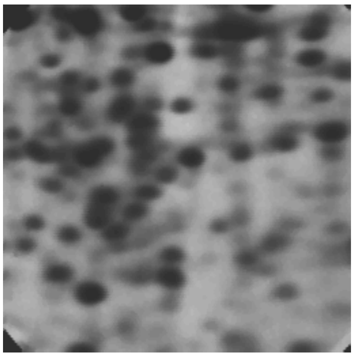
(c) Structuring element used for dilation

(d) Result of dilation and dam construction

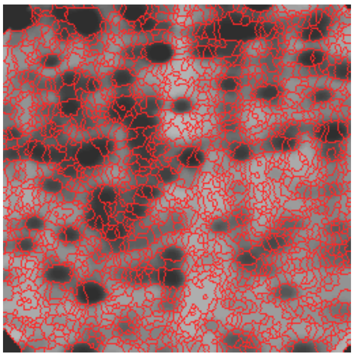


Segmentation by Morphological Watersheds

However, in practice, this transform produces
an important over-segmentation
due to noise or local irregularities in the gradient image.



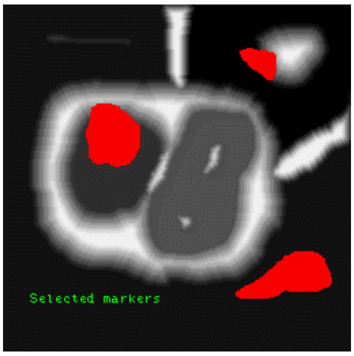
Electrophoresis gel image



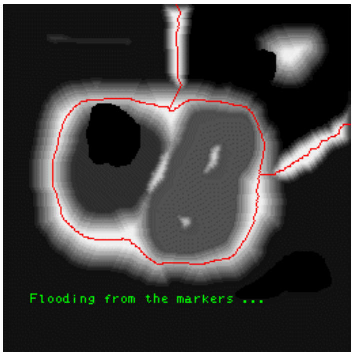
Watershed transformation of
the gradient image.

Marker-Controlled Watersheds

A major enhancement of the watershed transformation
consists in flooding the topographic surface
from a previously defined set of markers.



Markers of the blobs
and the background



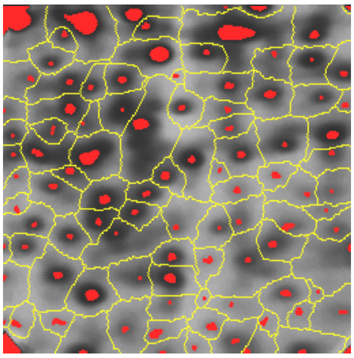
Marker-controlled watershed
of the gradient image.

step-by-step

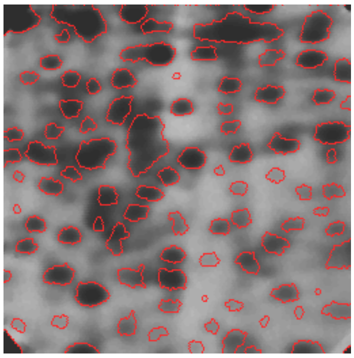
Appendix

Marker-Controlled Watersheds

With this method, we can prevent any over-segmentation



Markers of the blobs and the background



Marker-controlled watershed of the gradient image.

Appendix

Morphological Image Processing & Computer Vision

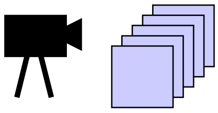
- The goal of **computer vision** is to make useful decisions about real physical objects and scenes based on sensed images.
- In order to make decisions about real objects, it is almost always necessary to construct some description or model of them from the image.
- The ultimate aim in a large number of image processing applications is to extract important features from image data, from which a description, interpretation, or understanding of the scene can be provided by the machine.
- The term “computer vision” is also called “machine vision”. However, we often use the term “machine vision” in the context of industrial applications and the term “computer vision” with the field in general.

Appendix

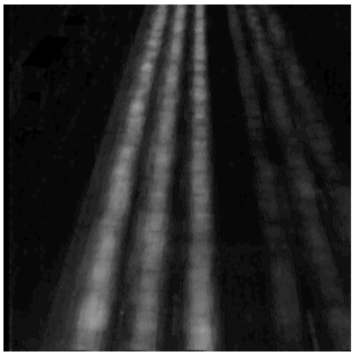
Computer Vision Application – traffic monitoring

- In order to count the vehicles in the different lanes of the road, an automatic segmentation of the lanes must be performed.

(A) original video frame



(B) an average image
emphasizing the still regions of the scene



(C) a differential image
enhancing the moving parts of the scene

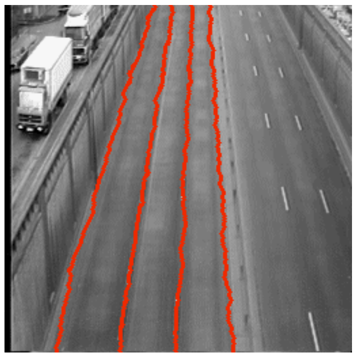
Appendix

Computer Vision Application – traffic monitoring

- In order to count the vehicles in the different lanes of the road, an automatic segmentation of the lanes must be performed.

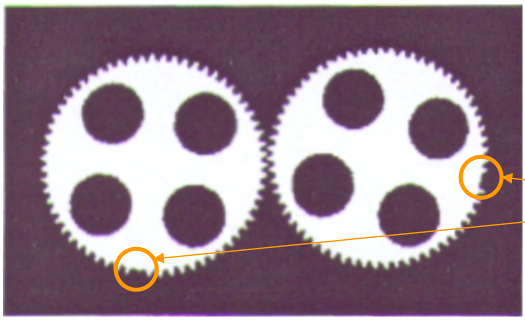
(D) the segmented image
from the differential image in (C)

(E) an masked image
from (B) and (D)



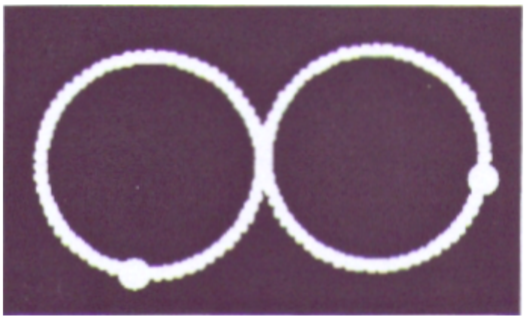
(F) the segmented lanes
using morphological watersheds

Computer Vision Application – the gear-tooth inspection procedure



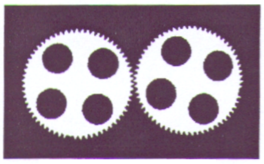
A binary image of a watch gear

2 missing or broken teeth



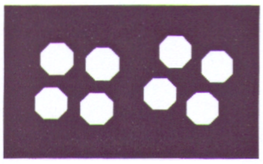
Inspection result:
2 large blobs → 2 defects in the teeth

Computer Vision Application – the gear-tooth inspection procedure

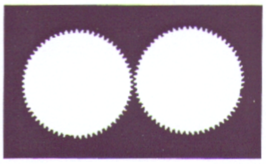


(a) Original image **B**

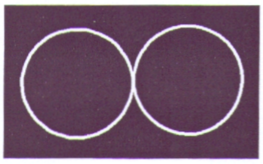
(b) **B1** = **B** ⊖ **hole_ring**



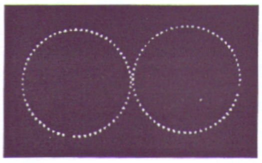
(c) **B2** = **B1** ⊕ **hole_mask**



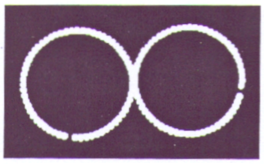
(d) **B3** = **B** OR **B2**



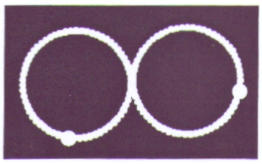
(e) **B7** (see text)



(f) **B8** = **B** AND **B7**



(g) **B9** = **B8** ⊕ **tip_spacing**



(h) RESULT = ((**B7**-**B9**) ⊕ **defect_cue**) OR **B9**

(i) **Structuring Elements**

hole_ring: a ring of pixels whose diameter is slightly larger than the diameters of the four holes in the watch gears. If fits just around these holes and can be used to mark a few pixels at their centers.

hole_mask: an octagon that is slightly larger than the holes in the watch gears.

gear_body: a disk structuring element that is as big as the gear minus its teeth.

sampling_ring_spacer: a disk structuring element that is used to move slightly outward from the gear body.

sampling_ring_width: a disk structuring element that is used to dilate outward to the tips of the teeth.

tip_spacing: a disk structuring element whose diameter spans the tip-to-tip space between teeth.

defect_cue: a disk structuring element whose purpose is to dilate defects in order to show them to the user.

Appendix

Computer Vision Application – the gear-tooth inspection procedure

- Binary morphology can be used to perform very specific inspection tasks in industrial machine vision. Sternberg [1] showed how a watch gear could be inspected to check whether it had any missing or broken teeth.
- Figure (a) in the previous page shows a binary image of a watch gear. The watch gear has four holes inside of the main object and is surrounded by a number of teeth, which are individually visible in the image. In order to process the watch gear images, Sternberg defined several special purpose structuring elements (see Figure (i)) whose shapes and sizes were derived from the physical properties of the watch gear.
- Figure (a) – (h) illustrate the gear-tooth inspection procedure. Figure (a) shows the original binary image to be inspected. Figure (b) shows the result of eroding the original image with the **hole_ring** structuring element. The result image has 1-pixels in a tiny cluster in the centre of each hole. These are the only pixel locations where the **hole_ring** structuring element completely overlapped the object region. Figure (c) shows the result of dilating the previous image with structuring element **hole_mask**. The result here is four octagons covering the original four holes. Figure (d) shows the result of ORing the four octagons into the original binary image. The result is the gear with the four holes filled in.

Appendix

Computer Vision Application – the gear-tooth inspection procedure

- The next step is to produce a sampling ring that can be used to check the teeth. It is produced by taking the image of Figure (d), opening it with structuring element **gear_body** to get rid of the teeth, dilating that with structuring element **sampling_ring_spacer** to bring it out to the base of the teeth, dilating that with the structuring element **sampling_ring_width** to bring the next image out to the tip of the teeth, and subtracting the second to the last result from the last result to get a ring that just fits over the teeth. The sampling ring is shown in Figure (e).
- Once we have the sampling ring, it is ANDed with the original image to produce an image of just the teeth, as shown in Figure (f). The gaps are already visible, but not marked. Dilating the teeth image with the structuring element **tip_spacing** produces the solid ring image shown in Figure (g) which has spaces in the solid ring wherever there are defects in the teeth. Subtracting this result from the sampling ring leaves only the defects, which are dilated by structuring element **defect_cue** and shown to the user as large blobs on the screen.

Reference
[1] Sternberg, S.R. 1985. An overview of image algebra and related architectures. *Integrated Technology for Parallel Image Processing*. Academic Press, London, 79-100.