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CS 4495 Computer Vision

*Binary images and Morphology*

**Aaron Bobick School of Interactive Computing**

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Administrivia

•PS7 – read about it on Piazza

•PS5 – grades are out.

•Final – Dec 9

• Study guide will be out by Thursday hopefully sooner.

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Binary Image Analysis

Operations that produce or process binary images, typically 0’s and 1’s

•0 represents background

•1 represents foreground

00010010001000 00011110001000 00010010001000

Slides: Linda Shapiro

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Binary Image Analysis

Used in a number of practical applications

•Part inspection

•Manufacturing

•Document processing

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What kinds of operations?

•Separate objects from background and from one another

•Aggregate pixels for each object

•Compute features for each object

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Example: Red blood cell image

• Many blood cells are separate objects

• Many touch – bad!

• Salt and pepper noise from thresholding

• How useable is this data?

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Results of analysis

• 63 separate objects detected

• Single cells have area about 50

• Noise spots

• Gobs of cells

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Useful Operations

• Thresholding a gray-scale image

• Determining good thresholds

• Connected components analysis

• Binary mathematical morphology

• All sorts of feature extractors, statistics (area, centroid, circularity, ...)

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Thresholding

• Background is black

• Healthy cherry is bright

• Bruise is medium dark

• Histogram shows two cherry regions (black background has been removed)

stnuocl exiP0 Grayscale values

255

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Histogram-Directed Thresholding

•How can we use a histogram to separate an image into 2 (or several) different regions?

Is there a single clear threshold? 2? 3?

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Automatic Thresholding: Otsu’s Method

Assumption: The histogram is bimodal

Grp 1 tt

Grp 2

Grp 2

Method: Find the threshold tt that minimizes the weighted sum of within-group variances for the two groups that result from separating the gray tones at value tt

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Thresholding Example

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Connected Components Labeling

Once you have a binary image, you can identify and then analyze each connected set of pixels

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Connected Components Methods

•Recursive Tracking (almost never used)

•Parallel Growing (needs parallel hardware)

• Row-by-Row (most common)

• Classical Algorithm - 2 pass

• Efficient Run-Length Algorithm (developed for speed in real industrial applications)

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Equivalent LabelsOriginal Binary Image

0 0 0 1 1 1 0 0 0 0 1 1 1 1 0 1 1 1 1 0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 0 0 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 0 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1

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Equivalent Labels

• CC = 0

• Scan across rows:

• If 1 and connected:

• Propgate lowest label behind or above (4 or 8 connected)

• Remember conflicts

• If 1 and not connected:

• CC++ and label CC

• If 0:

• Label 0

• Re-label based on table

0 0 0 1 1 1 0 0 0 0 1 1 1 1 0 1 1 1 1 0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 0 0 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 0 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1

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Equivalent Labels

• CC = 0

• Scan across rows:

0 0 0 1 1 1 0 0 0 0 2 2 2 2 0 3 3 3 3

• If 1 and connected:

• **Propgate lowest label behind or above (4 or 8 connected)**

0 0 0 1 1 1 1 0 0 0 2 2 2 2 0 0 3 3 3 0 0 0 1 1 1 1 1 0 0 2 2 2 2 0 0 3 3 3 0 0 0 1 1 1 1 1 1 0 2 2 2 2 0 0 3 3 3 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 3 3 3 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 3 3 3

• Remember conflicts

• **If 1 and not connected:**

• **CC++ and label CC**

0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1

• If 0:

• Label 0

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Equivalent Labels

• CC = 0

• Scan across rows:

0 0 0 1 1 1 0 0 0 0 2 2 2 2 0 3 3 3 3

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0 0 0 1 1 1 1 0 0 0 2 2 2 2 0 0 3 3 3 0 0 0 1 1 1 1 1 0 0 2 2 2 2 0 0 3 3 3 0 0 0 1 1 1 1 1 1 0 2 2 2 2 0 0 3 3 3 0 0 0 1 1 1 1 1 1 1 **1** 1 1 1 0 0 3 3 3 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 3 3 3

• Remember conflicts

• If 1 and not connected:

• CC++ and label CC

0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 **1** 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1

• If 0:

• Label 0

• Re-label based on table

1 ≡ 2 1 ≡ 3

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Equivalent Labels

• CC = 0

• Scan across rows:

• If 1 and connected:

• Propgate lowest label behind or above (4 or 8 connected)

• Remember conflicts

• If 1 and not connected:

• CC++ and label CC

• If 0:

• Label 0

• Re-label based on table

0 0 0 1 1 1 0 0 0 0 1 1 1 1 0 1 1 1 1 0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 0 0 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 0 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 **1** 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 0 0 0 0 0 1 1 1 1 1

1 ≡ 2 1 ≡ 3

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Labeling shown as Pseudo-Color

Connected components of 1’s from thresholded image

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Labeling shown as Pseudo-Color

Connected components of cluster labels

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Mathematical Morphology

Two basic operations

•Dilation

•Erosion

And several composite relations

•Closing and opening

•Thinning and thickening . . .

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Dilation

Dilation expands the connected sets of 1s

of a binary image.

It can be used for:

•Growing features

•Filling holes and gaps

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Erosion

Erosion shrinks the connected sets of 1s of a binary image.

It can be used for:

•Shrinking features

•Removing bridges, branches, protrusions

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Structuring Element

A shape mask used in basic morphological ops.

• Any shape, size that is digitally representable

• With a defined origin

box hexagon disk something

Box (length,width) Disk (diameter)

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Dilation

Input: Binary image B, structuring element S

• Move S over B, placing origin at each pixel

• Considering only the 1-pixel locations in S, compute the binary *OR* of corresponding elements in B

origin 0 0 0 0 1dilate 0 0 1 1 0

1 1 0 0 0 0 0 1 1 1 0 0 1 1 0

B

0 0 S

B ⊕ S

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Binary text example

Original Structuring

Element S Dilated by S

1 1 1 1 1

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Erosion

Input: Binary image B, structuring element S

• Move S over B, placing origin at each pixel

• Considering only the 1-pixel locations in S, compute the binary *AND* of corresponding elements in B

0 0 1 1 0 0 0 1 1 0 0 0 1 1 0 1 1 1 1 1

1110 0 0 0 0 erode 0 0 1 1 0 0 0 1 1 0 0 0 0 0 0

B

S origin**B** ⊖ **S**

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Effect of disk size on erosion

Original image

Erosion with a disk of radius 5

Radius 10

Radius 10

Radius 20

Radius 20

Radius 20

Slide: Ioannis Ivrissimtzis

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Opening and Closing

• The two most useful binary morphology operations are Opening and Closing.

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Opening

•Opening is the compound operation of erosion followed by dilation (with the same structuring element)

• Can show that the opening of A by B is the union of all translations of B that fit entirely within A. Opening is **idempotent:** Repeated operations has no further effects!

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Opening

Binary image A and structuring element B

Translations of B that fit entirely within A

The opening of A by B is shown shaded

The opening of A by B is shown shaded

Intuitively, the opening is the area we can paint when the brush has a footprint B and we are not allowed to paint outside A.

Slide: Ioannis Ivrissimtzis

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Opening

• Opening is the compound operation of erosion followed by dilation (with the same structuring element)

• Can show that the opening of A by B is the union of all translations of B that fit entirely within A.

• Opening is **idempotent:** Repeated operations has no further effects!

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Opening example – cell colony

Use large structuring element that fits into big objects

• Structuring Element: 11 pixel disc

Slide: Thomas Moeslund

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Closing

•Closing is the compound operation of dilation followed by erosion (with the same structuring element)

• Can show that the closing of A by B is the complement of union of all translations of B that do not overlap A.

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Closing

Binary image A and structuring element B

Translations of B that do not overlap A

The closing of A by B is shown shaded

The closing of A by B is shown shaded

Intuitively, the closing is the area we can not paint when the brush has a footprint B and we are not allowed to paint inside A.

Slide: Ioannis Ivrissimtzis

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Closing

•Closing is the compound operation of dilation followed by erosion (with the same structuring element)

• Can show that the closing of A by B is the complement of union of all translations of B that do not overlap A.

• Closing is **idempotent**: Repeated operations has no further effects!

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Closing Example - Segmentation

Simple segmentation:

1. Threshold 2. Closing with disc of size 20

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Original image Opening

Closing Opening followed by closing

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Real example – Fingerprint analysis

Original image Opening

Opening following by closing

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Some Basic Morphological Algorithms

•Boundary extraction

•Region filling

•Extraction of connected components

•Convex Hull

•Thinning

•Skeletons

•Pruning

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Boundary extraction

Let AA ⊕ BB denote the dilation of AA by BB and let AA ⊖ BB denote the erosion of AA by BB.

The boundary of AA can be computed as:

AA − AA ⊖ BB

where BB is a 3x3 square structuring element.

That is, we subtract from AA an erosion of it to obtain its boundary.

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Example of boundary extraction

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Thinning

AA ⊗ BB

= AA − AA ⊛ BB = A ∩ AA ⊛ BB C

Thinning example

Point just removed 8 7

26

25

**results of the first pass results of the second pass final results**

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Semi-real thinning

All lines are thinned to one pixel width Now you can check connectivity

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How powerful is morphology

•It depends...

•If almost “clean” binary images then very powerful to both clean up images and to detect variations from desired image.

•Example...

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Gear Tooth Inspectionoriginal binary image

detected defects

*How did they do it?*

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Geometric and Shape Properties

•area

•centroid

•perimeter

•perimeter length

•circularity

•elongation

•mean and standard deviation of radial distance

•bounding box

•extremal axis length from bounding box

•second order moments (row, column, mixed)

•lengths and orientations of axes of best-fit ellipse

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Morphology today

•Binary morphology still has a science behind it – it’s almost like advanced algebra because it’s all about set operations and mathematical relations.

•It doesn’t appear much in research in computer vision but we all do it. Almost all the time. It’s simply critical to making image analysis work.

•Not sexy, but very important.