


Edges and Binary Image Analysis

Thursday, Sept 10
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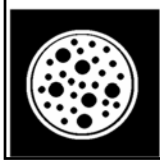
UT-Austin




Previously

- Filters allow local image neighborhood to influence our description and features
  - Smoothing to reduce noise (before)
  - Derivatives to locate contrast, gradient
- Filters have highest response on neighborhoods that "look like" it; can be thought of as template matching.
- Seam carving application:
  - use image gradients to measure "interestingness" or "energy"
  - remove 8-connected seams so as to preserve image's energy.

Today

- Edge detection
  - process the image gradient to find curves/contours
- Binary image analysis
  - blobs and regions

Edge detection

- **Goal**: map image from 2d array of pixels to a set of curves or line segments or contours.
- **Why?**

Figure from D. Lowe

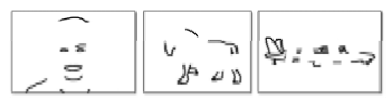


Figure from J. Shotton et al., PAMI 2007

- **Main idea**: look for strong **gradients**, post-process

Gradients -> edges

Primary edge detection steps:

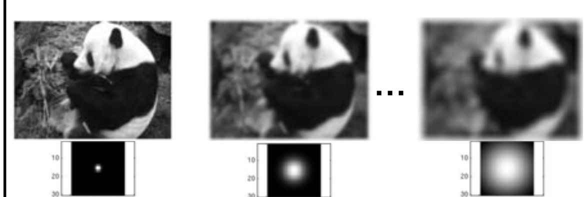
1. Smoothing: suppress noise
2. Edge enhancement: filter for contrast
3. Edge localization

   Determine which local maxima from filter output are actually edges vs. noise

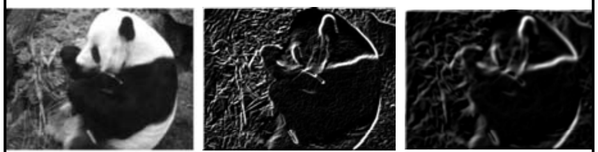
   - Threshold, Thin

Smoothing with a Gaussian

Recall: parameter σ is the "scale" / "width" / "spread" of the Gaussian kernel, and controls the amount of smoothing.



Effect of σ on derivatives



σ = 1 pixel σ = 3 pixels

The apparent structures differ depending on Gaussian's scale parameter.

Larger values: larger scale edges detected
Smaller values: finer features detected

So, what scale to choose?

It depends what we're looking for.

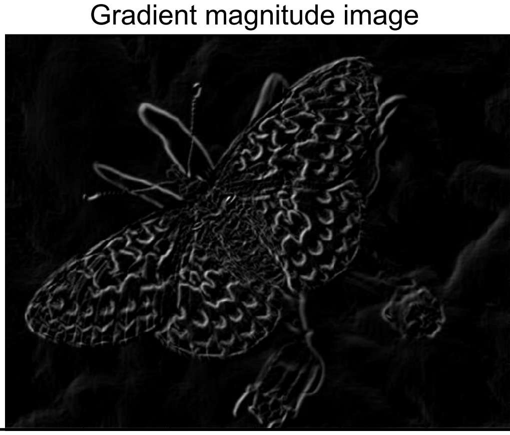
Too fine of a scale…can't see the forest for the trees.
Too coarse of a scale…can't tell the maple grain from the cherry.

Thresholding

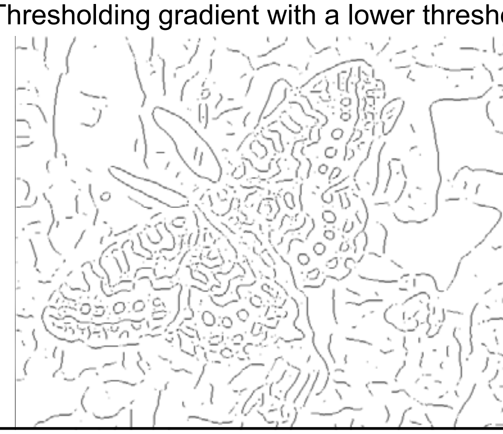
- Choose a threshold value t
- Set any pixels less than t to zero (off)
- Set any pixels greater than or equal to t to one (on)

Original image

Gradient magnitude image



Thresholding gradient with a lower threshold



Thresholding gradient with a higher threshold

Canny edge detector

- Filter image with derivative of Gaussian
- Find magnitude and orientation of gradient
- **Non-maximum suppression**:
  - Thin multi-pixel wide "ridges" down to single pixel width
- Linking and thresholding (**hysteresis**):
  - Define two thresholds: low and high
  - Use the high threshold to start edge curves and the low threshold to continue them
- MATLAB: `edge(image, 'canny');`
- `>>help edge`

Source: D. Lowe, L. Fei-Fei

The Canny edge detector

original image (Lena)

Slide credit: Steve Seitz

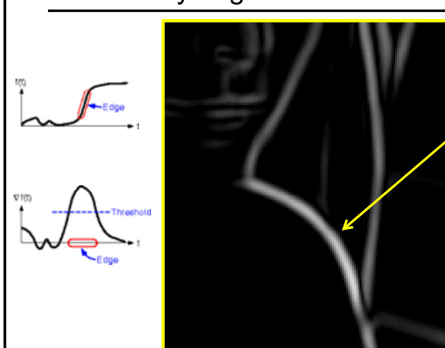
The Canny edge detector

norm of the gradient

The Canny edge detector

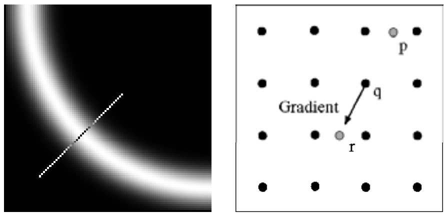
thresholding

The Canny edge detector



How to turn these thick regions of the gradient into curves?

Non-maximum suppression



Check if pixel is local maximum along gradient direction, select single max across width of the edge
- requires checking interpolated pixels p and r

D. Forsyth

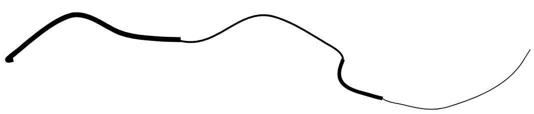
The Canny edge detector

Problem: pixels along this edge didn't survive the thresholding

thinning
(non-maximum suppression)

Hysteresis thresholding

- Use a high threshold to start edge curves, and a low threshold to continue them.



Source: Steve Seitz

Hysteresis thresholding

original image

high threshold
(strong edges)

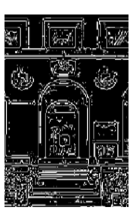
low threshold
(weak edges)

hysteresis threshold

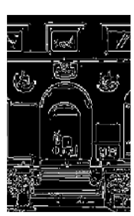
Source: L. Fei-Fei

Hysteresis thresholding

high threshold
(strong edges)



low threshold
(weak edges)



hysteresis threshold

Object boundaries vs. edges

Background

Texture

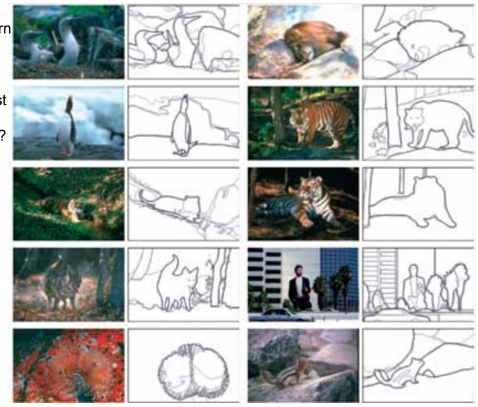
Shadows

Edges vs. human perception of contours

image | **human segmentation** | **gradient magnitude**

Berkeley segmentation database:
http://www.eecs.berkeley.edu/Research/Projects/CS/vision/grouping/segbench/

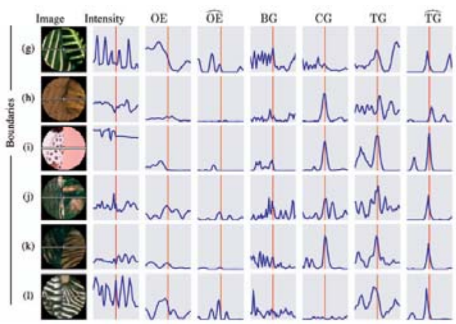
Possible to learn from humans which combination of features is most indicative of a "good" contour?



[D. Martin et al. PAMI 2004]

Human-marked segment boundaries

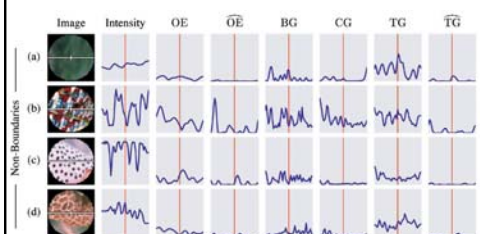
What features are responsible for perceived edges?



Feature profiles (oriented energy, brightness, color, and texture gradients) along the patch's horizontal diameter

[D. Martin et al. PAMI 2004]

What features are responsible for perceived edges?



Feature profiles (oriented energy, brightness, color, and texture gradients) along the patch's horizontal diameter

[D. Martin et al. PAMI 2004]

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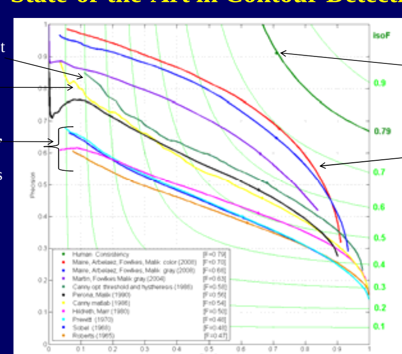
State-of-the-Art in Contour Detection

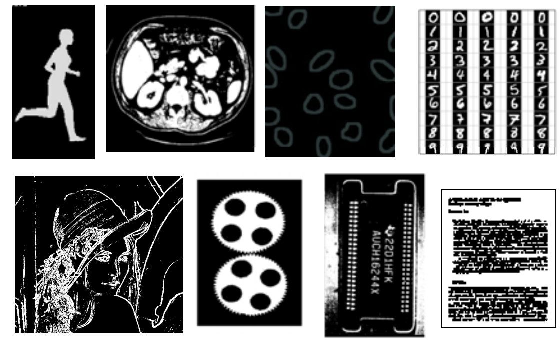


UC Berkeley | Source: Jitendra Malik: http://www.cs.berkeley.edu/~malik/malik-talks-ptrs.html | Computer Vision Group

Today

- Edge detection
  - process the image gradient to find curves/contours
- Binary image analysis
  - blobs and regions

Binary images



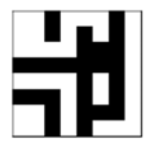
Binary image analysis: basic steps

- Convert the image into binary form
  - Thresholding
- Clean up the thresholded image
  - Morphological operators
- Extract separate blobs
  - Connected components
- Describe the blobs with region properties

Binary images

- Two pixel values
  - Foreground and background
  - Mark region(s) of interest

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



Thresholding

- Grayscale -> binary mask
- Useful if object of interest's intensity distribution is distinct from background

$$F_T[i,j] = \begin{cases} 1 & \text{if } F[i,j] \geq T \\ 0 & \textit{otherwise.} \end{cases}$$

$$F_T[i,j] = \begin{cases} 1 & \text{if } T_1 \leq F[i,j] \leq T_2 \\ 0 & \textit{otherwise.} \end{cases}$$

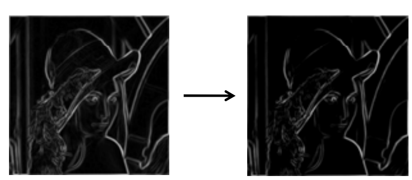
$$F_T[i,j] = \begin{cases} 1 & \text{if } F[i,j] \in Z \\ 0 & \textit{otherwise.} \end{cases}$$

- Example
  http://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL_COPIES/FITZGIBBON/simplebinary.html

Thresholding

- Given a grayscale image or an intermediate matrix → threshold to create a binary output.

Example: edge detection



Gradient magnitude `fg_pix = find(gradient_mag > t);`

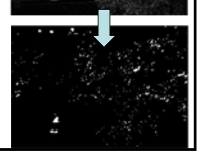
Looking for pixels where gradient is strong.

Thresholding

- Given a grayscale image or an intermediate matrix → threshold to create a binary output.

Example: background subtraction

Looking for pixels that differ significantly from the "empty" background.

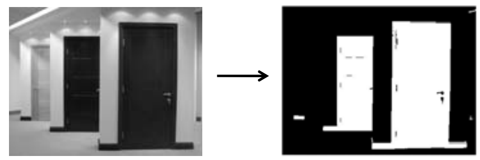


```
fg_pix = find(diff > t);
```

Thresholding

- Given a grayscale image or an intermediate matrix → threshold to create a binary output.

Example: intensity-based detection



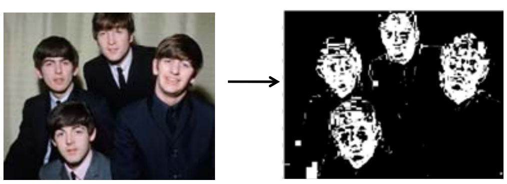
```
fg_pix = find(im < 65);
```

Looking for dark pixels

Thresholding

- Given a grayscale image or an intermediate matrix → threshold to create a binary output.

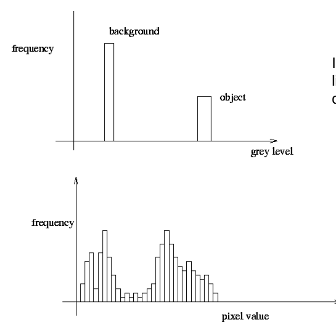
Example: color-based detection



```
fg_pix = find(hue > t1 & hue < t2);
```

Looking for pixels within a certain hue range.

A nice case: bimodal intensity histograms

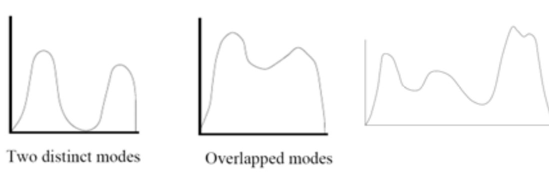


Ideal histogram, light object on dark background

Actual observed histogram with noise

Images: http://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL_COPIES/OWENS/LECT2/node3.html

Not so nice cases

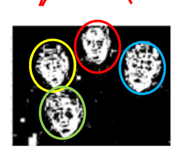


Shapiro and Stockman

Issues

- What to do with "noisy" binary outputs?
  - Holes
  - Extra small fragments

- How to demarcate multiple regions of interest?
  - Count objects
  - Compute further features per object



Morphological operators

- Change the shape of the foreground regions via intersection/union operations between a scanning structuring element and binary image.
- Useful to clean up result from thresholding
- Basic operators are:
  - Dilation
  - Erosion

Dilation

- Expands connected components
- Grow features
- Fill holes

Before dilation

After dilation

Erosion

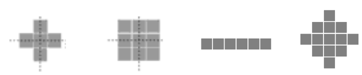
- Erode connected components
- Shrink features
- Remove bridges, branches, noise

Before erosion

After erosion

Structuring elements

- **Masks** of varying shapes and sizes used to perform morphology, for example:



- Scan mask across foreground pixels to transform the binary image

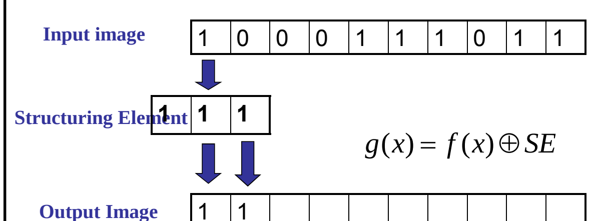
```
>> help strel
```

Dilation vs. Erosion

At each position:

- **Dilation**: if current pixel is foreground, OR the structuring element with the input image.

Example for Dilation (1D)



Adapted from T. Moeslund

Example for Dilation

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element	**1**	**1**	**1**							
Output Image	1	1								

Example for Dilation

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element		**1**	**1**	**1**						
Output Image	1	1	0							

Example for Dilation

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element			**1**	**1**	**1**					
Output Image	1	1	0	0						

Example for Dilation

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element				**1**	**1**	**1**				
Output Image	1	1	0	1	1	1				

Example for Dilation

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element					**1**	**1**	**1**			
Output Image	1	1	0	1	1	1	1			

Example for Dilation

Input image	1	0	0	0	1	1	1	0	1	1
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Example for Dilation

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element							**1**	**1**	**1**	
Output Image	1	1	0	1	1	1	1	1		

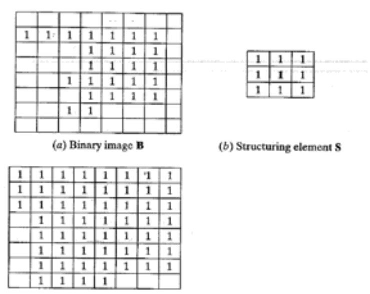
Example for Dilation

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element								**1**	**1**	**1**
Output Image	1	1	0	1	1	1	1	1	1	1

Note that the object gets bigger and holes are filled.

```
>> help imdilate
```

2D example for dilation



(a) Binary image B

(b) Structuring element S

(c) Dilation B ⊕ S

Shapiro & Stockman

Dilation vs. Erosion

At each position:

- **Dilation**: if **current pixel** is foreground, OR the structuring element with the input image.
- **Erosion**: if **every pixel** under the structuring element's nonzero entries is foreground, OR the current pixel with S.

Example for Erosion (1D)

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element	**1**	**1**	**1**							
Output Image	0									

$g(x) = f(x) \ominus SE$

Example for Erosion (1D)

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element	**1**	**1**	**1**							
Output Image	0	0								

$g(x) = f(x) \ominus SE$

Example for Erosion

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element		**1**	**1**	**1**						
Output Image	0	0	0							

Example for Erosion

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element			**1**	**1**	**1**					
Output Image	0	0	0	0						

Example for Erosion

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element				**1**	**1**	**1**				
Output Image	0	0	0	0	0					

Example for Erosion

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element					**1**	**1**	**1**			
Output Image	0	0	0	0	0	1				

Example for Erosion

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element						**1**	**1**	**1**		
Output Image	0	0	0	0	0	1	0			

Example for Erosion

Input image	1	0	0	0	1	1	1	0	1	1
Structuring Element							**1**	**1**	**1**	
Output Image	0	0	0	0	0	1	0	0		

Example for Erosion

Input image

1	0	0	0	1	1	1	0	1	1

Structuring Element

1	**1**	**1**

Output Image

0	0	0	0	0	1	0	0	0	

Example for Erosion

Input image

1	0	0	0	1	1	1	0	1	1

Structuring Element

1	**1**	

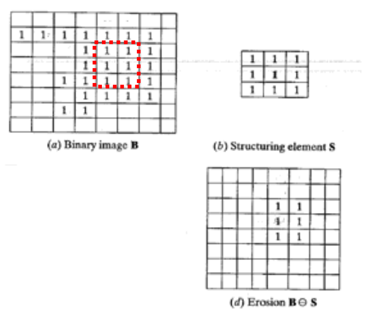
Output Image

0	0	0	0	0	1	0	0	0	1

Note that the object gets smaller

```
>> help imerode
```

2D example for erosion

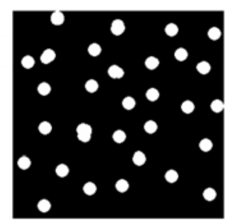


Shapiro & Stockman

Opening

- Erode, then dilate
- Remove small objects, keep original shape

Before opening



After opening

Closing

- Dilate, then erode
- Fill holes, but keep original shape

Before closing

After closing

Applet: http://bigwww.epfl.ch/demo/jmorpho/start.php

Issues

- What to do with "noisy" binary outputs?
  - Holes
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- How to demarcate multiple regions of interest?
  - Count objects
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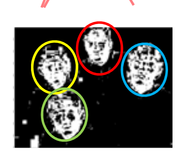
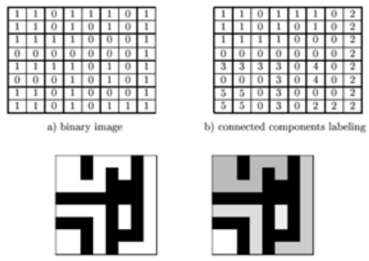


Connected components

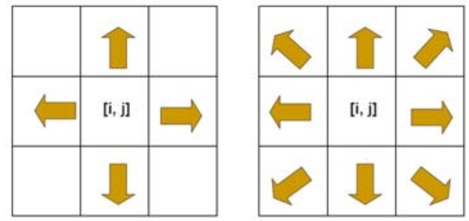
- Identify distinct regions of "connected pixels"



Shapiro and Stockman

Connectedness

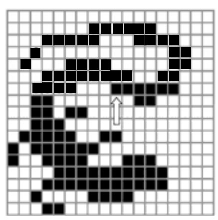
- Defining which pixels are considered neighbors



Source: Chaitanya Chandra

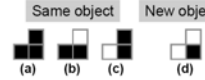
Connected components

- We'll consider a sequential algorithm that requires only 2 passes over the image.
- **Input**: binary image
- **Output**: "label" image, where pixels are numbered per their component
- Note: foreground here is denoted with black pixels.

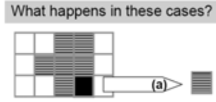


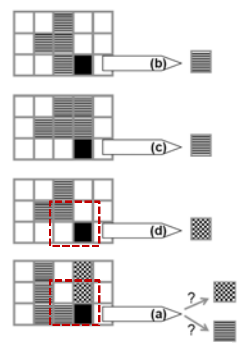
Sequential connected components

- Labeling a pixel only requires to consider its prior and superior neighbors.
- It depends on the type of connectivity used for foreground (4-connectivity here).



What happens in these cases?





Sequential connected components

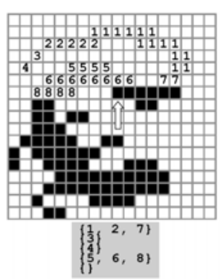
- Process the image from left to right, top to bottom.
  1. If the next pixel to process is 1-pixel:

     Already processed

     1. If only one of its neighbors (superior or left) is 1-pixel, copy its label.
     2. If both are, and have the same label, copy it.
     3. If they have different labels:

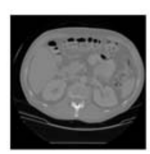
        superior? smallest?

        1. Copy the label from the prior.
        2. Reflect the change in the table of equivalences.
     4. Otw, assign a new label.
  2. More pixels? Go to step 1.

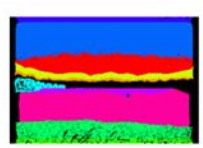


- Re-label with the smallest of equivalent labels.
- Pixels of the same segment always have the same label.

Connected components



connected components of 1's from thresholded image



connected components of cluster labels

Slide credit: Pinar Duygulu

Region properties

- Given connected components, can compute simple features per blob, such as:
  - Area (num pixels in the region)
  - Centroid (average x and y position of pixels in the region)
  - Bounding box (min and max coordinates)
  - Circularity (ratio of mean dist. to centroid over std)

Circularity

a second measure uses variation off of a circle

circularity(2):

$$C_2 = \frac{\mu_R}{\sigma_R}$$

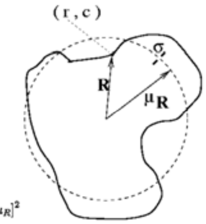
where μ_R and $\sigma_R{}^2$ are the mean and variance of the distance from the centroid of the shape to the boundary pixels (r_k, c_k).

mean radial distance:

$$\mu_R = \frac{1}{K}\sum_{k=0}^{K-1} \|(r_k, c_k) - (\bar{r}, \bar{c})\|$$

variance of radial distance:

$$\sigma_R^2 = \frac{1}{K}\sum_{k=0}^{K-1} [\|(r_k, c_k) - (\bar{r}, \bar{c})\| - \mu_R]^2$$



[Haralick]

Shapiro & Stockman

Binary image analysis: basic steps (recap)

- Convert the image into binary form
  - Thresholding
- Clean up the thresholded image
  - Morphological operators
- Extract separate blobs
  - Connected components
- Describe the blobs with region properties

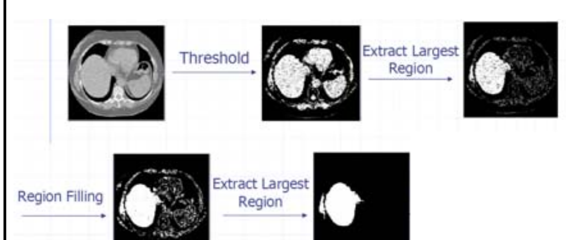
Matlab

```
• N = hist(Y,M)
• L = bwlabel (BW,N);
• STATS = regionprops(L,PROPERTIES) ;
   –      'Area'
   –      'Centroid'
   –      'BoundingBox'
   –      'Orientation', …
• IM2 = imerode(IM,SE);
• IM2 = imdilate(IM,SE);
• IM2 = imclose(IM, SE);
• IM2 = imopen(IM, SE);
```

Example using binary image analysis: OCR

[Luis von Ahn et al. http://recaptcha.net/learnmore.html]

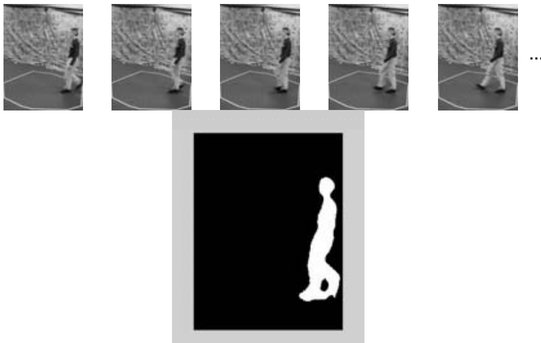
Example using binary image analysis: segmentation of a liver



Slide credit: Li Shen

Application by Jie Zhu, Cornell University

Example using binary image analysis: Bg subtraction + blob detection



Example using binary image analysis: Bg subtraction + blob detection

University of Southern California
http://iris.usc.edu/~icohen/projects/vace/detection.htm

Binary images

- Pros
  - Can be fast to compute, easy to store
  - Simple processing techniques available
  - Lead to some useful compact shape descriptors
- Cons
  - Hard to get “clean” silhouettes
  - Noise common in realistic scenarios
  - Can be too coarse of a representation
  - Not 3d

Summary

- Operations, tools
  - Derivative filters
  - Smoothing, morphology
  - Thresholding
  - Connected components
  - Matched filters
  - Histograms
- Features, representations
  - Edges, gradients
  - Blobs/regions
  - Color distributions
  - Local patterns
  - Textures (next)

Next

- Texture: read F&P Ch 9, Sections 9.1, 9.3