

# Image Segmentation

- Gray-level thresholding
- Supervised vs. unsupervised thresholding
- Binarization using Otsu's method
- Locally adaptive thresholding
- Maximally stable extremal regions
- Color-based segmentation
- Region labeling and counting
- Region moments

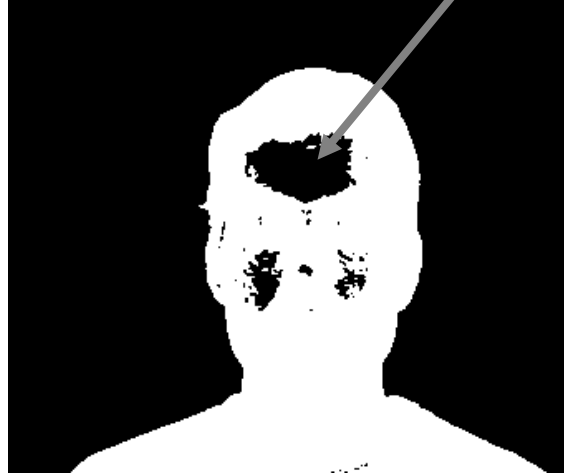


# Gray-level thresholding

How can holes be filled?



Original image  
*Peter*  $f[x,y]$



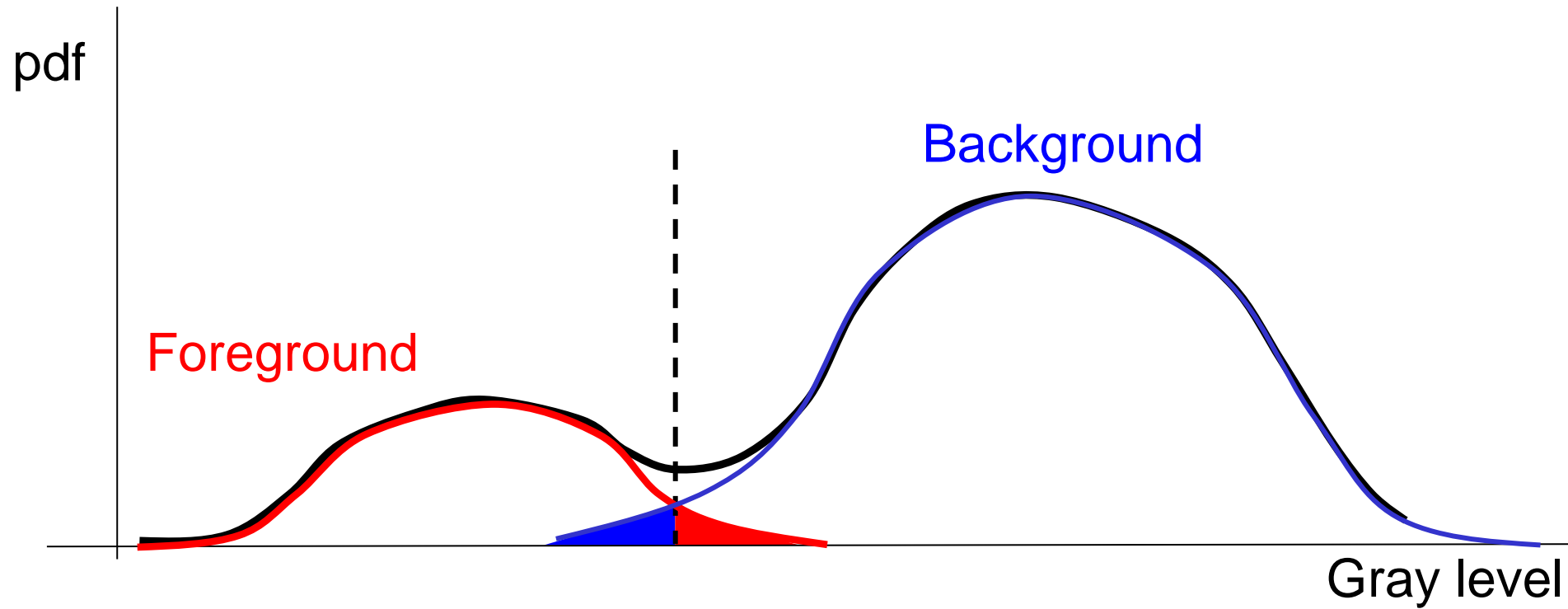
Thresholded  
*Peter*  $m[x,y]$



$$f[x,y] \cdot m[x,y]$$



# How to choose the threshold?



# Unsupervised thresholding

- Idea: find threshold  $T$  that minimizes *within-class variance* of both foreground and background (same as k-means)

$$\sigma_{within}^2(T) = \frac{N_{Fgrnd}(T)}{N} \sigma_{Fgrnd}^2(T) + \frac{N_{Bgrnd}(T)}{N} \sigma_{Bgrnd}^2(T)$$

- Equivalently, maximize *between-class variance*

$$\begin{aligned}\sigma_{between}^2(T) &= \sigma^2 - \sigma_{within}^2(T) \\ &= \left( \frac{1}{N} \sum_{x,y} f^2[x,y] - \mu^2 \right) - \frac{N_{Fgrnd}}{N} \left( \frac{1}{N_{Fgrnd}} \sum_{x,y \in Fgrnd} f^2[x,y] - \mu_{Fgrnd}^2 \right) - \frac{N_{Bgrnd}}{N} \left( \frac{1}{N_{Bgrnd}} \sum_{x,y \in Bgrnd} f^2[x,y] - \mu_{Bgrnd}^2 \right) \\ &= -\mu^2 + \frac{N_{Fgrnd}}{N} \mu_{Fgrnd}^2 + \frac{N_{Bgrnd}}{N} \mu_{Bgrnd}^2 = \frac{N_{Fgrnd}}{N} (\mu_{Fgrnd} - \mu)^2 + \frac{N_{Bgrnd}}{N} (\mu_{Bgrnd} - \mu)^2 \\ &= \frac{N_{Fgrnd}(T) \cdot N_{Bgrnd}(T)}{N^2} (\mu_{Fgrnd}(T) - \mu_{Bgrnd}(T))^2\end{aligned}$$

[Otsu, 1979]

# Unsupervised thresholding (cont.)

- Algorithm: Search for threshold  $T$  to maximize

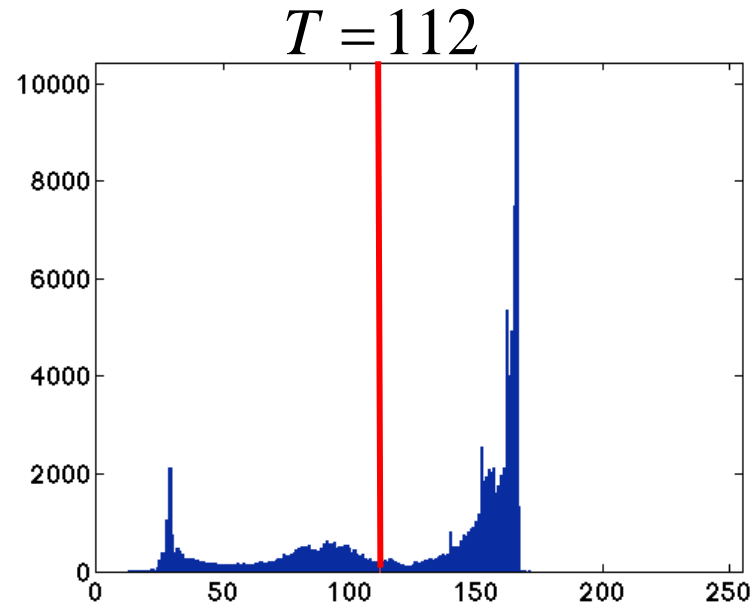
$$\sigma_{between}^2(T) = \frac{N_{Fgrnd}(T) \cdot N_{Bgrnd}(T)}{N^2} (\mu_{Fgrnd}(T) - \mu_{Bgrnd}(T))^2$$

- Useful recursion for sweeping  $T$  across histogram:

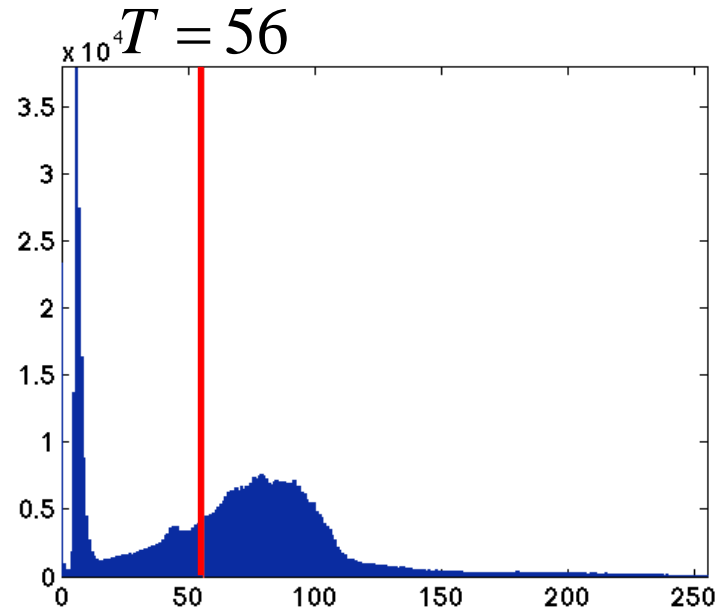
$$\begin{aligned} N_{Fgrnd}(T+1) &= N_{Fgrnd}(T) + n_T \\ N_{Bgrnd}(T+1) &= N_{Bgrnd}(T) - n_T \\ \mu_{Fgrnd}(T+1) &= \frac{\mu_{Fgrnd}(T) N_{Fgrnd}(T) + n_T T}{N_{Fgrnd}(T+1)} \\ \mu_{Bgrnd}(T+1) &= \frac{\mu_{Bgrnd}(T) N_{Bgrnd}(T) - n_T T}{N_{Bgrnd}(T+1)} \end{aligned}$$

[Otsu, 1979]

# Unsupervised thresholding (cont.)



# Unsupervised thresholding (cont.)



# Unsupervised thresholding (cont.)

The Stanford Daily

Tuesday, September 18, 2012 ♦ 13



SIMON WARREN/The Stanford Daily

Stanford defensive lineman Josh Mauro put the pressure on USC's Matt Barkley. Mauro was relentless in the second half as Stanford's defense completely shut down Barkley and his touted wide receivers.

## Handing out the USC game balls

By SAM FISHER  
FOOTBALL EDITOR

**Stephan Taylor:** It all starts and ends with Stanford's workhorse, Taylor was everything you could ask for and more against USC. He provided the big plays with a game-tying touchdown on the ground, another score through the air and the consistent ground-and-pound to wear down the Trojans at the end. His 213 total yards of offense to go with a pair of TDs had fans on both sides forgetting

about Andrew Luck.

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Please see **AWARDS**, page 15

### FOOTBALL

## The winding road ahead

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FOOTBALL EDITOR

Andrew Luck may be gone, but with Saturday night's win over USC, the Stanford Cardinal put itself in position to achieve beyond the path paved by number 12. You heard right: though there's plenty of work left to do, this 2012 Stanford team showed that it is capable of playing at a national championship level.

Though Stanford survived one of its toughest tests in the gauntlet that is the BCS National Championship eliminator, the road to Miami 2013 is no walk in the park. The toughest challenges remaining on the schedule are games at Notre Dame, Oregon and UCLA, all of whom are currently ranked in the top 20. The next two games, at Washington and then at home against Arizona, are no pushovers either. And as Stanford has showed top-ranked opponents in years past, any team on the Cardinal's schedule has the potential for a magical upset.

From Stanford's current vantage point, there are three paths the rest of the season could take. Door Number One leads to The Promised Land, a berth in the BCS National Championship Game. In all likelihood, because Stanford is not named Alabama or LSU, the Cardinal will have to win out to earn a trip to South Beach, including wins at No. 3 Oregon and a potential rematch against USC for the Pac-12 title.

For Stanford to even think about returning to the site of its 2011 Orange Bowl beat down of Virginia Tech, Josh Nunes will have to build off his fourth-quarter success against USC to play at a higher level consistently. From the 12-yard scramble on third-and-10 on, Nunes was good enough to win a championship. USC's defense is nowhere near a pushover, so Jordan Williamson's 0-3 kicking night is also a major concern. With the way the Stanford defense played against USC over the last 41 minutes Saturday night, a national championship isn't completely out of the question, but it's still not the most likely ending to 2012.

Waiting behind Door Number Two for Stanford is a trip to a BCS bowl for the third straight season. Stanford has a bit more wiggle room to get back to the BCS, thanks to a strong strength of schedule. However, the path is anything but straightforward. One thing we do know is that if Stanford can win the Pac-12, the Rose Bowl becomes the worst-case scenario. To get there, Stanford almost certainly has to win at Oregon on Nov. 17, one of the toughest tasks in all of college football.

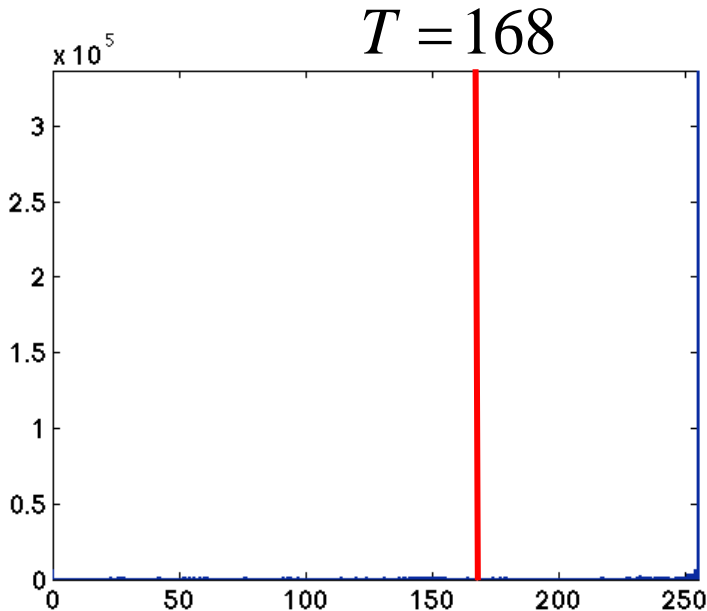
If Stanford can't beat the Ducks, a BCS bowl remains a legitimate possibility. Stanford is still struggling to shake the reputation of not having a big enough fan base to get bowls excited, so grabbing an at-large selection to the BCS won't be easy. Still, as Stanford showed in

the last two seasons, beating everyone on the schedule except for Oregon is probably good enough to warrant a top-four BCS ranking and an automatic bid to a BCS game.

Door Number Three is the disappointment, the setback, the wasted opportunity. Stanford put itself in a remarkable position with its win over the second-ranked Trojans. However, if the Card regresses to San Jose State-game form at any point, it is primed to be upset a few times. It might not even take that bad of a performance, as Stanford has five teams left on its schedule in the AP Top 25, including road games at No. 3 Oregon, No. 11 Notre Dame and No. 19 UCLA. If Stanford loses more than two games, it will in all likelihood end up in a second-tier bowl game for the first time since the 2009 season, when Stanford lost a close game to Oklahoma in the Sun Bowl.

There is obviously tremendous uncertainty as to where the rest of the season heads, but it's truly remarkable for Stanford to be in the position it is in now. No Toby Gerhart, no Jim Harbaugh and no Andrew Luck; just Josh Nunes, Stephan Taylor, a rabid defense and a whole bunch of guys showing a lot of heart. The superstar names might be gone, but the talent left behind is rising to the top, making Door Number One not so crazy to think about.

Contact Sam Fisher at [safisher@stanford.edu](mailto:safisher@stanford.edu).



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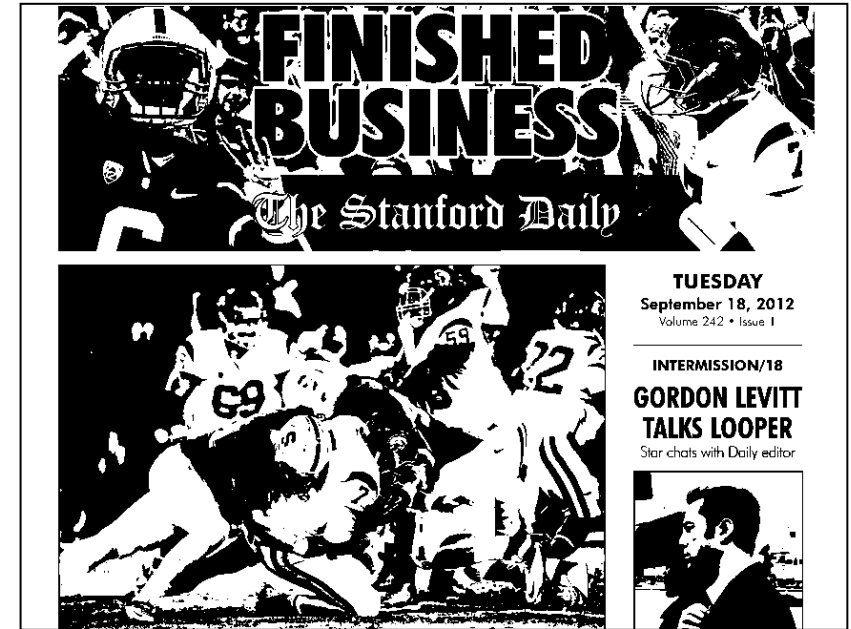
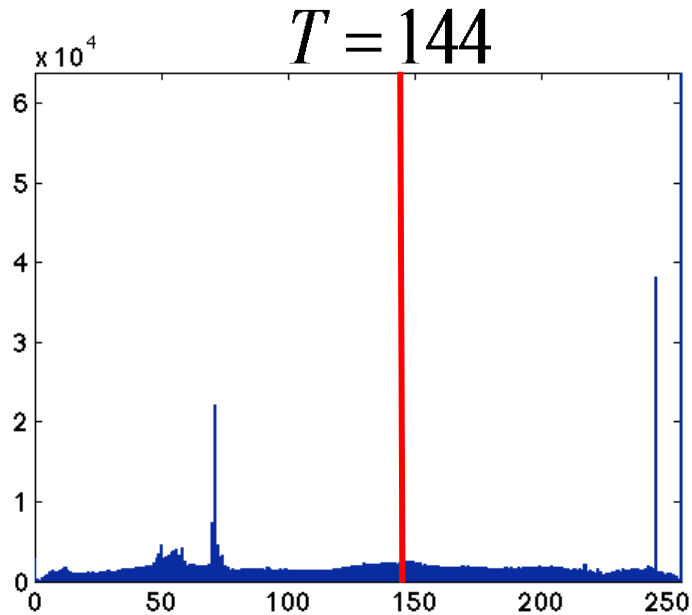
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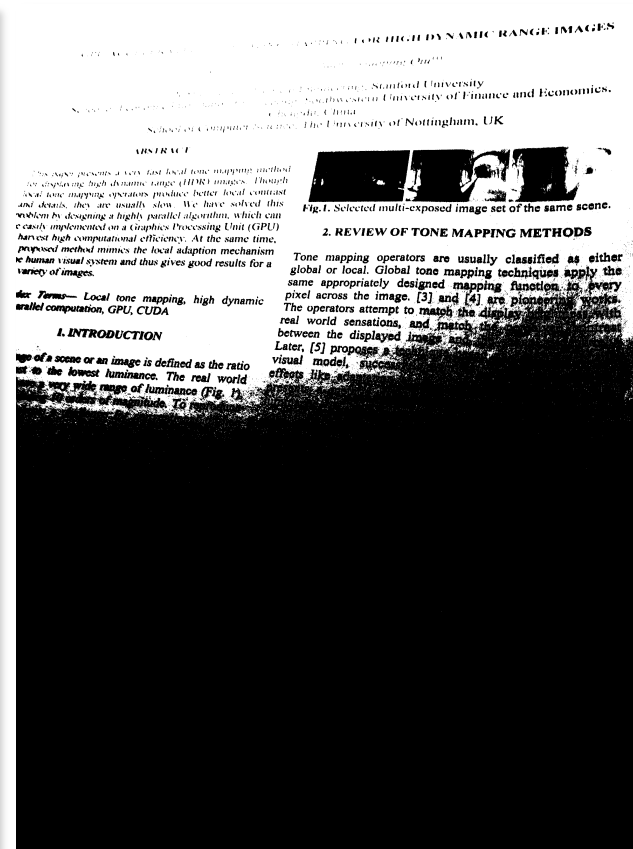
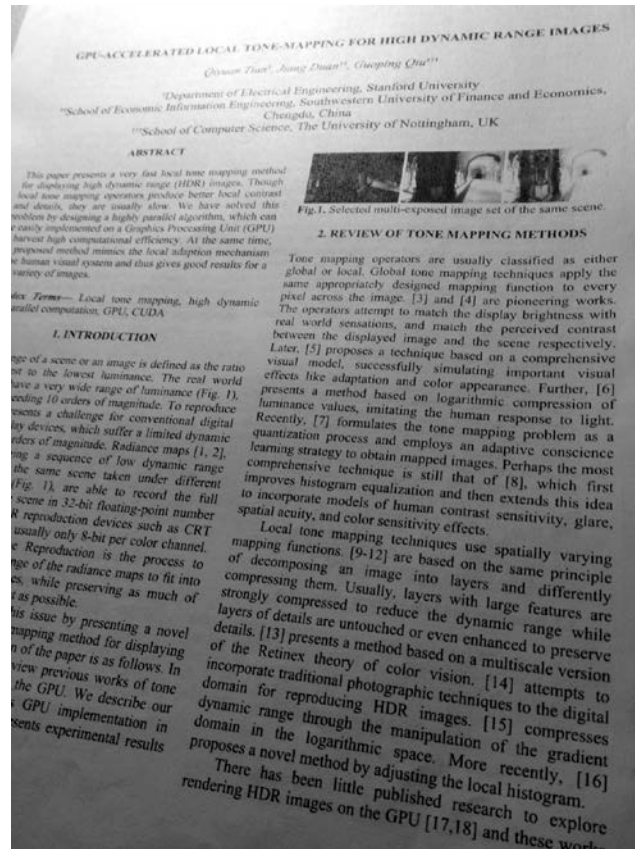


# Unsupervised thresholding (cont.)



# Sometimes, a global threshold does not work

Original image

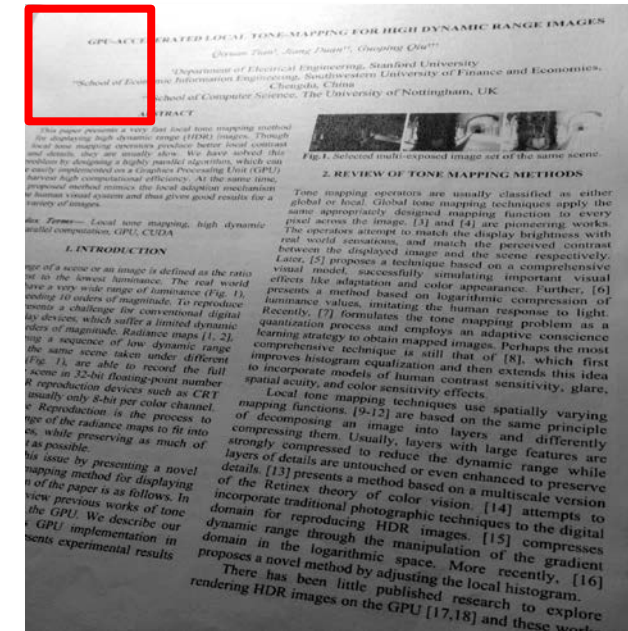


Thresholded with  
Otsu's Method

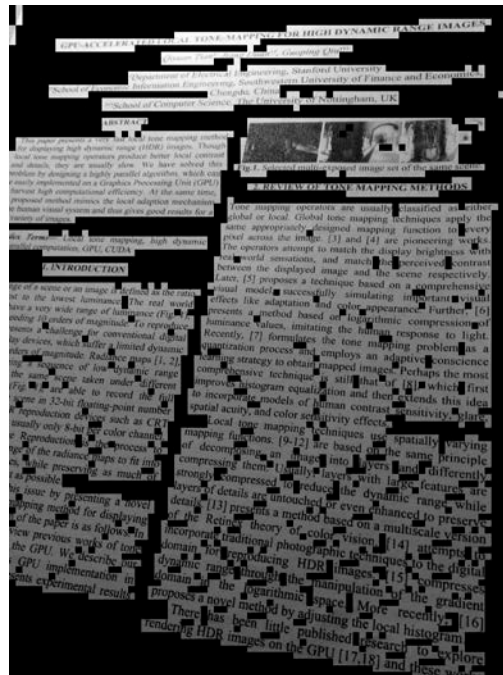


# Locally adaptive thresholding

- Slide a window over the image
- For each window position, decide whether to perform thresholding
  - Thresholding should not be performed in uniform areas
  - Use variance or other suitable criterion
- Non-uniform areas: apply Otsu's method (based on local histogram)
- Uniform areas: classify the entire area as foreground or background based on mean value



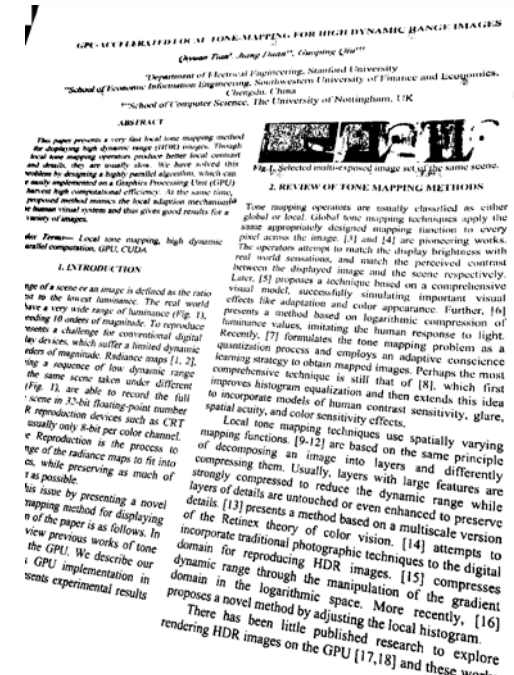
# Locally adaptive thresholding (example)



Non-uniform areas



Local threshold values



Locally thresholded result



# Maximally stable extremal regions

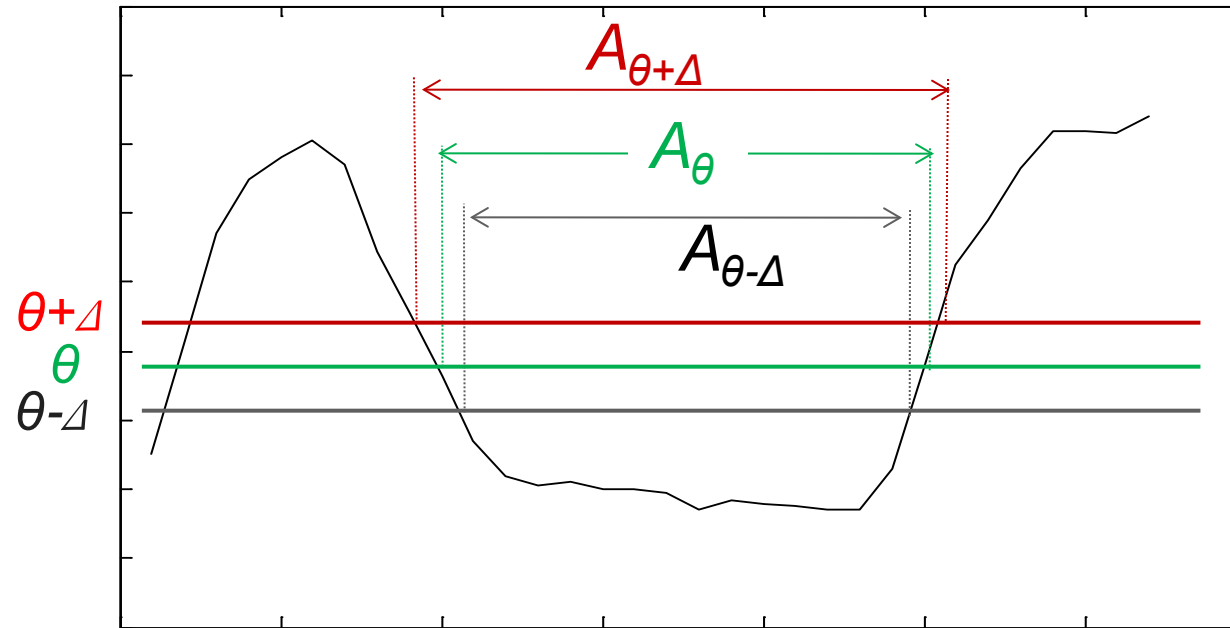
- Extremal region: any connected region in an image with all pixel values above (or below) a threshold
- Observations:
  - Nested extremal regions result when the threshold is successively raised (or lowered).
  - The nested extremal regions form a “component tree.”
- Key idea: choose thresholds  $\theta$  such that the resulting bright (or dark) extremal regions are nearly constant when these thresholds are perturbed by  $\pm\Delta$

→ “*maximally stable*” extremal regions (MSER)

[Matas, Chum, Urba, Pajdla, 2002]



# MSEs: illustration



$$\text{Local minimum of } \left| \frac{A_{\theta - \Delta} - A_{\theta + \Delta}}{A_{\theta}} \right| \rightarrow \text{MSER}$$

[Matas, Chum, Urba, Pajdla, 2002]

# Level sets of an image

1	1	1	1	1	1	1	1	1	1	1	5	4	4	8
1	7	6	4	2	2	3	3	3	3	1	5	4	4	8
1	7	6	4	2	2	3	3	3	3	1	5	4	4	8
1	7	6	4	2	2	3	3	3	3	1	5	4	4	8
1	7	6	4	2	2	5	5	5	5	1	5	4	4	8
1	6	6	4	2	2	5	5	5	6	1	5	4	4	4
1	6	6	4	2	2	6	6	6	6	1	5	5	5	5
1	4	4	4	2	2	6	6	6	6	1	5	5	5	5
1	1	1	1	1	2	6	1	1	1	1	2	2	2	2
1	8	8	5	1	2	6	1	7	7	1	2	2	2	2
1	8	8	5	1	1	1	1	7	7	1	1	1	1	2
1	8	8	5	5	5	3	3	7	7	1	1	1	1	2
1	8	8	5	5	3	3	3	7	7	7	1	1	1	2
1	8	8	5	5	3	3	3	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

$f[x, y]$

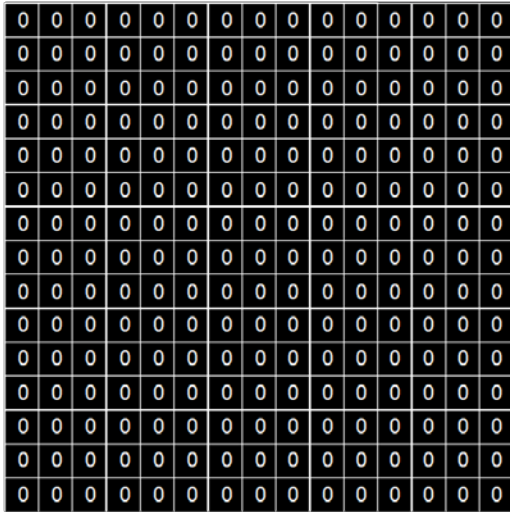
Image

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

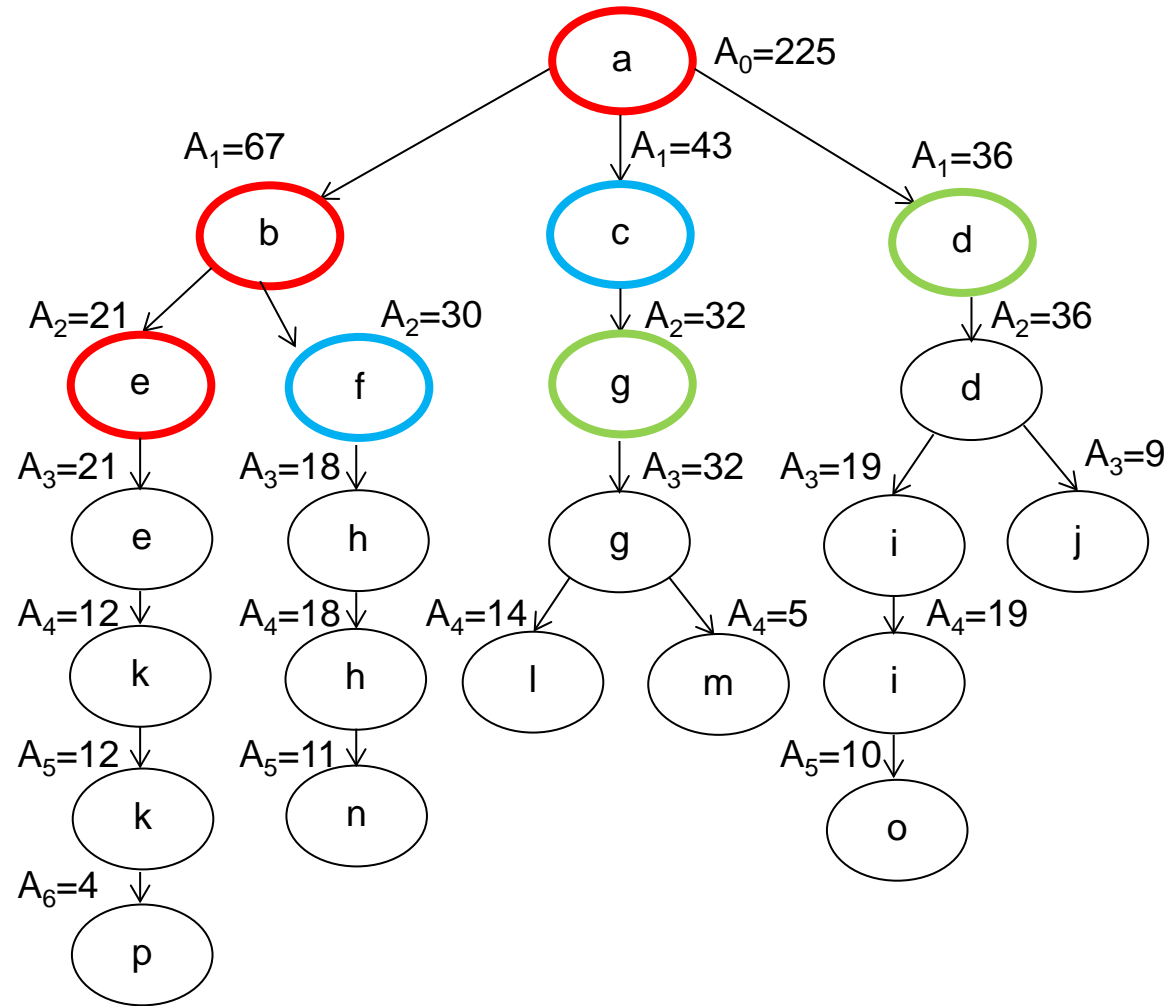
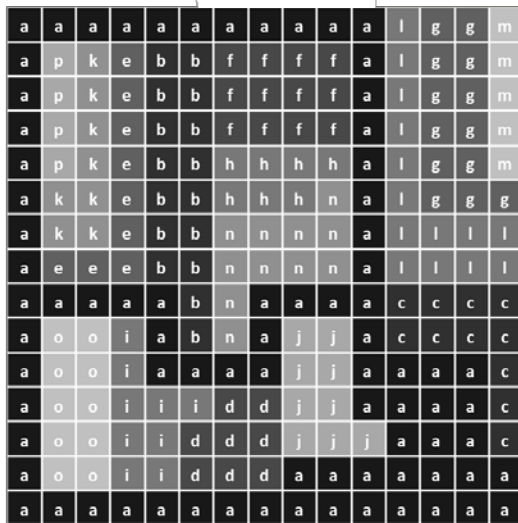
$f[x, y] > 8$

Level Set

# Component tree of an image



$f[x, y] > 8$



Local minima of sequence

$$\left| \frac{A_{\theta-\Delta} - A_{\theta+\Delta}}{A_{\theta}} \right|$$

$\theta = \Delta, \Delta + 1, K \rightarrow \text{MSERs}$



# MSER: examples



Dark MSERs,  $\Delta=15$



Original image



Bright MSERs,  $\Delta=15$

# MSER: examples



Dark MSERs,  $\Delta=15$

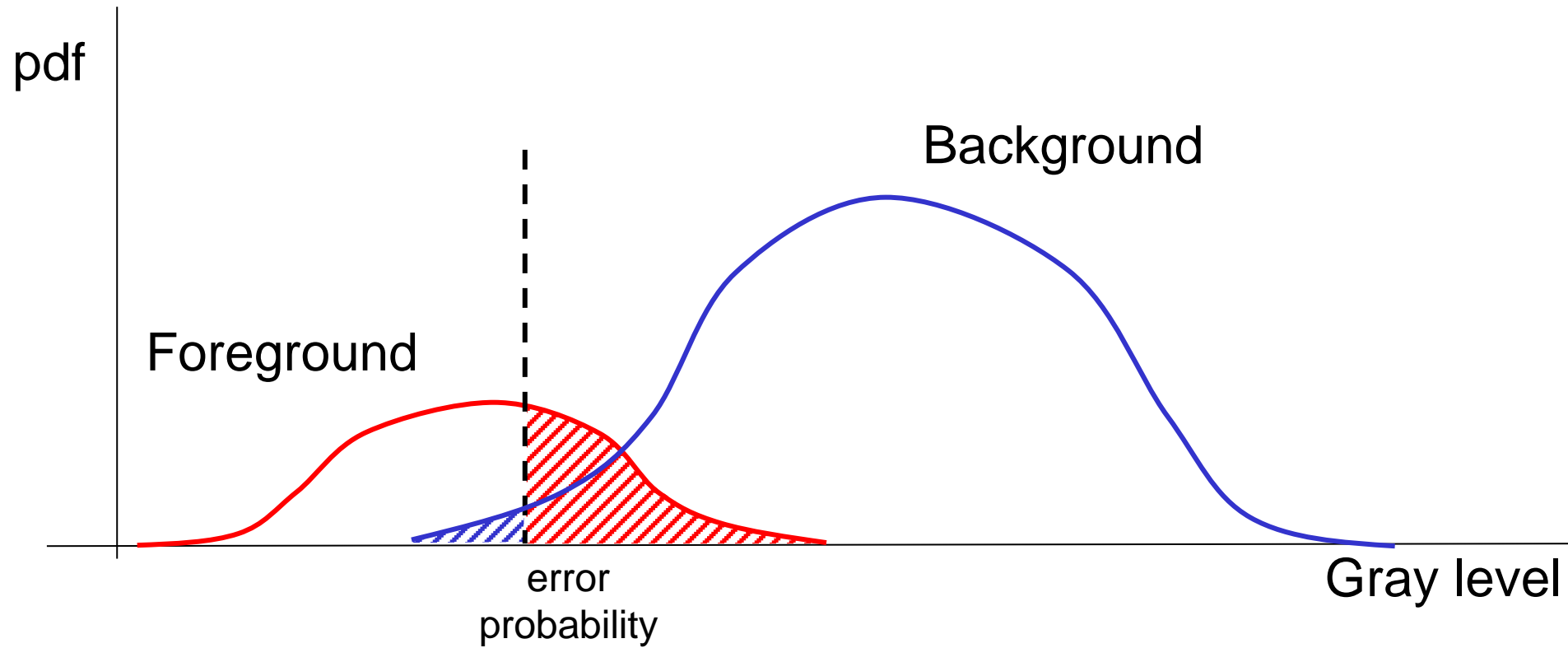


Original image

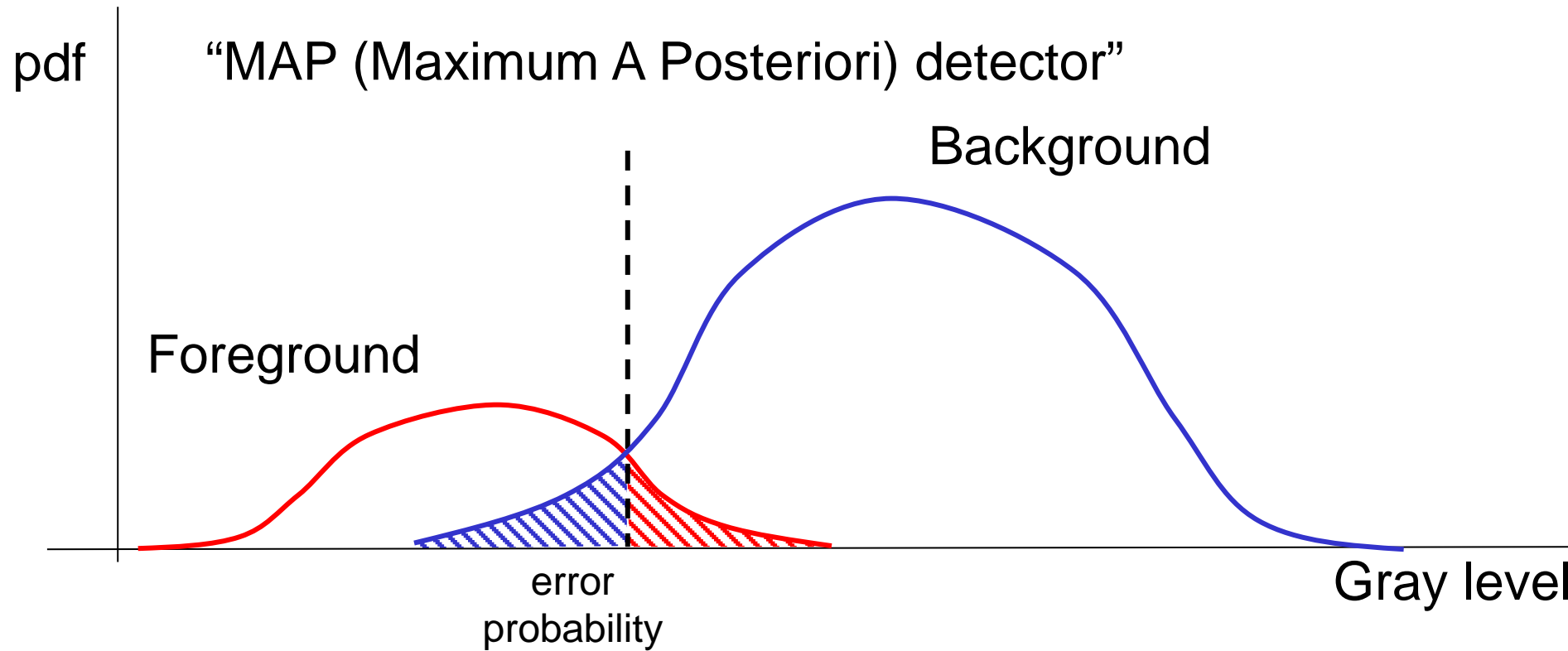


Bright MSERs,  $\Delta=15$

# Supervised thresholding



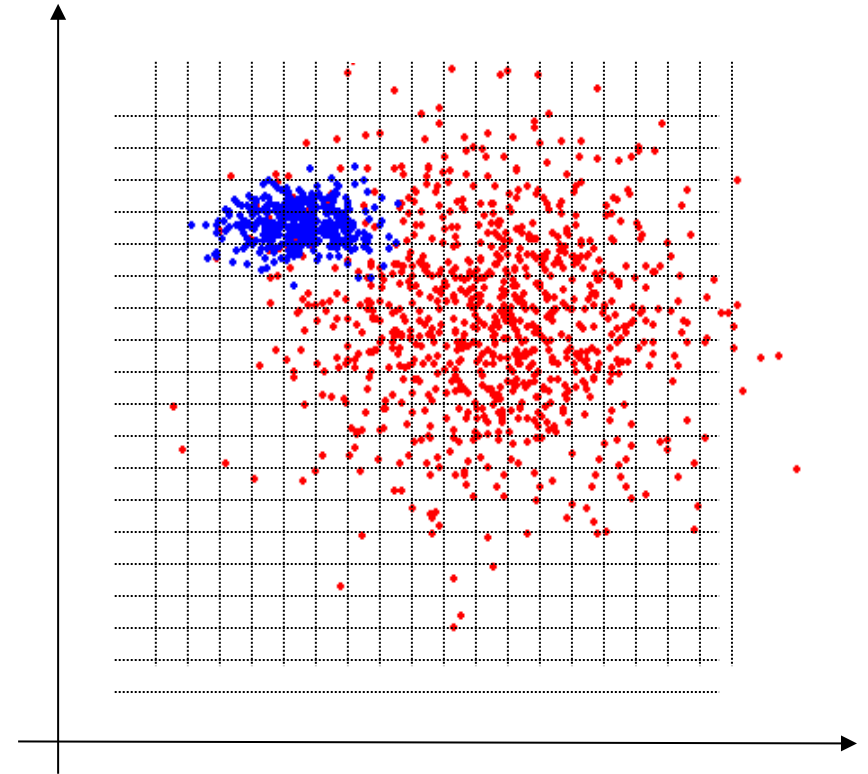
# Supervised thresholding



If errors  $BG \rightarrow FG$  and  $FG \rightarrow BG$  are associated with different costs:  
“Bayes minimum risk detector” is optimal.

# Multidimensional MAP detector

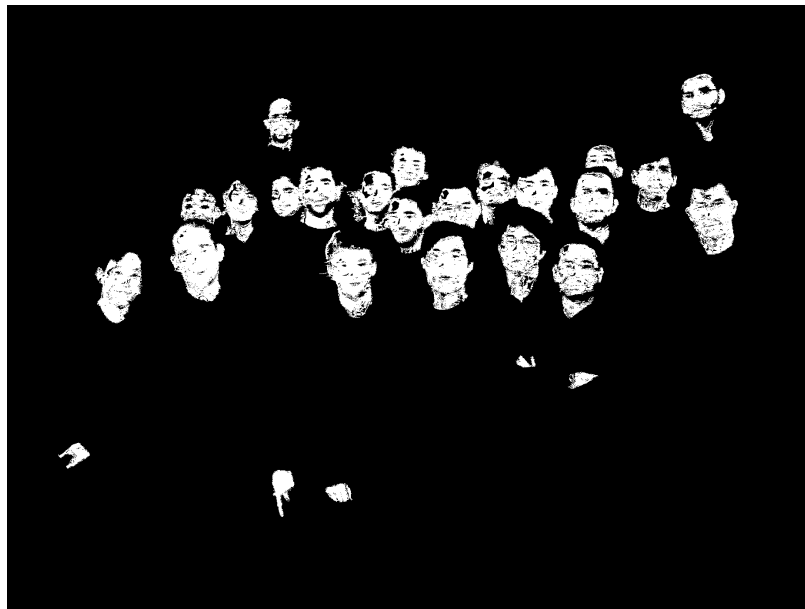
- Training
  - Provide labelled set of training data
  - Subdivide n-dimensional space into small bins
  - Count frequency of occurrence for each bin and class in training set, label bin with most probable class
  - (Propagate class labels to empty bins)
- For test data: identify bin, look up the most probable class



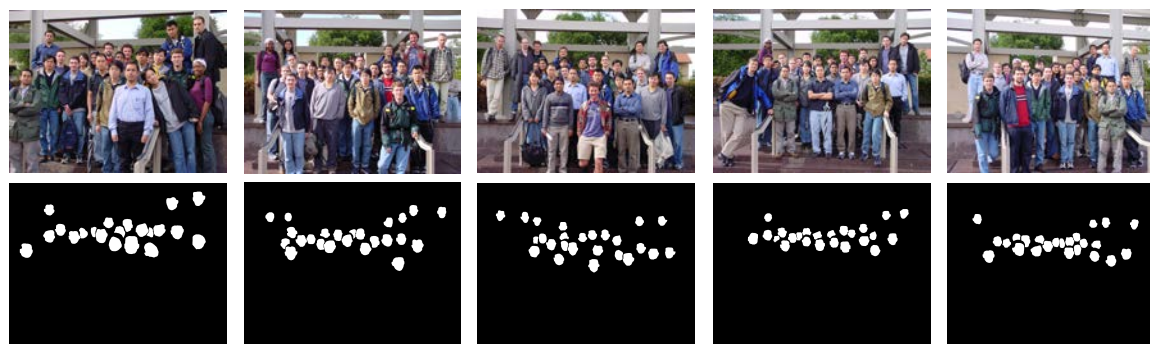
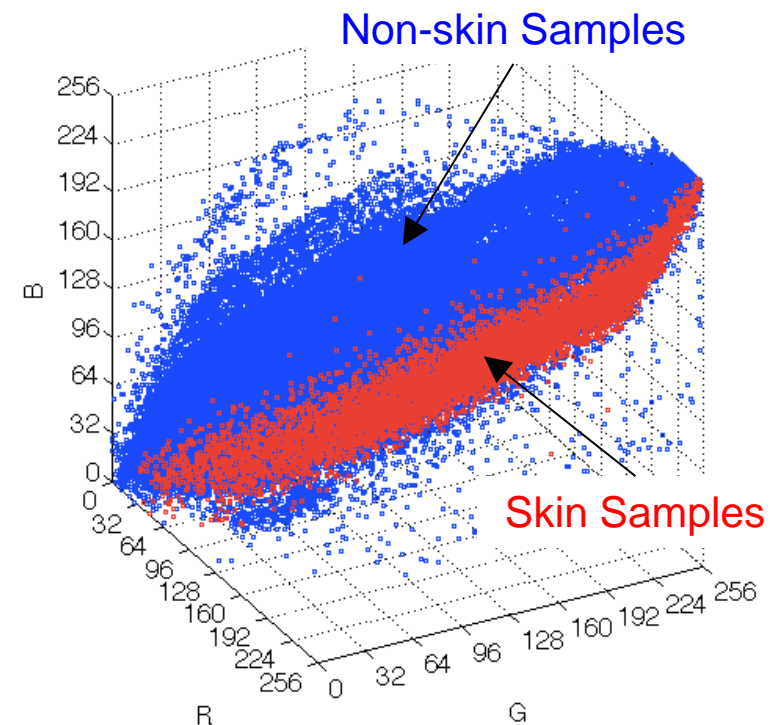
# MAP detector in RGB-space



Original image



Skin color detector



Five training images

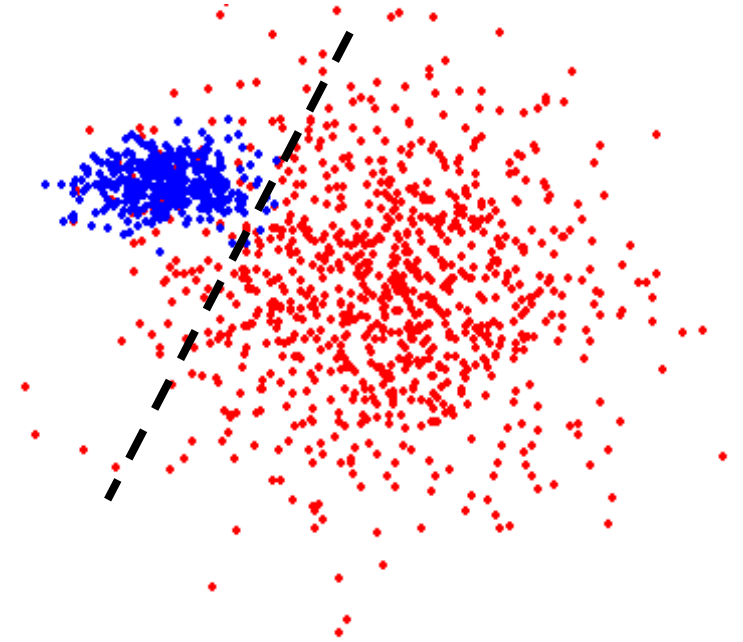


# Linear discriminant function

- To segment image with  $n$  components  $f_i$ ,  $i=1,2,\dots,n$  into two classes, perform test

$$\sum_i w_i f_i + w_0 \geq 0 \quad ?$$

- Categories are separated by hyperplane in  $n$ -space
- Numerous techniques to determine weights  $w_i$ ,  $i=0,1,2,\dots,n$ , see, e.g., [\[Duda, Hart, Stork, 2001\]](#)
- Can be extended to the intersection of several linear discriminant functions
- Can be extended to multiple classes



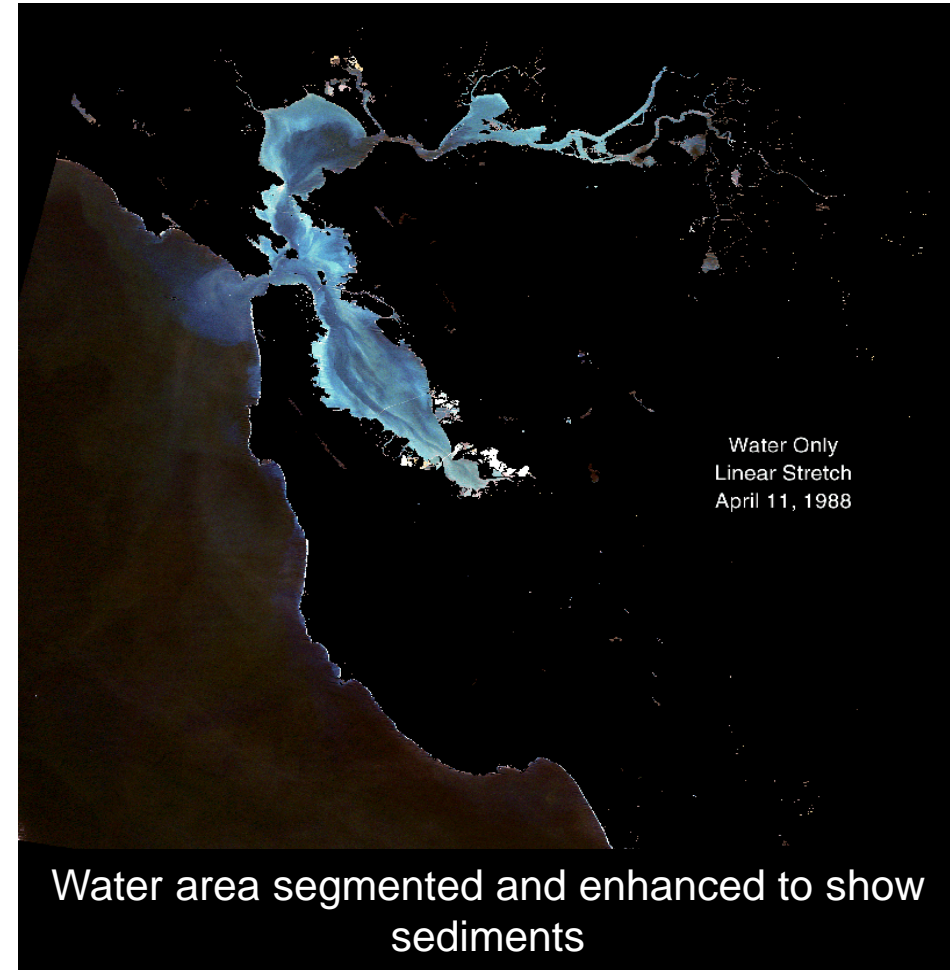
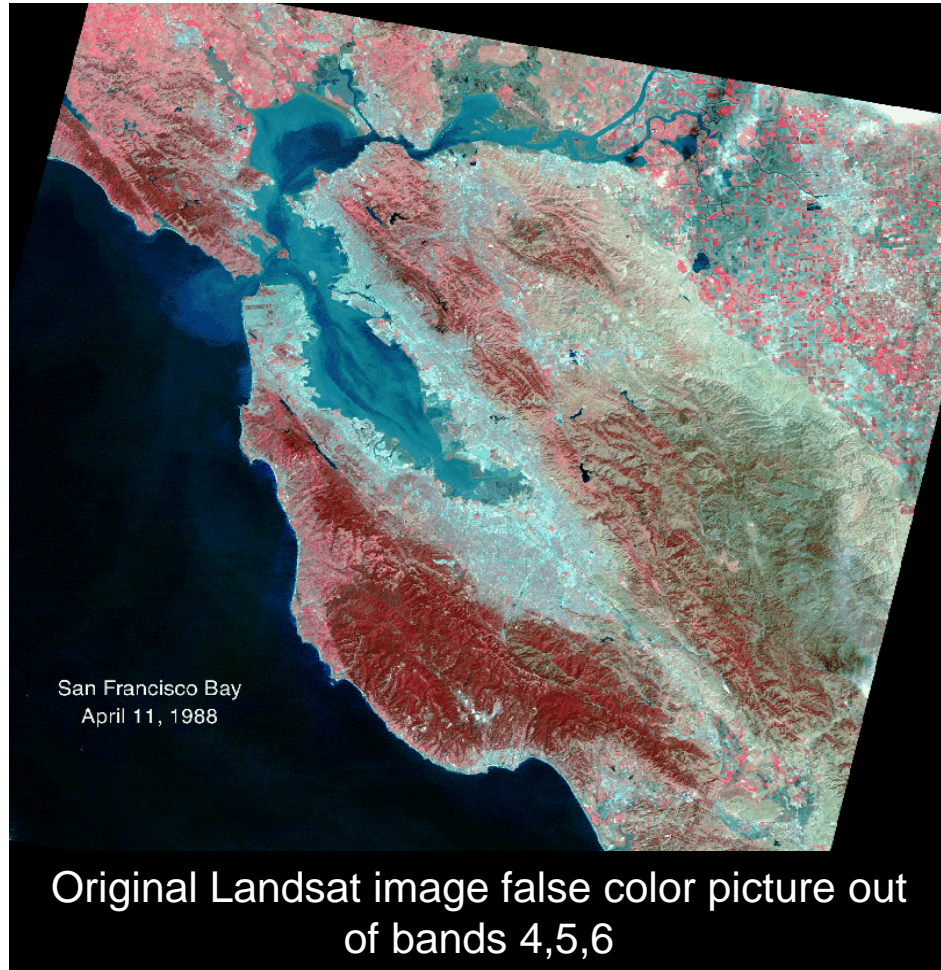


# Chroma keying





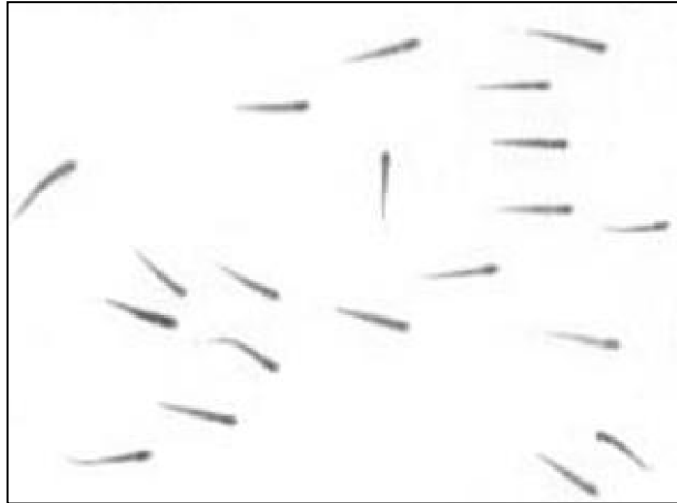
# Landsat image processing



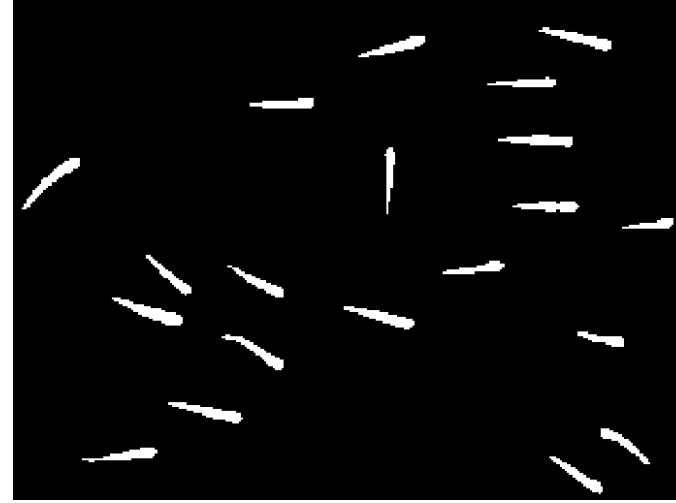
Source: US Geological Survey USGS, <http://sfbay.wr.usgs.gov/>

# Region labeling and counting

- How many fish in this picture?



Original *Fish* image



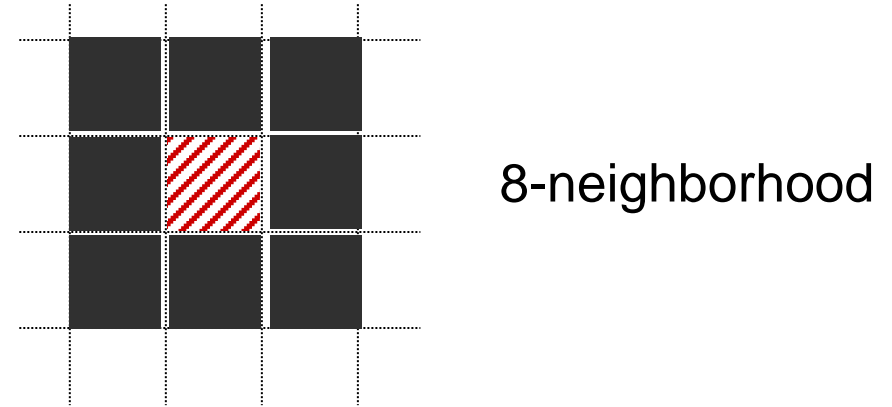
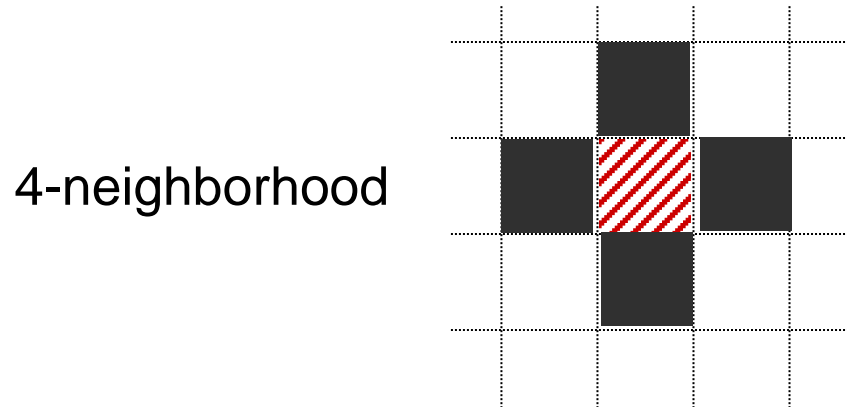
after thresholding

- Which pixels belong to the same object (region labeling)?
- How large is each object (region counting)?



# 4-connected and 8-connected neighborhoods

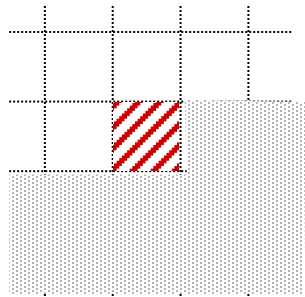
- Definition: a **region** is a set of pixels, where each pixel can be reached from any other pixel in the region by a finite number of steps, with each step starting at a pixel and ending in the neighborhood of the pixel.



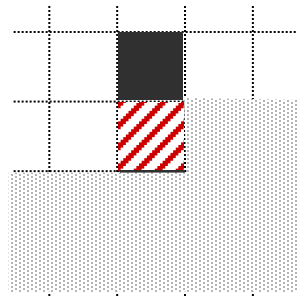
- Typically, either definition leads to the same regions, except when a region is only connected across diagonally adjacent pixels.

# Region labeling algorithm (4-neighborhood)

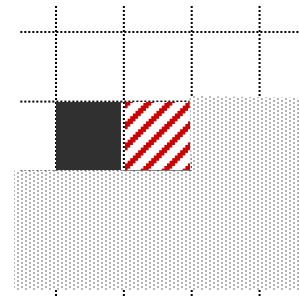
- Loop through all pixels  $f[x,y]$ , left to right, top to bottom
- If  $f[x,y]=0$ , do nothing.
- If  $f[x,y]=1$ , distinguish 4 cases



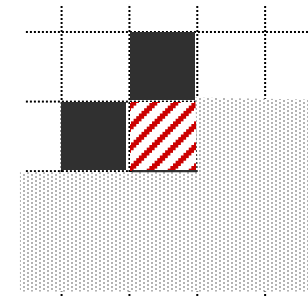
Generate new  
region label



Copy label  
from above



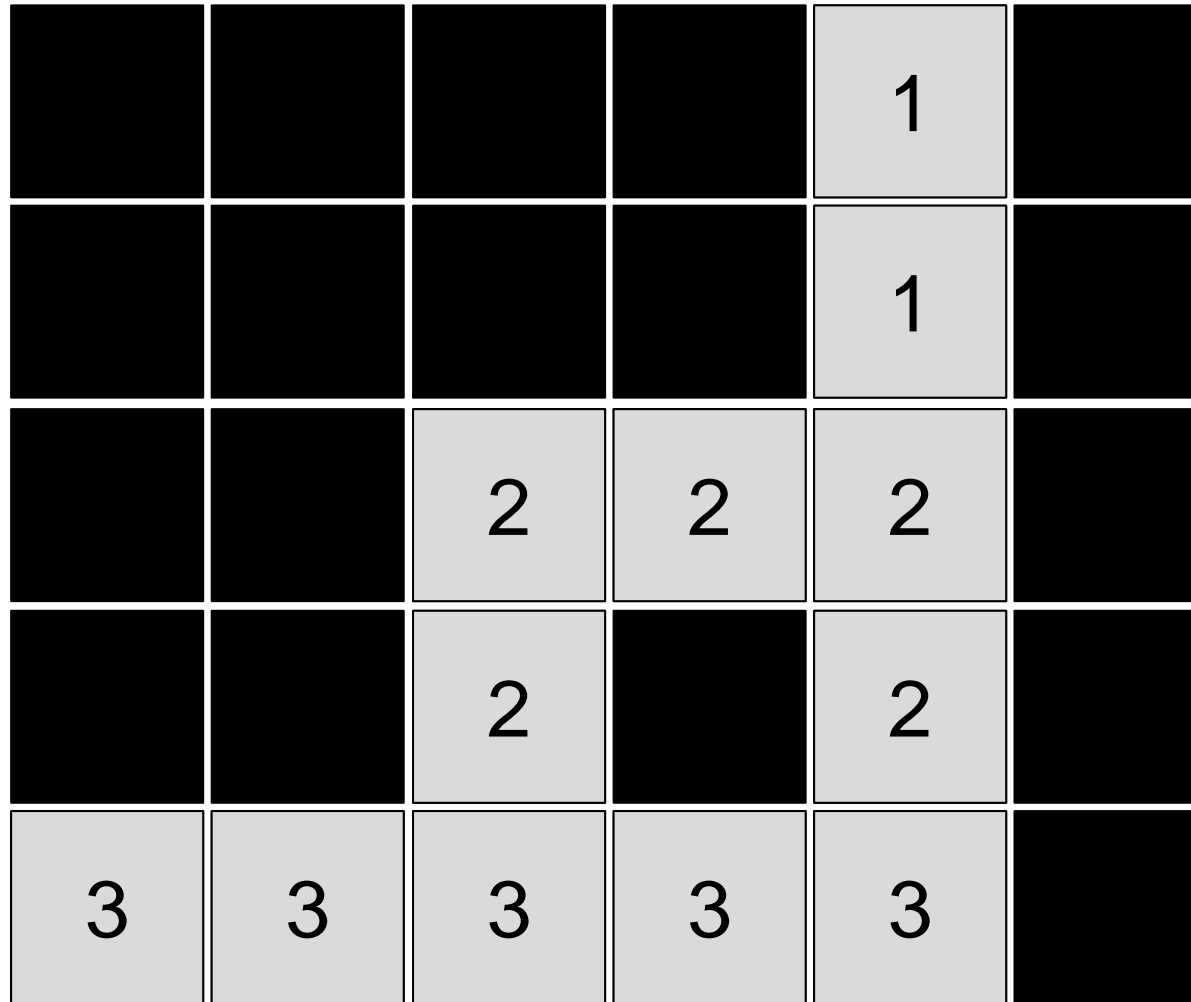
Copy label  
from the left



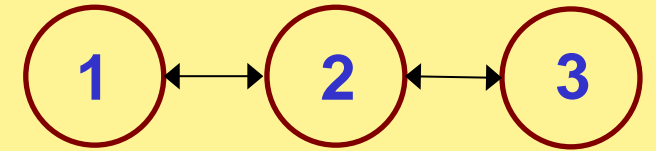
Copy label from the left. If  
labels above and to the left are  
different, store equivalence.

- Second pass through image to replace equivalent label by the same label.

# Region labeling example (4-neighborhood)

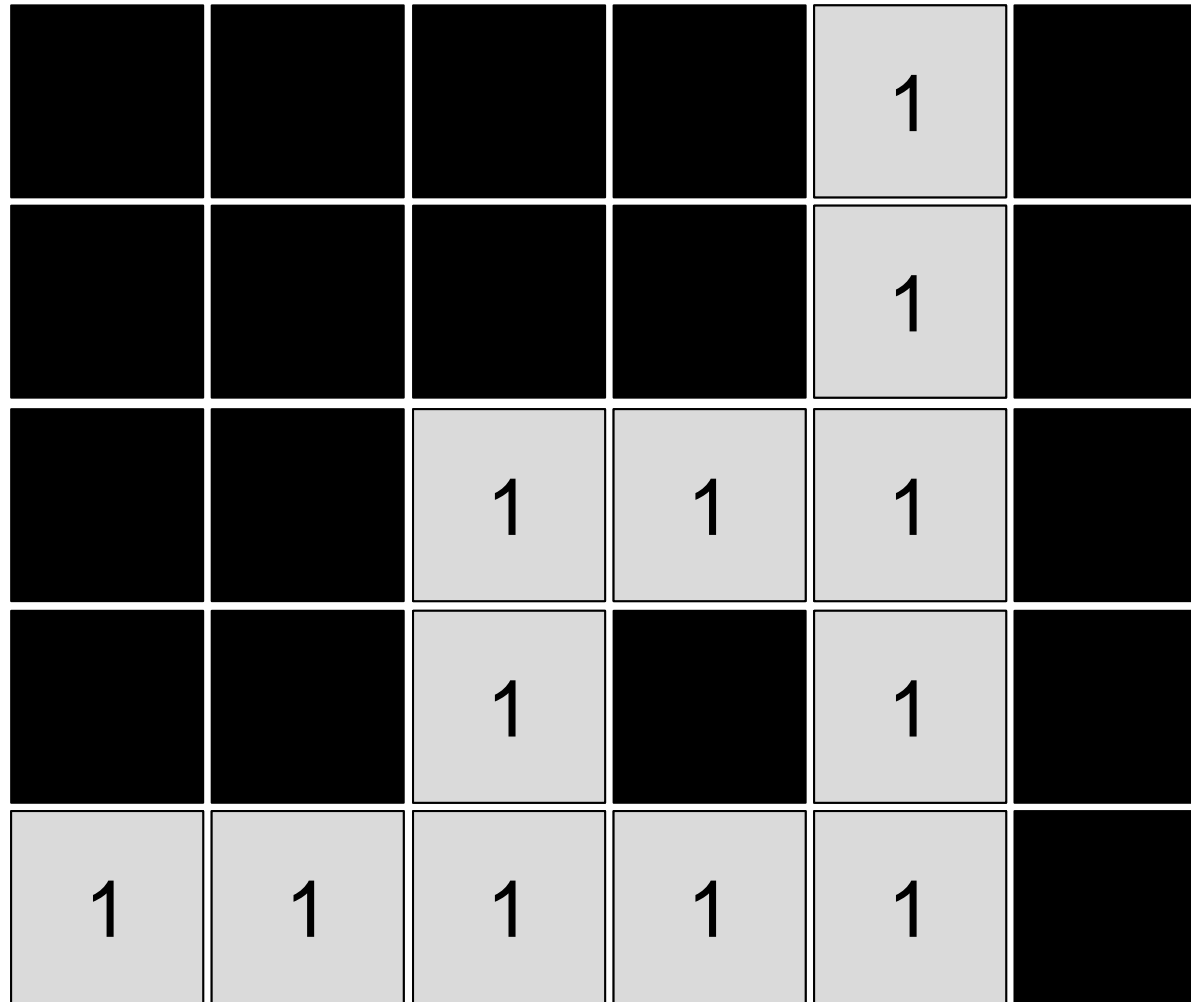


List of Region Labels



*All three labels are equivalent, so merge into single label.*

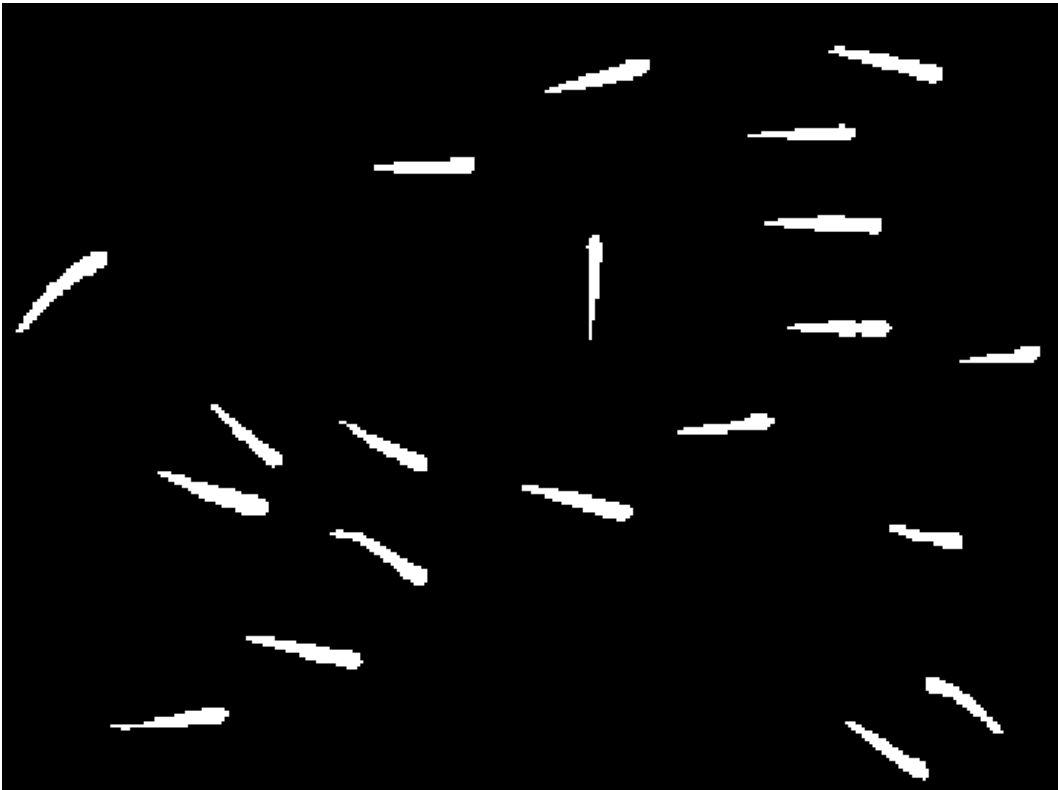
# Region labeling example (4-neighborhood)



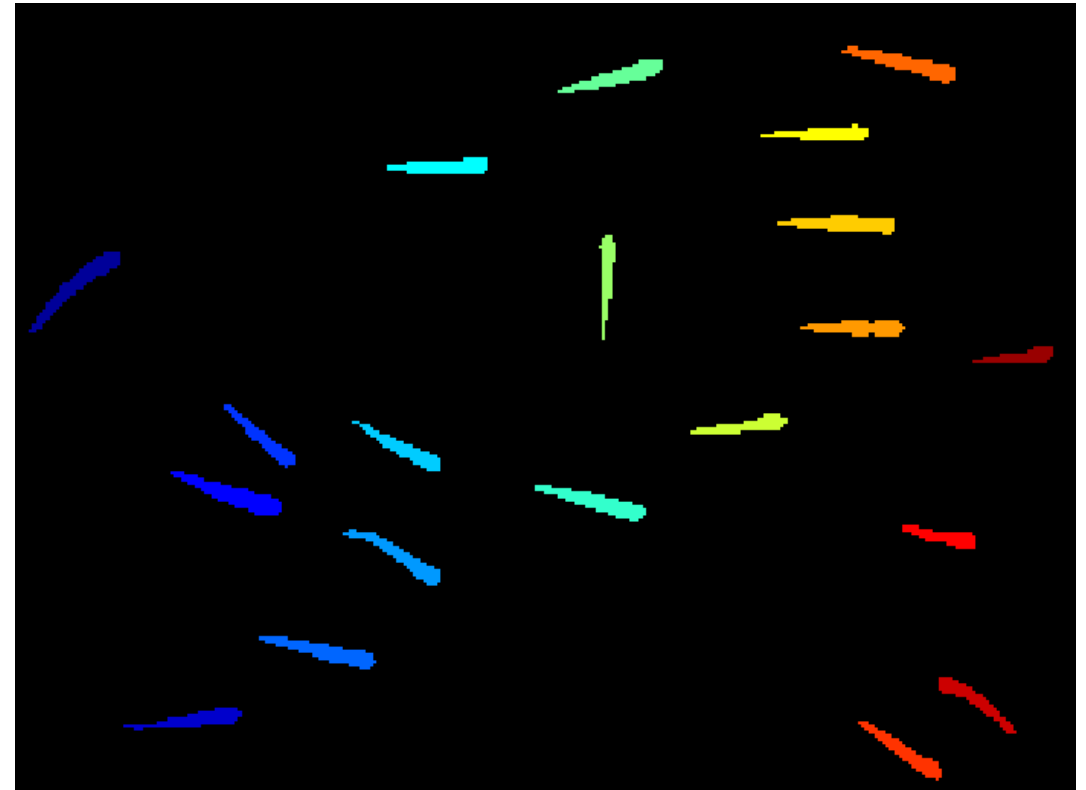
List of Region Labels

1

# Example: region labeling



Thresholded image



20 labeled regions



# Region counting algorithm

- Measures the size of each region
- Initialize  $counter[label]=0$  for all  $label$
- Loop through all pixels  $f[x,y]$ , left to right, top to bottom
  - If  $f[x,y]=0$ , do nothing.
  - If  $f[x,y]=1$ , increment  $counter[label[x,y]]$

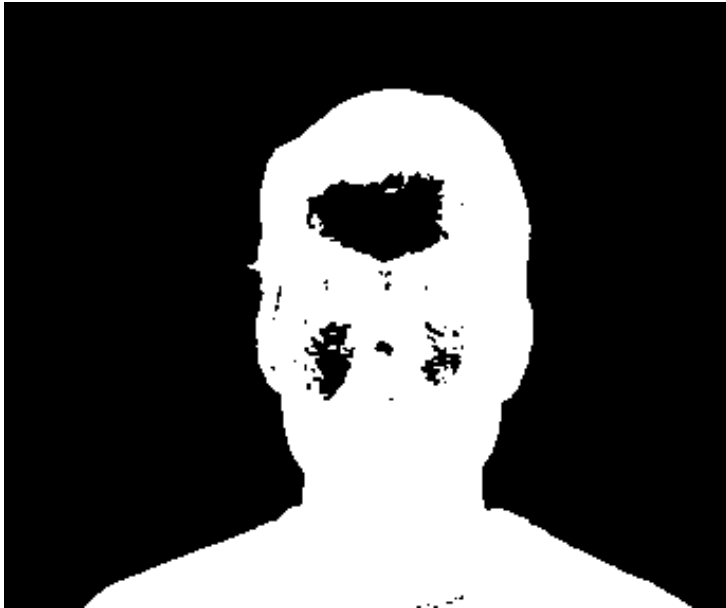


# Small region removal

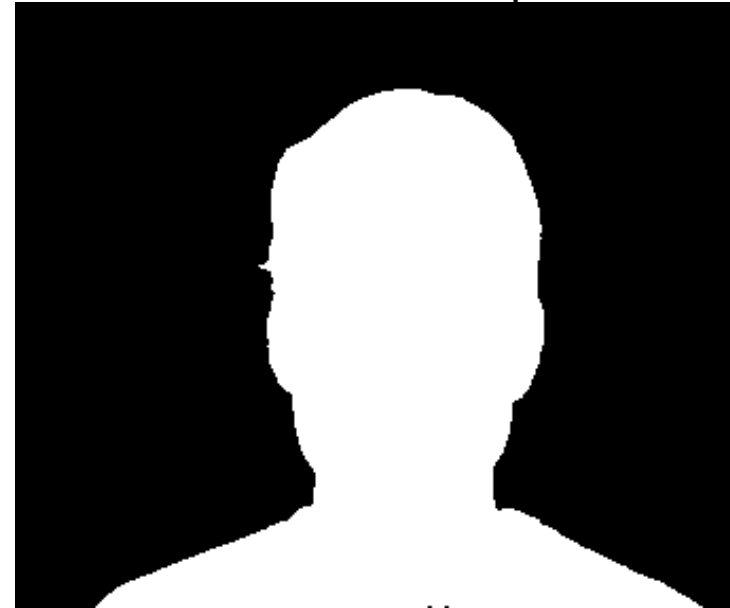
- Loop through all pixels  $f[x,y]$ , left to right, top to bottom
  - If  $f[x,y]=0$ , do nothing.
  - If  $f[x,y]=1$  and  $counter[label[x,y]] < S$ , set  $f[x,y]=0$
- Removes all regions smaller than  $S$  pixels

# Hole filling as dual to small region removal

Mask with holes



After NOT operation, (background) region labeling, small region removal, and second NOT operation



# Region moments

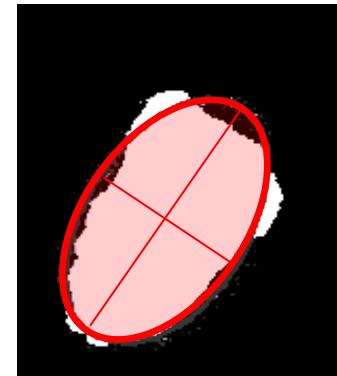
- Raw moments  $M_{pq} = \sum_{x,y \in \text{Region}} x^p y^q$

- Central moments

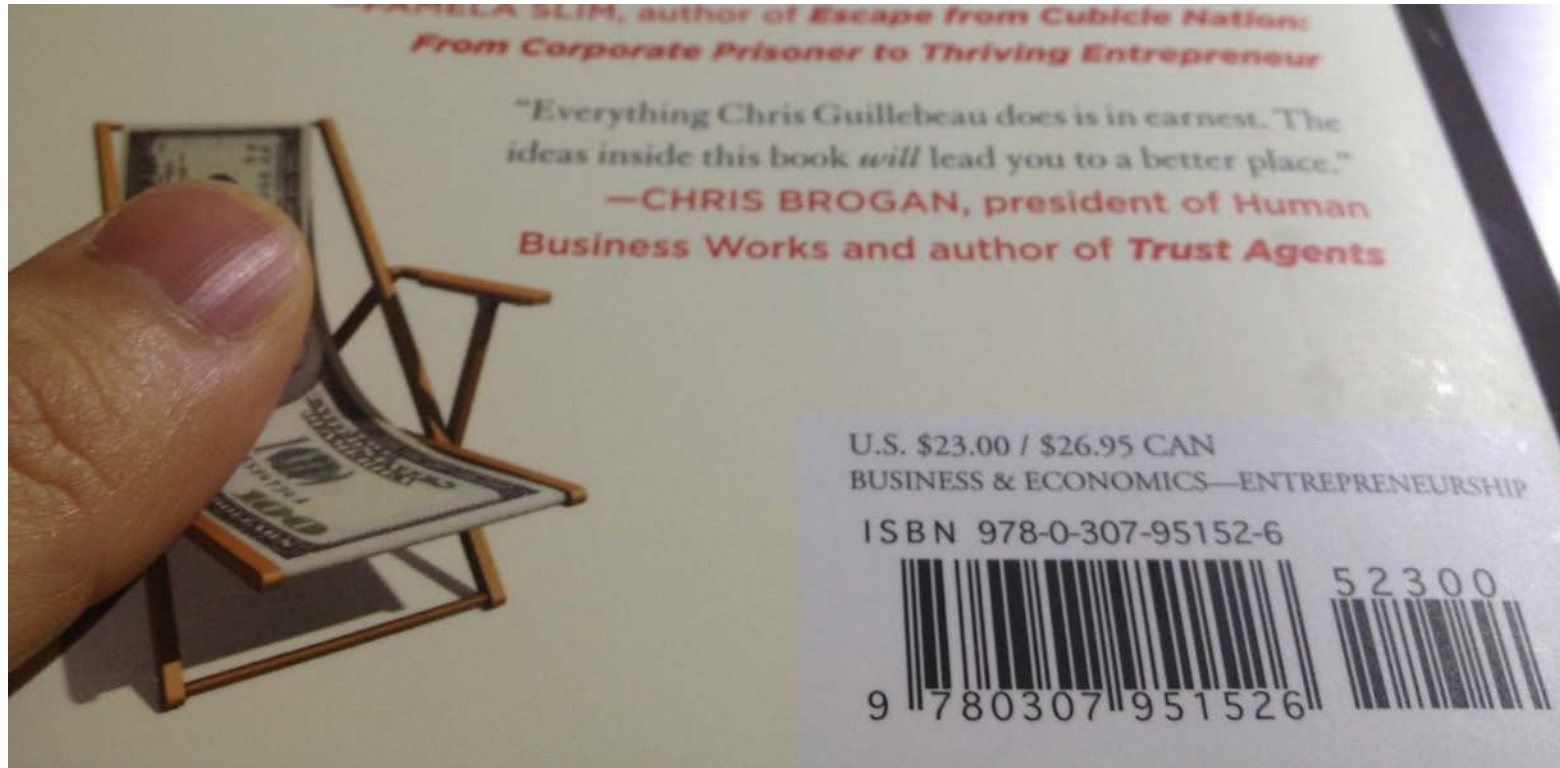
$$\mu_{pq} = \sum_{x,y \in \text{Region}} (x - \bar{x})^p (y - \bar{y})^q \quad \text{with} \quad \bar{x} = \frac{M_{10}}{M_{00}} \quad \text{and} \quad \bar{y} = \frac{M_{01}}{M_{00}}$$

- Region orientation and eccentricity:  
calculate eigenvectors of covariance

matrix 
$$\begin{bmatrix} \mu_{20} & \mu_{11} \\ \mu_{11} & \mu_{02} \end{bmatrix}$$



# Example: Detecting bar codes

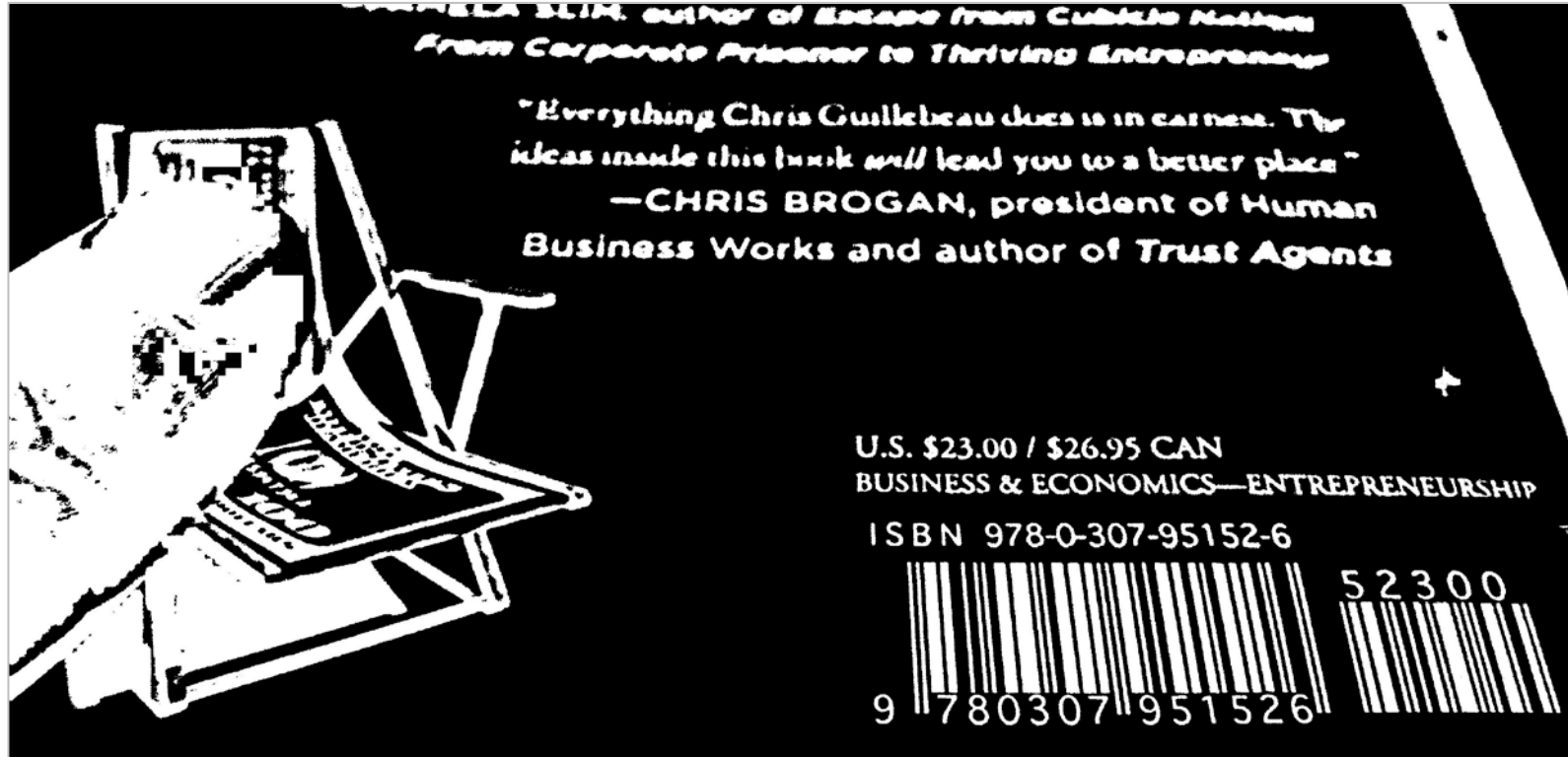


Original Image



# Example: Detecting bar codes

Locally adaptive  
thresholding



# Example: Detecting bar codes

Locally adaptive  
thresholding

Filtering by  
eccentricity

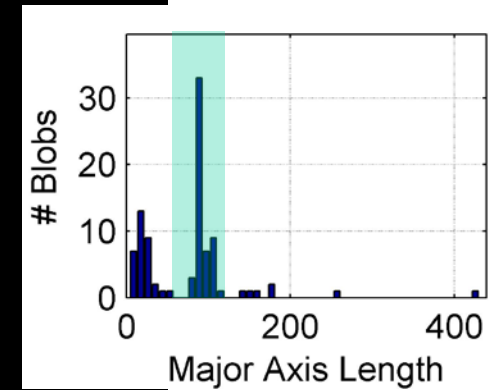


# Example: Detecting bar codes

Locally adaptive  
thresholding

Filtering by  
eccentricity

Filtering by major  
axis length



# Example: Detecting bar codes

Locally adaptive  
thresholding

Filtering by  
eccentricity

Filtering by major  
axis length

Filtering by  
orientation

