

**BLG453E COMPUTER VISION**  
Fall 2017 Term  
**Week 8**



İstanbul Technical University  
Computer Engineering Department

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**Teaching Assistant:** Enes ALBAY

Thanks: Some Slides in this presentation are from the lecture notes of Prof. Greg Slabaugh at City University of London

**Learning Outcomes of the Course**

Students will be able to:

1. Discuss the main problems of computer (artificial) vision, its uses and applications
2. Design and implement various image transforms: point-wise transforms, neighborhood operation-based spatial filters, and geometric transforms over images
3. Define and construct segmentation, feature extraction, and visual motion estimation algorithms to extract relevant information from images
4. Construct least squares solutions to problems in computer vision
5. Describe the idea behind dimensionality reduction and how it is used in data processing
6. Apply object and shape recognition approaches to problems in computer vision

### Week 8-9: Image Segmentation

At the end of Week : Students will be able to (Learning Objectives of the week):

3. Define and construct segmentation, feature extraction, and visual motion estimation algorithms to extract relevant information from images



Prank: <https://www.youtube.com/watch?v=wFa6NlgSRKQ>

### Green Screen

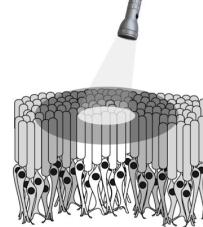
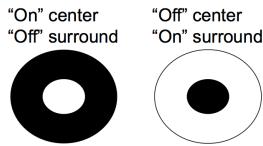


[https://en.wikipedia.org/wiki/Chroma\\_key](https://en.wikipedia.org/wiki/Chroma_key)

## Center Surround Organization in the Eye Neurons

### Center Surround Organization

Optimal stimuli (polka dots)



Some neurons receive net excitatory in the center and net inhibitory from the surround, and others receive net inhibitory in the center and net excitatory synapses in the surround.

Video min: 1:04: <http://www.youtube.com/watch?v=KE952yueVLA>

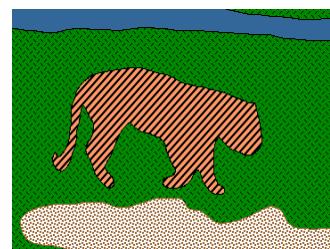
As a result: **retinal ganglion cell are more sensitive to patterns of light that are not uniform, but are changing in a way that, that matches their center surround organization**

That can make them most responsive to light spots on a dark background, which is referred to as having an on center and off surround, or dark spots on a light background, which is referred to as having an off center and on surround.

**This is a step towards identifying boundaries of objects** (happens later in visual cortex)

Prof. J. Groh, Duke University

## From Images to Objects/Regions: Segmentation



- Segmentation partitions an image into regions of interest.
- The first stage in many automatic image analysis systems.
- A complete segmentation of an image domain is a finite set of regions  $R_1, \dots, R_N$ , such that  $\Omega = \bigcup R_i$

## Segmentation

- Segmentation has a variety of practical uses



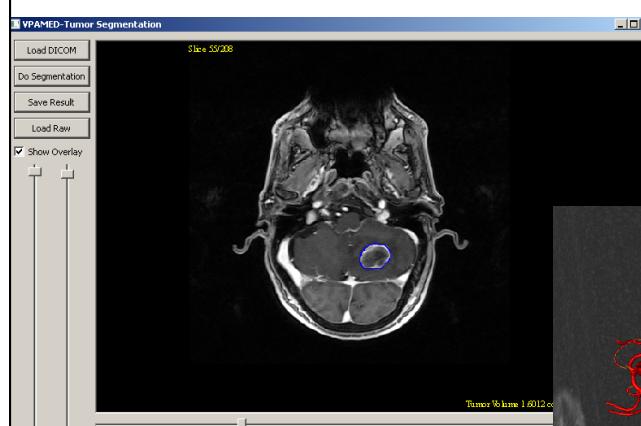
cut out

recolouring  
(courtesy of Tommaso)

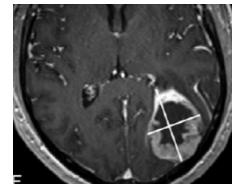
compositing



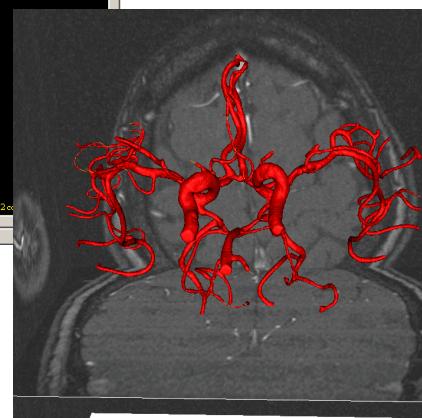
## Segmenting anatomical structures



Some results from  
Dr. Andac Hamamci and Dr. Suheyla Cetin's  
PhD thesis results at Prof. G. Unal's group

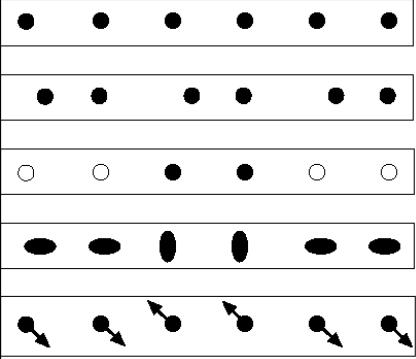
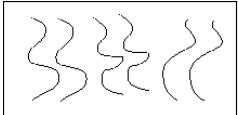
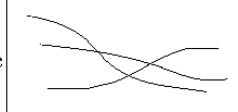
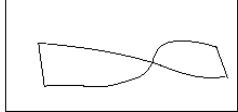


measurement



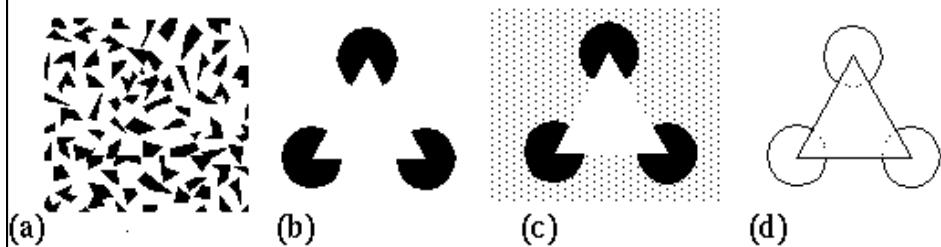
### Biological basis:

For humans at least, Gestalt psychology identifies several properties that result in grouping/segmentation:

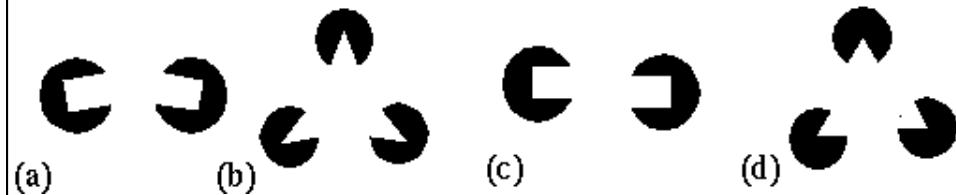
	Not grouped		Parallelism
	Proximity		Symmetry
	Similarity		Continuity
	Similarity		Closure
	Common Fate		

Slide: Bradski&Trun

### Consequence: Groupings by Invisible Completions



Stressing the invisible groupings:



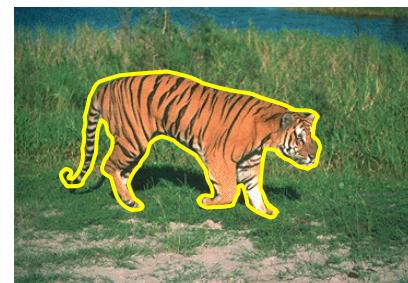
\* Images from Steve Lehar's Gestalt papers: <http://cns-alumni.bu.edu/pub/slehar/Lehar.html>



And the famous invisible dog eating  
under a tree:

Slide: Bradski&Trun

### Segmenting objects



How could this be done?



## Image Segmentation

- Many approaches proposed
  - cues: color, contours, textural patterns
  - automatic vs. user-guided
  - no clear winner
- Is user-input required?
- \* Our visual system is proof that automatic methods are possible, classical image segmentation methods are automatic
- \* Argument for user-directed methods? only user knows desired scale/object of interest

Segmentation algorithms must be chosen and evaluated with an application in mind

## Problem of Image Segmentation:



Segmentation: Labeling pixels in an image so that the image is partitioned into “meaningful” regions

Input: a grayscale or color image or image volume

Output: a binary (K-ary) image with labels

e.g. Labels = “foreground” vs “background”  
or Labels = 0 or 1

Labels: 0, 1, 2, ... K (K objects) if more than two regions exist:

Image from Kohli, MICCAI 2009 tutorial

## Segmentation

- Image segmentation partitions an image into regions (aka *segments*).

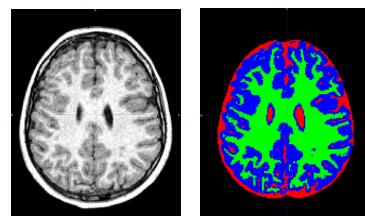


- You can think of image segmentation as assigning a label to each pixel in the image. In the case above, there are two labels: *bird* (foreground, white) and *non-bird* (background, black).

Slide: Dr. Greg Slabaugh, City University of London

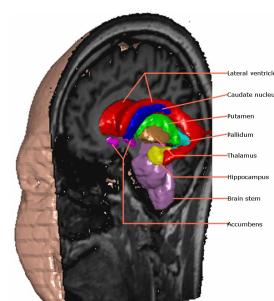
## Segmentation

- There can be any number of labels



Four labels:  
 1. Non-brain  
 2. Grey matter  
 3. White matter  
 4. CSF

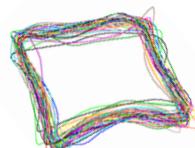
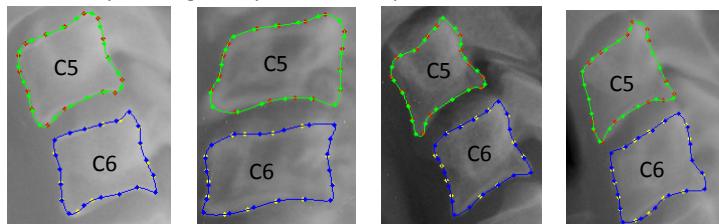
- Different types of data; more than two dimensions



Slide: Dr. Greg Slabaugh, City University of London

## Segmentation

- The boundary of a segment provides a *shape*.



A collection of aligned C4 vertebra shapes. From this, we can do all sorts of interesting things:

- Population statistics
- Mean, variation (principal component analysis)
- (more)

Slide: Dr. Greg Slabaugh, City University of London

## Under and over segmentation

- An image that has been broken into too many segments is considered to be *over-segmented*



- Not enough segments is considered *under-segmented*



Slide: Dr. Greg Slabaugh, City University of London

## Bird counting

- How would you determine the number of birds in this image?



<http://350sav.fotomaps.ru/flock-of-birds.php>

- One way is to count the dark blobs. First we need to *find* the dark blobs.
- Let's load the image and convert to grayscale

```
I = rgb2gray(imread('birds.png'));
```

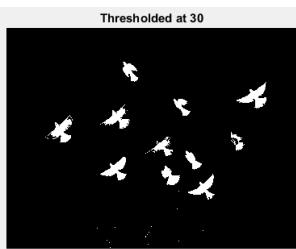


## Thresholding



- The simplest form of segmentation is to *threshold* an image. This assigns a value of 1 to any pixel that satisfies the threshold, otherwise, 0. A *binary* image is produced.

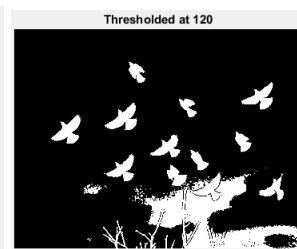
$$B(x, y) = \begin{cases} 1, & I(x, y) < T \\ 0, & \text{otherwise} \end{cases} \quad >T \text{ if looking for bright regions}$$



```
B = I < 30;
figure; imshow(B);
title('Thresholded at 30');
```



```
B = I < 70;
figure; imshow(B);
title('Thresholded at 70');
```



```
B = I < 120;
figure; imshow(B);
title('Thresholded at 120');
```

## Bird counting

The figure shows three images side-by-side. The first image, titled 'Thresholded at 70', is a binary image where birds are white shapes on a black background. The second image, titled 'Opened', shows the same birds after a morphological operation. The third image, titled 'Labeled. Number of birds = 12', shows the birds colored in various shades of blue, cyan, and yellow, indicating they are different objects. A legend at the bottom right identifies the colors: blue for one type, cyan for another, and yellow for a third.

```
I = rgb2gray(imread('birds.png'));
B = I < 70;
figure; imshow(B); title('Thresholded at 70');
E = imopen(B, ones(3,3));
figure; imshow(E); title('Opened');
L = bwlabel(E);
figure; imagesc(L); colormap('jet');
title(['Labeled. Number of birds = ' num2str(max(L(:)))]);
```

**So, the simplest Segmentation approach is global thresholding**

Simplest way to segment an image : create a binary image by separating the image domain into two regions

It labels each pixel **in** or **out** of the region of interest by comparison of the grey level with a threshold  $T$ :

$$g(x, y) = \begin{cases} 1 & \text{if } f(x, y) \geq T \\ 0 & \text{otherwise} \end{cases}$$

**Basic Thresholding Algorithm**

```
for x=1:X
    for y=1:Y
        B(x,y) = (I(x,y) >= T);
    end
end
```

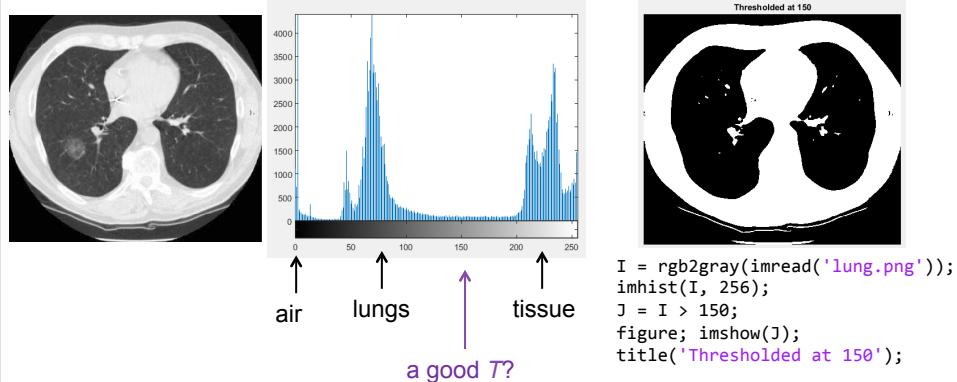
Don't write it like this at home!

A grayscale image of a maple leaf on the left, and its binary version (black leaf on a white background) on the right, resulting from a global thresholding operation.

Picture: Bryan Morse notes, BYU

## Finding a good threshold

- The success of thresholding often depends on finding a good threshold  $T$ .
- Recall the histogram  $h(I)$  of an image. It counts how many pixels of a particular intensity are in the image.

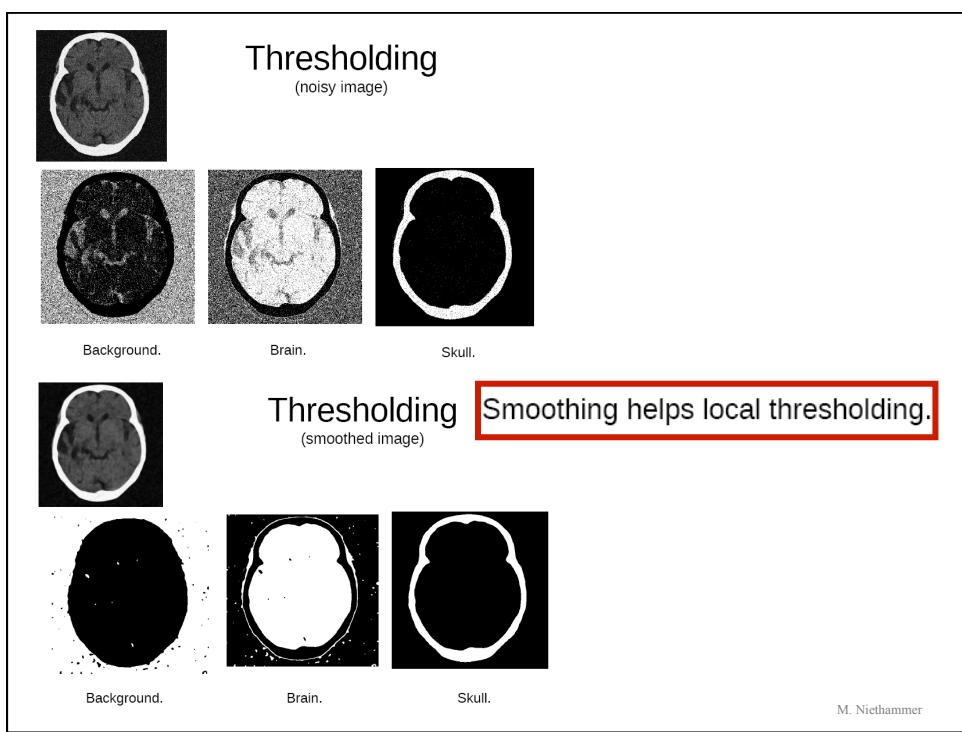
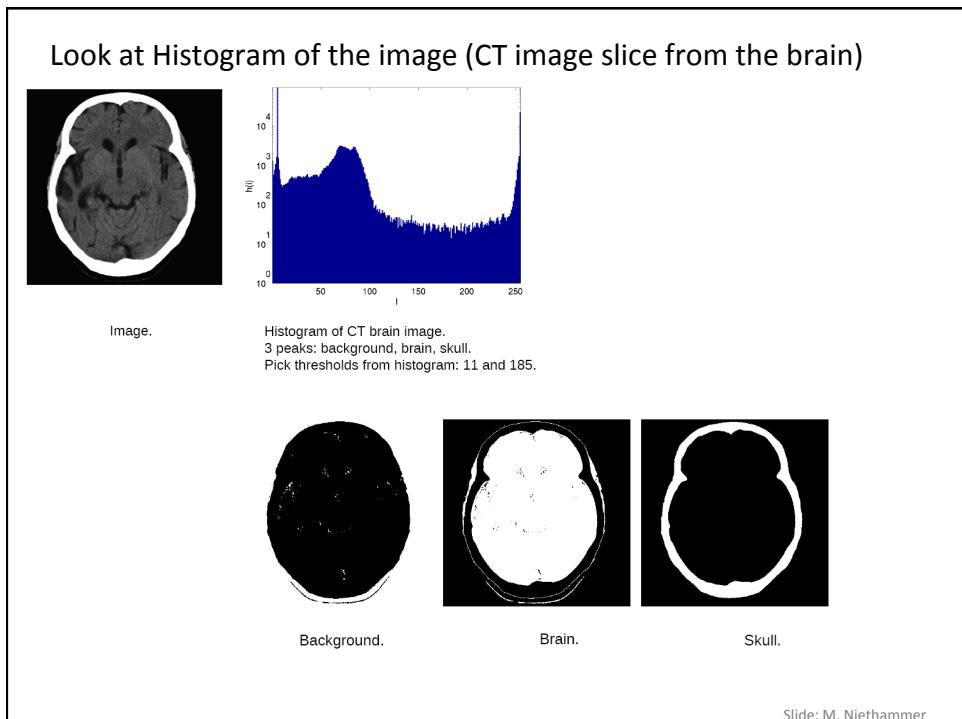


Recall Histogram:

Recall that a normalized histogram is a probability distribution:

$$p(I) = \frac{n(I)}{n}$$

That is, the number of pixels  $n(I)$  having grayscale intensity  $I$  as a fraction of the total number of pixels  $n$ .



## Skin segmentation

\* Segmentation of skin a notoriously difficult problem, given the variation observed in practice. One can perform simple skin detectors using *colour thresholding*.



Examples below: Work in a color space (other than (R,G,B)): Y, U, and V values; Y stores the brightness (luminance), and the color (chrominance) stored as U and V values.

### [Chai et al.]

Convert to YUV

$\text{Skin} = (77 \leq U \leq 127) \text{ and } (133 \leq V \leq 173)$

```
I = imread('faces.png');
YUV = rgb2ycbcr(I);
U = YUV(:, :, 2); V = YUV(:, :, 3);
R = I(:, :, 1); G = I(:, :, 2); B = I(:, :, 3);
[rows, cols, planes] = size(I);
```

```
% Chai et al.
skin = zeros(rows, cols);
ind = find(77 <= U & U <= 127 & ...
133 <= V & V <= 173);
skin(ind) = 1;
```

```
figure; subplot(3, 1, 1); imshow(I);
subplot(3, 1, 2); imshow(skin); title('Chai');
```

### [Al-Tairi et al.]

Convert to YUV

$\text{Skin} = (80 < U < 130) \text{ and } (136 < V < 200) \text{ and } (V > U) \& (R > 80) \text{ and } (G > 30) \& (B > 15) \text{ and } |R-G| > 15$

```
% Al-Tairi et al.
skin = zeros(rows, cols);
ind = find(80 < U & U < 130 & 136 < V & ...
V <= 200 & V > U & R > 80 & G > 30 & ...
B > 15 & abs(R-G) > 15);
skin(ind) = 1;
```

```
subplot(3, 1, 3); imshow(skin); title('Al-Tairi');
```

## Example



Chai

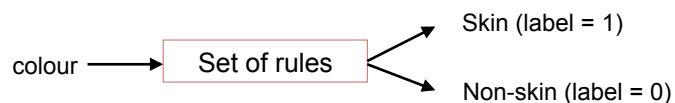


Al-Tairi



## Rule-based

- We have a set of rules that label a pixel as skin or non-skin.
- More abstractly, we can think of this as



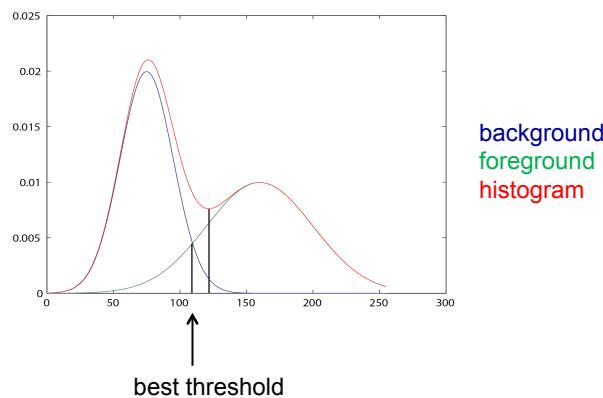
⇒ This is a rule-based classifier

In this case, the rules have been generated by a human by looking at many datasets.

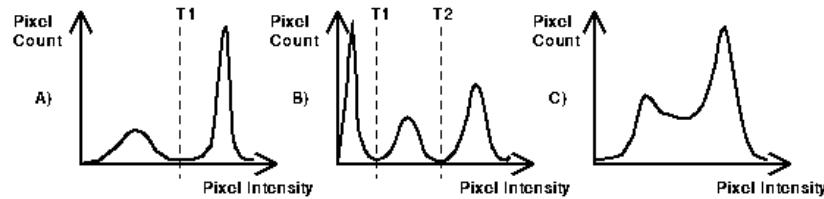
\* An alternative is to use *machine learning* to develop a supervised approach to skin detection. Supervised learning is another way to perform segmentation, topic of another time

## Automatic thresholding methods

- Many automatic methods to determine the threshold assume a *bimodal* histogram, meaning there are two peaks (one for foreground, the other for background)



### Bimodal histogram      Trimodal histogram:

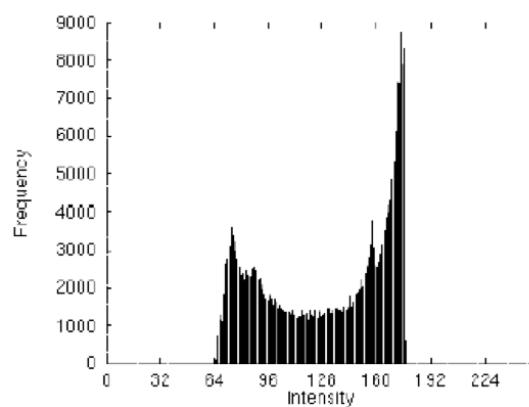


For instance, the segmentation thresholds  $T$  are set as the local minima of the histogram

Methods of threshold detection: Usually based on histogram analysis

### Finding Modes of Histograms

Idea: find two peaks (modes) and the local minimum in between

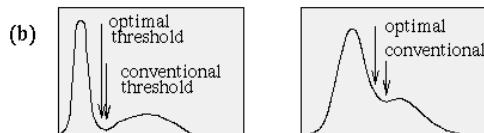
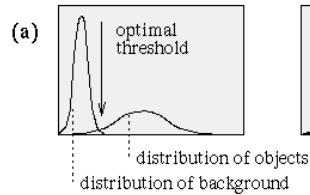
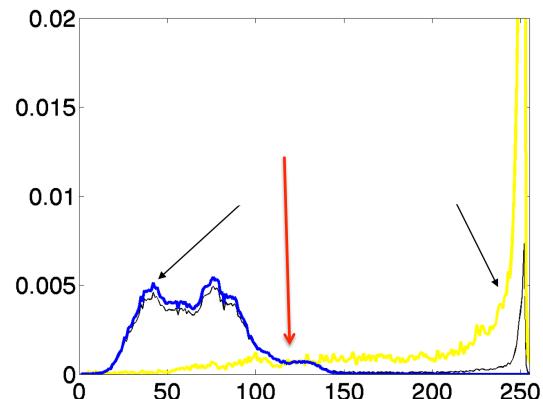
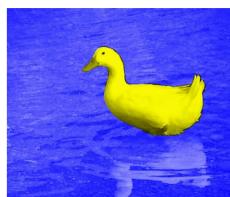


Problems :  
Noisy Histograms  
Are there better ways?

Bryan Morse, BYU

## Optimal Thresholding

- Idea: the histogram is the sum of two overlapping distributions.
- Optimal threshold: the overlapping point of these distributions.



**Figure 5.4** Grey level histograms approximated by two normal distributions; the threshold is set to give minimum probability of segmentation error: (a) Probability distributions of background and objects, (b) corresponding histograms and optimal threshold.

Problem 1: Don't know the distributions

Problem 2: "Optimal threshold" as the intersection of two distributions is not the same as the local minimum.

Figure: Bryan Morse, BYU

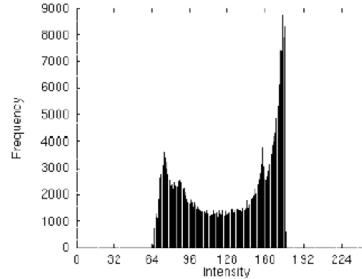
## “Optimal” Thresholding

### One approach was proposed by Otsu

One can express the total variance of image intensities as:

$$\sigma^2(T) = \underbrace{\sigma_{\text{Within}}^2(T)}_{\substack{\text{Within-class} \\ \text{variance}}} + \underbrace{\sigma_{\text{Between}}^2(T)}_{\substack{\text{Between-class} \\ \text{variance}}}$$

T: unknown threshold



Since the total variance is constant and independent of  $T$ , the effect of changing the threshold is merely to move the contributions of the two terms back and forth.

*So, minimizing the within-class variance is the same as maximizing the between-class variance with respect to “optimal” threshold  $T$  to be estimated.*

The nice thing about this is that we can calculate the quantities in  $\sigma_{\text{Between}}^2(T)$  recursively as we run through the range of  $T$  values when we compute the variance

## Optimal thresholding (Otsu)

- An approach was proposed by Otsu.
- Otsu’s method finds the threshold  $T$  that minimises the within-class variance, defined as

$$\sigma^2 = w_f \sigma_f^2 + w_b \sigma_b^2$$

where  $\sigma_f^2$  and  $\sigma_b^2$  are the variances of the foreground and background, and

$$w_b = \sum_{I=0}^T p(I) \quad w_f = \sum_{I=T+1}^{255} p(I)$$

are weights formed by summing the histogram pdf over the background and foreground intensities, respectively.

In Matlab, Otsu thresholding is implemented with the function `grayThresh`, which returns a threshold in the range of 0 to 1.

For the previous example, `level = 255*graythresh(I)` returns a value of 139.

## Optimal thresholding (Otsu)

Easier way to calculate:

- If you subtract the “within-class” variance from the total variance of the combined distribution, you get the “between-class” variance:

$$\begin{aligned}\sigma_{\text{Between}}^2(T) &= \sigma_{\text{total}}^2 - \sigma_{\text{within}}^2(T) \\ &= w_B(T)[\mu_B(T) - \mu]^2 + w_F(T)[\mu_F(T) - \mu]^2\end{aligned}$$

where  $\sigma^2$  is the combined variance and  $\mu$  is the combined mean.

\* Since total variance is independent of the threshold, maximizing the between-class variance is the same as minimizing the within-class variance.

Substituting:

$$\mu = w_B(T)\mu_B(T) + w_F(T)\mu_F(T)$$

and simplifying, we get:

$$\sigma_{\text{Between}}^2(T) = w_B(T)w_F(T)[\mu_B(T) - \mu_F(T)]^2$$

## “Optimal” Thresholding (Otsu’s method)

Goal: Find T that maximizes the measure:

$$\sigma_{\text{Between}}^2(T) = w_B(T)w_F(T)[\mu_B(T) - \mu_F(T)]^2$$

ALGORITHM:

i. For each potential threshold T:

1. Separate the pixels into two clusters according to the threshold T
2. Find the mean of each cluster (don’t have to calculate the variance in this way – if you minimize within-class variance instead, you have to calculate the variances of each cluster)
3. Calculate the above measure

ii. Output: Choose the threshold T that gives the maximum measure.

Extra Slide 1: OTSU'S THRESHOLDING Method: Details for an even more efficient implementation  
Note the notation change from w\_ weights to n\_ and B(background) and O(object)

Idea: select  $T$  to minimize the *within-class* variance—the weighted sum of the variances of each cluster:

$$\sigma_{\text{Within}}^2(T) = n_B(T) \sigma_B^2(T) + n_O(T) \sigma_O^2(T)$$

where

$$n_B(T) = \sum_{i=0}^{T-1} p(i)$$

$$n_O(T) = \sum_{i=T}^{N-1} p(i)$$

$\sigma_B^2(T)$  = the variance of the pixels in the background ( $< T$ )

$\sigma_O^2(T)$  = the variance of the pixels in the foreground ( $\geq T$ )

and  $[0, N - 1]$  is the range of intensity levels.

Extra Slide 2: A very efficient implementation

- ▶ Better Still: Update  $n_B(T)$ ,  $n_O(T)$ , and the respective cluster means  $\mu_B(T)$  and  $\mu_O(T)$  with the pixels that move from one cluster to the other as  $T$  increases:

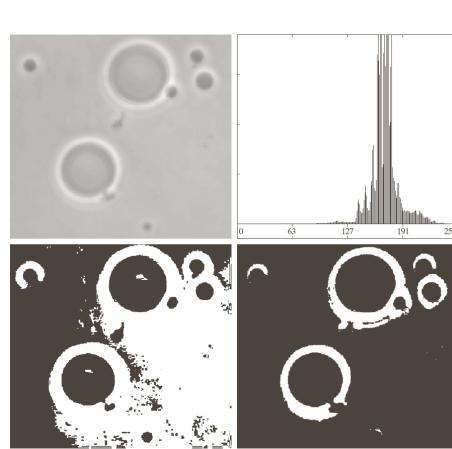
$$n_B(T + 1) = n_B(T) + n_T$$

$$n_O(T + 1) = n_O(T) - n_T$$

$$\mu_B(T + 1) = \frac{\mu_B(T) n_B(T) + n_T T}{n_B(T + 1)}$$

$$\mu_O(T + 1) = \frac{\mu_O(T) n_O(T) - n_T T}{n_O(T + 1)}$$

### Result of Otsu

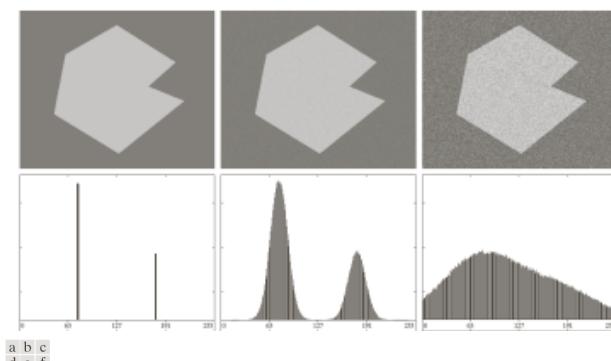


a b  
c d

**FIGURE 10.39**  
 (a) Original image.  
 (b) Histogram (high peaks were clipped to highlight details in the lower values).  
 (c) Segmentation result using the basic global algorithm from Section 10.3.2.  
 (d) Result obtained using Otsu's method. (Original image courtesy of Professor Daniel A. Hammer, the University of Pennsylvania.)

Digital Image Processing, Gonzalez and Woods

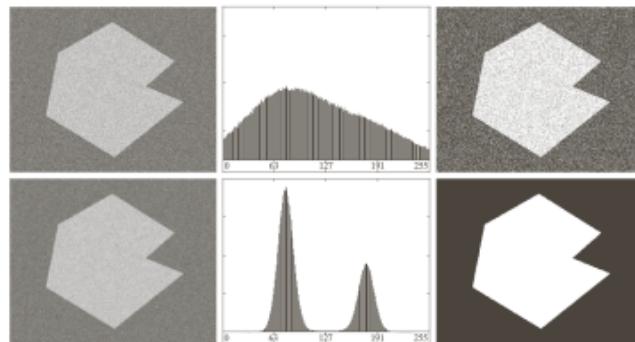
### Effect of Noise in Thresholding



**FIGURE 10.36** (a) Noiseless 8-bit image. (b) Image with additive Gaussian noise of mean 0 and standard deviation of 10 intensity levels. (c) Image with additive Gaussian noise of mean 0 and standard deviation of 50 intensity levels. (d)–(f) Corresponding histograms.

Digital Image Processing, Gonzalez and Woods

### Effect of Noise and Smoothing in Thresholding

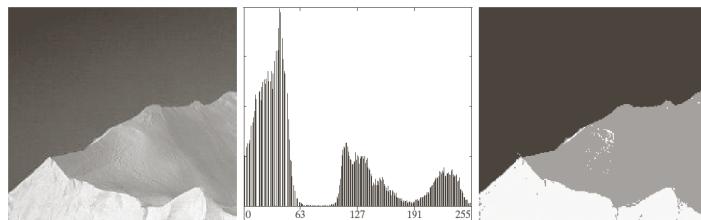


a b c  
d e f

**FIGURE 10.40** (a) Noisy image from Fig. 10.36 and (b) its histogram. (c) Result obtained using Otsu's method. (d) Noisy image smoothed using a  $5 \times 5$  averaging mask and (e) its histogram. (f) Result of thresholding using Otsu's method.

Digital Image Processing, Gonzalez and Woods

### Ternary Segmentation: i.e. Segment the image into 3 regions



a b c

**FIGURE 10.45** (a) Image of iceberg. (b) Histogram. (c) Image segmented into three regions using dual Otsu thresholds. (Original image courtesy of NOAA.)

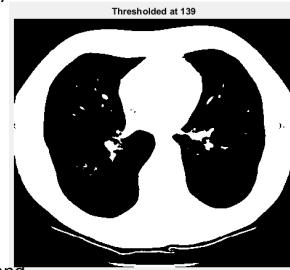
Digital Image Processing, Gonzalez and Woods

## Iterative Thresholding method (Another Method)

1. Set  $T$  to some initial value, and determine foreground and background pixels.
2. Compute  $m_b$ , the mean of the background, and  $m_f$ , the mean of the foreground, based on the current value of  $T$ .
3. Set  $T = (m_b + m_f)/2$
4. Go to step 2 until convergence (when  $T$  no longer changes).

```
I = rgb2gray(imread('lung.png'));
T = 50;
lastT = 0;
while (abs(T - lastT) > 1)
    lastT = T;
    mf = mean(I(I>T));
    mb = mean(I(I<=T));
    T = 0.5*(mb+mf);
end
```

In this example, the loop executes 5 times, with  $T$  starting at 50, and going to 81.9, 126.7, 138.2, 139.3, 139.4



An idea to set the initial Threshold: Start with  $m_b$  as the average of the four corner pixel, which is assumed to be the background, and  $m_f$  as the average of everything else. Go to step 3 of the algorithm above and continue.

## Idea behind Iterative Threshold Selection

- ▶ Idea: pick a threshold such that each pixel on each side of the threshold is closer in intensity to the mean of all pixels on that side of the threshold than the mean of all pixels on the other side of the threshold.
- ▶ Let

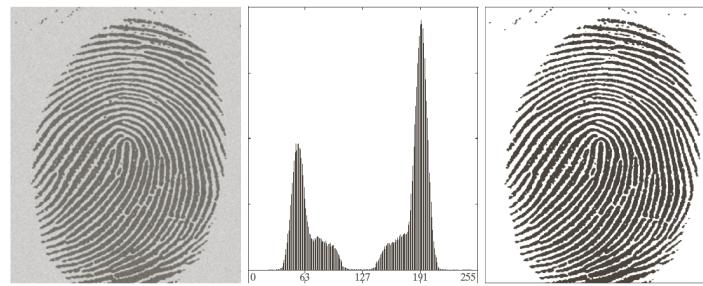
$$\begin{aligned}\mu_B(T) &= \text{the mean of all pixels less than the threshold (background)} \\ \mu_O(T) &= \text{the mean of all pixels greater than the threshold (object)}\end{aligned}$$

We want to find a threshold such that the greylevels for the object are closest to the average of the object:

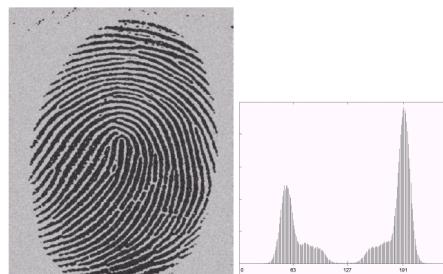
$$\forall g \geq T : |g - \mu_B(T)| > |g - \mu_O(T)|$$

and the greylevels for the background are closest to the average of the background:

$$\forall g < T : |g - \mu_B(T)| < |g - \mu_O(T)|$$



**FIGURE 10.38** (a) Noisy fingerprint. (b) Histogram. (c) Segmented result using a global threshold (the border was added for clarity). (Original courtesy of the National Institute of Standards and Technology.)

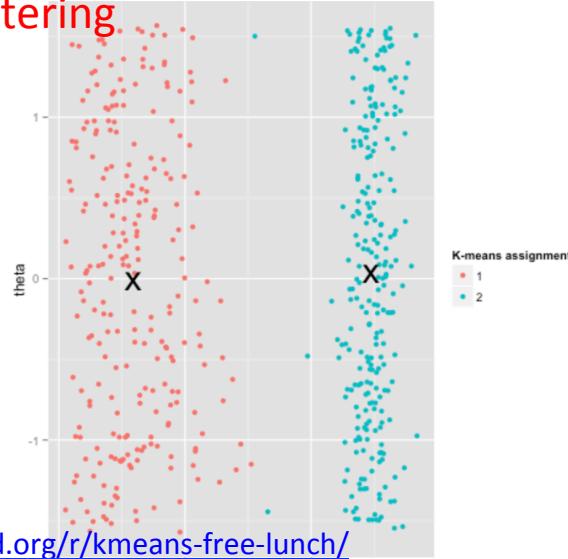


**FIGURE 10.29**  
(a) Original  
image. (b) Image  
histogram.  
(c) Result of  
segmentation with  
adaptive  
threshold  
estimated by  
iteration.  
(Original courtesy  
of the National  
Institute of  
Standards and  
Technology.)

## K means Clustering

- The optimal (iterative) thresholding method described on the previous slide is an example of the K means algorithm, where K = 2.
- K means is a clustering technique, in this case grouping pixels of similar intensity into two groups, or *clusters*.
- However, K means can be used to cluster data into any number (K) classes. The data can be based on intensity, colour, or any attribute associated with a pixel (e.g., texture, depth, etc.)
- It requires K to be provided in advance.

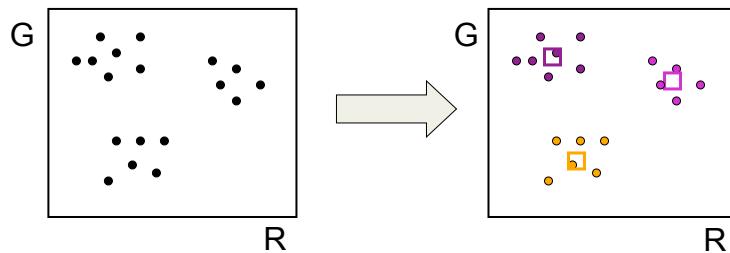
NEXT: K-means clustering



- <http://varianceexplained.org/r/kmeans-free-lunch/>
- <http://stats.stackexchange.com/questions/133656/how-to-understand-the-drawbacks-of-k-means>

## Segmentation as a Clustering Problem

- How to choose the representative colors?  
– This is a clustering problem!



### Objective

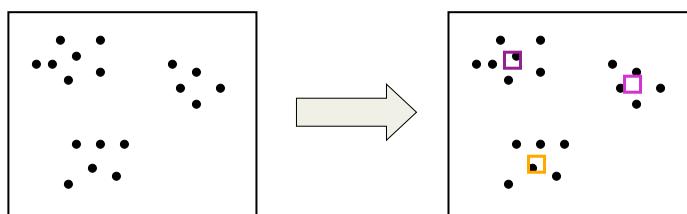
- Each point should be as close as possible to a cluster center  
– Minimize sum squared distance of each point to closest center

$$\sum_{\text{clusters } i} \sum_{\text{points } p \text{ in cluster } i} \|p - c_i\|^2$$

R. Szeliski Slides

## Break it down into subproblems

- Suppose I tell you the cluster centers  $c_i$   
– Q: how to determine which points to associate with each  $c_i$ ?  
• A: for each point  $p$ , choose closest  $c_i$



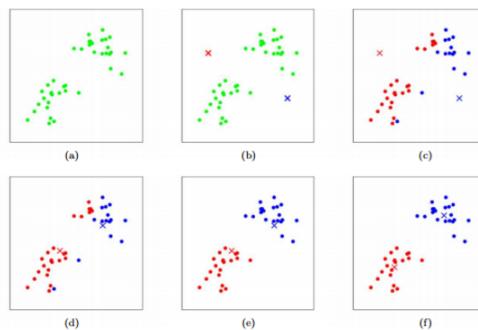
### Suppose I tell you the points in each cluster

- Q: how to determine the cluster centers?  
• A: choose  $c_i$  to be the mean of all points in the cluster

R. Szeliski Slides

## Algorithm: K-means clustering

1. Start with a set of N points (green points below)
2. Randomly initialize the K cluster centers,  $c_1, \dots, c_K$  (x's below)
3. **Assignment:** Given cluster centers, determine points in each cluster
  - For each point p, find the closest  $c_i$ . Put p into cluster i
4. **Update:** Given points in each cluster, calculate new means  $c_i$ 
  - Set  $c_i$  to be the mean of assigned points in cluster i
5. Go to 3 until convergence (e.g. means  $c_i$  no longer change)



Java demo (please check if the link still works)  
[http://home.dei.polimi.it/matteucc/Clustering/tutorial\\_html/AppletKM.html](http://home.dei.polimi.it/matteucc/Clustering/tutorial_html/AppletKM.html)

## K-means clustering

K-means minimizes the objective function: Sum of Within-Cluster Variance, which is also Mean Squared Error within each cluster.

Equivalently: it is based on Sum of Squared Distances (SSD) between points in a cluster and the mean point

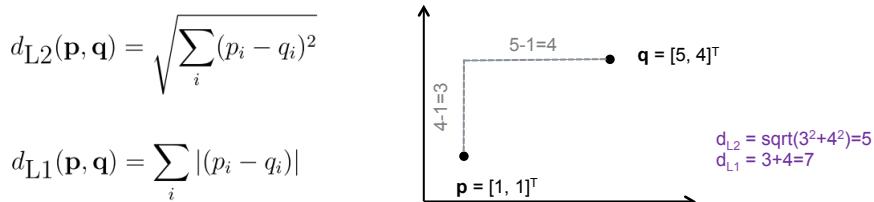
$$\sum_{\text{clusters } i} \sum_{\text{points } p \text{ in cluster } i} \|p - c_i\|^2$$

### Properties

- Will always converge to *some* solution
- Can be a “local minimum”
  - does not always find the global minimum of objective function

## Issues with K means

- What is K?
  - In some applications, there is an obvious K. In others, it may be unclear.
- How to initialise the means? Potentially different results each time the algorithm is run
  - One can rerun the algorithm multiple times and merge the results
- Dealing with high dimensional data
  - Finding nearest neighbours can be slow (e.g. kd tree can help)
- How do you measure distance?
  - Normally the L2 norm (Euclidean distance) is selected, but there are other options, for example, the L1 distance (aka CityBlock distance).



## K means

- Matlab has support for K means using with the [kmeans](#) function. It requires an NxM matrix. Here, N is the number of pixels, and M are the features (colours) used in the grouping. This can be achieved using the [reshape](#) function.



```
I = imresize(imread('road_sky.jpg'), 0.25);
imshow(I);
[rows, cols, planes] = size(I);

% Run k means on the RGB data, k = 3
R = double(reshape(I, rows*cols, 3));
[clusterID, clusterCentre] = kmeans(R, 3);

% Reshape back to an image and display using a colormap
clusterID = reshape(clusterID, rows, cols);
figure; imshow(clusterID,[]), title('image labeled by cluster index');
colormap(clusterCentre/255);
```

## K means

- Different results for different K



K = 2



K = 3



K = 4



K = 5

## K means

- Different results for different *runs* due to random initialisation.



K = 3



K = 3

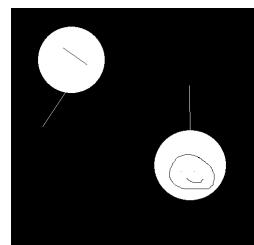
- Replicates (running the algorithm multiple times) can produce more consistent results

```
[clusterID, clusterCentre] = kmeans(R, 3, 'Replicates', 3);
```

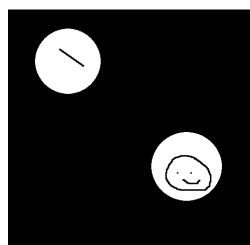
## Mathematical morphology

- A related class of nonlinear image processing techniques is known as mathematical morphology.
- These technique also use kernels, which are called *structuring elements* in the nomenclature of this branch of image processing.
- There are two basic operations, *erosion* and *dilation*. *Erosion* is like a **min filter** (over the structuring element extent on the image), and *dilation* is like a **max filter**. These operations are often used on binary images, but can be used on grayscale images too.
- A *closing* is dilation, followed by erosion. It fills holes smaller than the structuring element. An *opening* is erosion, followed by dilation. It removes objects smaller than the structuring element.
- Mathematical morphology may be useful in “cleaning up” segmentations.

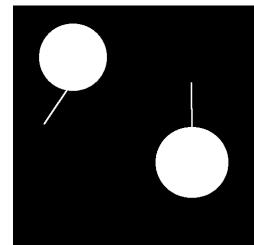
## Erosion and Dilation



Original image

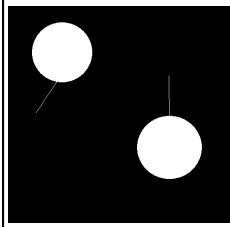


```
J = imerode(I, ones(3,3));
figure; imshow(J);
title('erosion');
```

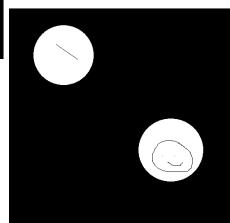


```
J = imdilate(I, ones(3,3));
figure; imshow(J);
title('dilation');
```

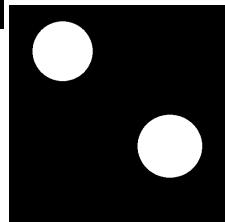
## Closing and Opening



```
J = imclose(I, ones(3,3));
figure; imshow(J);
```



```
J = imopen(I, ones(3,3));
figure; imshow(J);
```

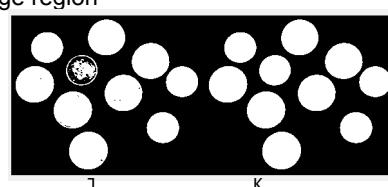


```
K = ones(3,3);
J1 = imopen(I, K);
J2 = imclose(J1, K);
figure; imshow(J2);
```

## Some other handy morphological functions

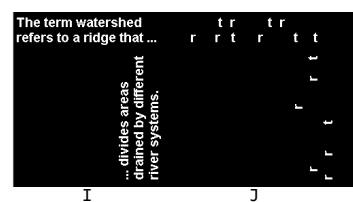
- [imfill](#) can be used to fill holes in each binary image region

```
I = imread('coins.png');
T = graythresh(I); % otsu threshold
J = I > 255*T;
K = imfill(J, 'holes');
imshowpair(J,K,'montage');
```



- [bwareafilt](#) can filter regions in a binary image based on size (in pixels)

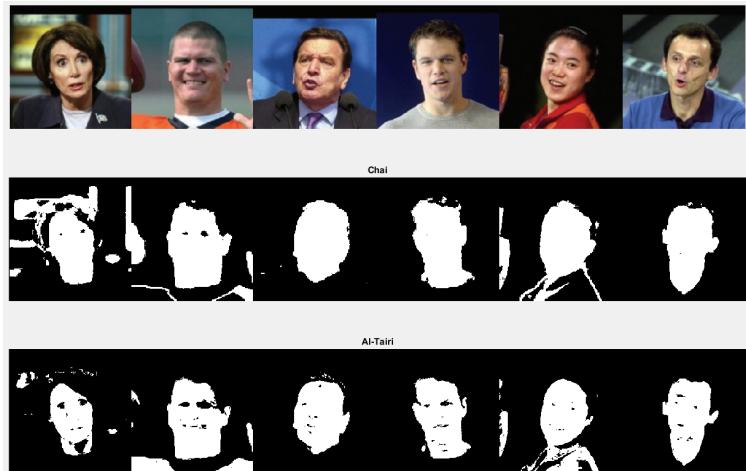
```
I = imread('text.png');
J = bwareafilt(I,[40 50]);
imshowpair(I,J,'montage');
```



- You can also use [regionprops](#) to get the properties of each region, like its area, perimeter, etc. Based on this, you can filter regions to keep those within prescribed limits

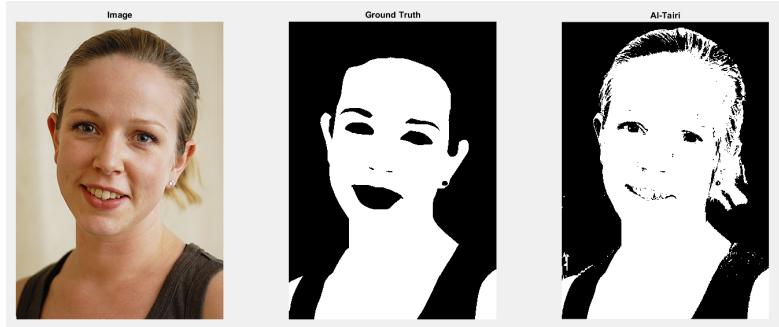
## Evaluating segmentations

- What makes for a “good” segmentation?



## Evaluating segmentations

- A common approach is to establish some ground truth. This can specify, for each pixel in the image if it should be part of the segmentation (or not).
- Example data for skin detection:  
[http://web.fsktm.um.edu.my/~cschan/downloads\\_skin\\_dataset.html](http://web.fsktm.um.edu.my/~cschan/downloads_skin_dataset.html)



The Segmentation Benchmark Datasets

<http://host.robots.ox.ac.uk/pascal/VOC/>

The [PASCAL](#) Visual Object Classes

- Provides standardised image data sets for object class recognition and segmentation
- Enables evaluation and comparison of different methods

Figure from Arbelaez et al. Semantic Segmentation using Regions and Parts, 2012, CVPR. (figure 5)

<http://www.eecs.berkeley.edu/Research/Projects/CS/vision/bsds/>

## Evaluating segmentations

- One can perform the segmentation, and using the ground truth, categorise pixels as:
  - True positives: correctly detected skin pixels
  - True negatives: correctly detected non-skin (background) pixels
  - False positives: non-skin pixels incorrectly detected as skin pixels
  - False negatives: skin pixels missed by the skin detector

## Accuracy, sensitivity, specificity

- One can then produce quantitative measures
  - Accuracy  
 $ACC = (TP + TN) / (TP + FP + FN + TN)$   
*This measures the number of correctly labelled pixels in the image*
  - Sensitivity, or True Positive Rate  
 $SENS = TP / P = TP / (TP + FN)$   
*This measures the percentage of positives correctly labelled*
  - Specificity, or True Negative Rate  
 $SPEC = TN / N = (TN + FP)$   
*This measures the percentage of negatives correctly labelled*
- Where TP and TN are the number of true positives and true negatives, and FP and FN are the number of false positives and false negatives.
- A perfect result would have 100% accuracy, sensitivity, and specificity.

## Example

```
I = imread('face.jpg');
T = rgb2gray(imread('groundTruth.png')) / 255;
YUV = rgb2ycbcr(I);
U = YUV(:, :, 2); V = YUV(:, :, 3);
R = I(:, :, 1); G = I(:, :, 2); B = I(:, :, 3);
[rows, cols, planes] = size(I);

% Al-Tairi et al.
skin = zeros(rows, cols);
ind = find(80 < U & U < 130 & 136 < V & V <= 200 & V > U & R > 80 & G > 30 & ...
           B > 15 & abs(R-G) > 15);
skin(ind) = 1;
figure;
subplot(1, 3, 1); imshow(I); title('Image');
subplot(1, 3, 2); imshow(T*255); title('Ground Truth');
subplot(1, 3, 3); imshow(skin); title('Al-Tairi');

tpInd = find (skin == 1 & T == 1);
tnInd = find (skin == 0 & T == 0);
fpInd = find (skin == 1 & T == 0);
fnInd = find (skin == 0 & T == 1);
```

## Example, part 2

```

tpImage = zeros(rows, cols); tpImage(tpInd) = 1;
tnImage = zeros(rows, cols); tnImage(tnInd) = 1;
fpImage = zeros(rows, cols); fpImage(fpInd) = 1;
fnImage = zeros(rows, cols); fnImage(fnInd) = 1;

figure;
subplot(1, 4, 1); imshow(tpImage); title('true positives');
subplot(1, 4, 2); imshow(tnImage); title('true negatives');
subplot(1, 4, 3); imshow(fpImage); title('false positives');
subplot(1, 4, 4); imshow(fnImage); title('false negatives');

tp = length(tpInd); tn = length(tnInd);
fp = length(fpInd); fn = length(fnInd);

% Compute measures
accuracy = (tp + tn) / (tp + tn + fp + fn);
sens = tp / (tp + fn);
spec = tn / (tn + fp);
disp(['Accuracy = ' num2str(accuracy) ', sensitivity = ' num2str(sens) ', ...
specificity = ' num2str(spec)]);

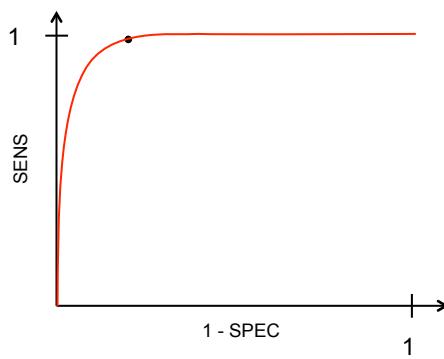
```

>> Accuracy = 0.8979 , sensitivity = 0.98949, specificity = 0.82425

*Interpretation: Sensitivity is high so many skin pixels correctly identified. However, specificity is lower, due primarily to the false positives. Overall, roughly 90% of the pixels are correctly labelled.*

## ROC curve

- A Receiver Operating Characteristic curve plots the sensitivity as a function of  $1 - \text{specificity}$ .
- In our previous example, SENS = 0.99,  $1 - \text{SPEC} = 0.18$
- One can sweep a parameter that trades off sensitivity vs specificity to generate a curve. The area under the curve gives another way to characterise the quality of a classification method.



## Confusion matrix

- The confusion matrix describes the number of predicted labels vs the ground truth. In this example, we have skin and non-skin pixels.

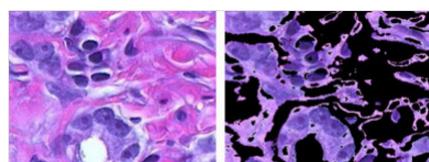
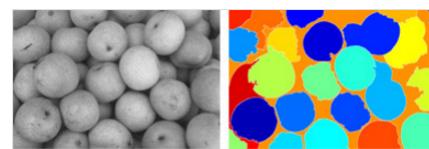
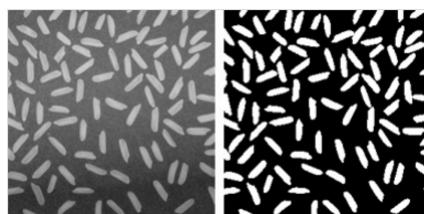
		Predicted	
		Skin	Non-skin
Actual	Skin	TP	FN
	Non-skin	FP	TN

- A perfect result would be a diagonal matrix (no FPs or FNs)
- The confusion matrix generalises to multiple labels

		Predicted		
		Label 1	Label 2	Label 3
Actual	Label 1			
	Label 2			
	Label 3			

## Matlab documentation and examples

- <http://uk.mathworks.com/discovery/image-segmentation.html?refresh=true>



## Segmentation based on Region Growing

<https://www.youtube.com/watch?v=WJGcaSmVE0E>

Region Growing labels pixels into segmentation labels based on:

- predefined criteria for growth
- starting from a set of seeds
- Important : growth or similarity criterion selected according to the problem under consideration
- Can be based on color, image statistics etc.
- Stop the region growing when no more pixels change label

## Region Growing

- ▶ Start with a single *seed pixel*  $p$  and expand from that.
- ▶ Define a similarity measure  $S(i, j)$  for pixels  $i$  and  $j$ .
- ▶ Add adjacent pixel  $q$  to pixel  $p$ 's region iff  $S(p, q) > T$  for some threshold  $T$ .
- ▶ Proceed to the other neighbors of  $p$  and do likewise.
- ▶ We can now similarly consider the neighbors of  $q$  and add them likewise if they are similar enough.

## Similarity Measures

Can use intensity, texture, color (hue), etc.

- ▶ Compare to seed pixel  
Sensitive to noise, not transitive
- ▶ Compare to neighboring pixel  
Transitive, can drift easily
- ▶ Compare to region statistics  
Not transitive, doesn't drift as easily
- ▶ Multiple seed points  
Can get an idea not only of values but *variance*

from Bryan Morse, BYU

## Region Growing

Design decisions:

1. How do we define similarity measure  $S$ ?
2. What threshold  $T$  do we use? Does it change or stay constant?
3. If we wish to add  $q$ 's neighbor  $r$ , do we use  $S(p, r)$ ,  $S(q, r)$ , or something else?

Next: A list-based efficient processing in C++ for a fast implementation: recursive

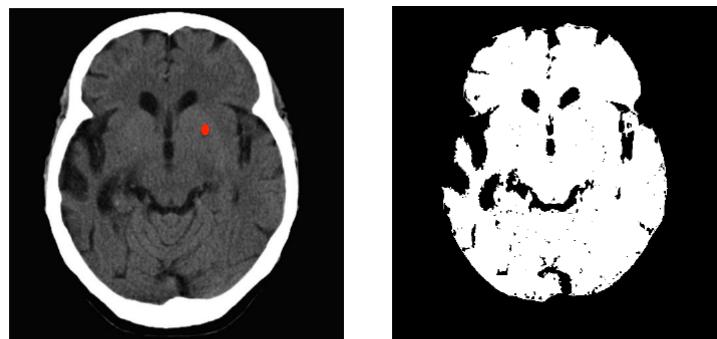
## Region Growing Algorithm ~ Connected Components

```
// Nice Simple Example C++ code for 3D segmentation:  
// check it out; for questions: send an email to me  
  
struct vector3Df {float x, y, z;  
};  
//INITIALIZE YOUR LISTS  
std::vector<vector3Df> *current; //holds current region voxels  
std::vector<vector3Df> *next; //holds voxels to be analyzed on the next iteration  
std::vector<vector3Df> *swap; //pointer used in swapping the two lists  
std::vector<vector3Df>::iterator it;  
int Y = xSize; int Z = xSize*ySize; int x,y,z,i,j,k;  
vector3Df point3D;  
point3D.x = seedX; point3D.y = seedY; point3D.z = seedZ; // the seed location: a 3D vector  
  
int OBJECT= 2;  
int MARKED = 1;  
  
next = new std::vector<vector3Df>;  
current = new std::vector<vector3Df>;  
  
next->clear(); //clear the two lists  
current->clear();  
//initialize the current list with the seed voxel  
current->push_back(point3D);
```

## Region Growing Algorithm (cont'd)~ Connected Comp

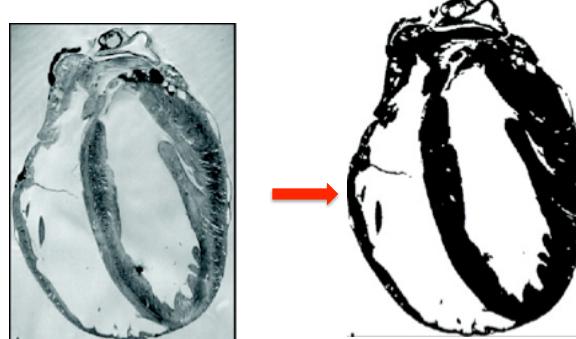
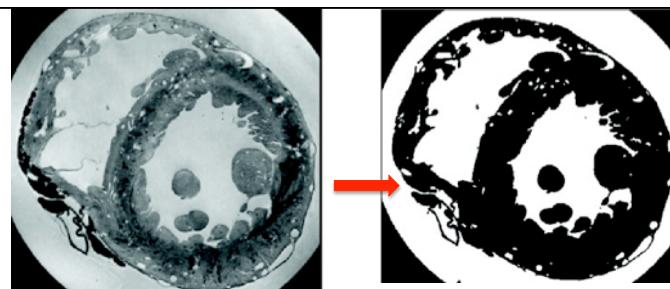
```
while(!current->empty()) //while there are still current voxels  
{for (it = current->begin(); it != current->end(); it++) { //for each current voxel  
    x = (int)it->x; y = (int)it->y; z = (int)it->z;  
    segMap[x+y*Y+z*Z] = OBJECT; //mark current voxel as object in the seg. map  
  
    for(i=-1;i<=1;j++)for(j=-1;j<=1;j++)for(k=-1;k<=1;k++)  
    { //***** for each nbr of current voxel  
        // check if its in the volume  
        if( (x+i<0 || x+i>=xSize || y+j<0 || y+j>=ySize || z+k<0 || z+k>=zSize) continue;  
  
        //DESIGN: Similarity Criterion  
        if( (segMap[(x+i)+(y+j)*Y+(z+k)*Z] == OBJECT && (fabs(Image[x+y*Y+z*Z] -  
Image[(x+i)+(y+j)*Y+(z+k)*Z]) < epsilon) ) {  
            segMap[(x+i)+(y+j)*Y+(z+k)*Z] = OBJECT; //mark the nbr as object/connected  
            point3D.x = x+i; point3D.y = y+j; point3D.z = z+k; //add it to the "next" list  
            next->push_back(point3D); }  
    } //*****end for each nbr of current voxel  
} //*****for each current voxel  
swap = current; //swap "current" and "next" lists... old "next" is new "current"  
current = next;  
next = swap; next->clear();  
}// end while //free allocated memory ;  
delete next; delete current; .....
```

## Segmentation based on Region Growing



Region growing started with a seed point in the brain (e.g. the red dot shown)

For example, here adds neighboring points to the region if they are less than a threshold away from a running (re-calculated or updated every step) mean intensity

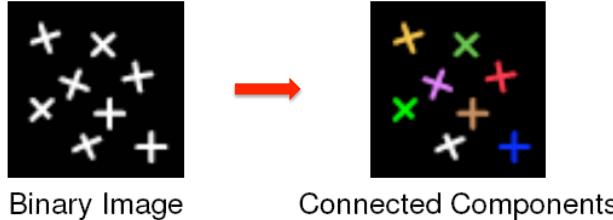


Next step after segmentation of multi-region scenes or objects is to label different parts separately. How? We can use connected component labeling

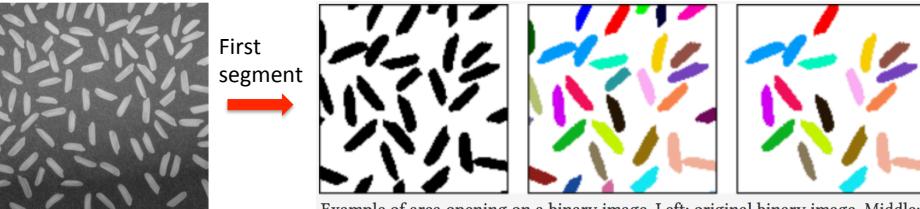
Figure from: "Development of an anatomically detailed MRI-derived rabbit ventricular model and assessment of its impact on simulations of electrophysiological function", American J Physiology, MJ Bishop et al 2010

## Connected Component Labeling

How to label (or color) separately connected segmented regions in an image ?



Binary Image      Connected Components

First segment

Example of area opening on a binary image. Left: original binary image. Middle: identification of connected components. Right: only the connected components with a sufficient size (defined by the area), have been retained.

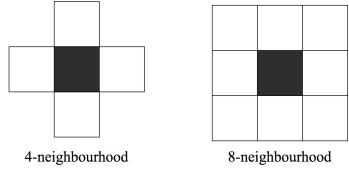
<http://imagej.net/MorphoLibJ>

## Pixel Connectivity

Q: are the dark pixels in this image connected?

To answer that: We need to define which pixels are counted as neighbors

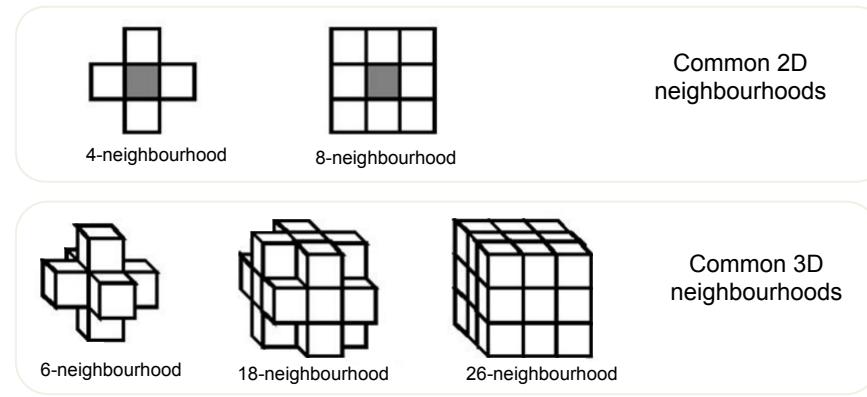
Pixel Neighbourhoods



4-neighbourhood      8-neighbourhood

## Spatial Connectedness: going beyond color

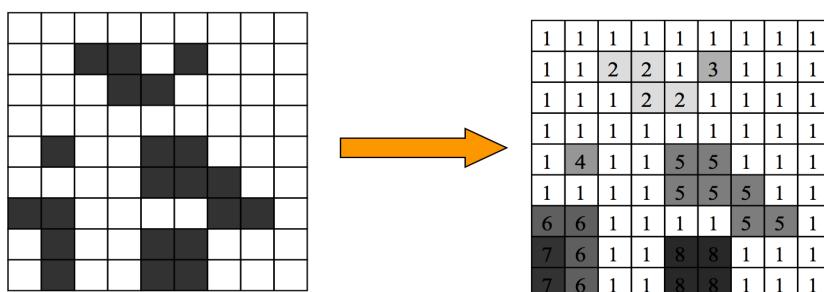
- Colour (or intensity) is a powerful feature and typically used in image segmentation. However, typically there is additional contextual information we can use, often encoded *spatially*.
- When segmenting a pixel  $p$ , we might consider pixels in  $p$ 's neighbourhood.
- This require a definition what a neighbouring pixel is.



<https://www.linkedin.com/pulse/20140506202304-14648565-3d-is-not-1-5-times-2d>

## Connected Components Labeling

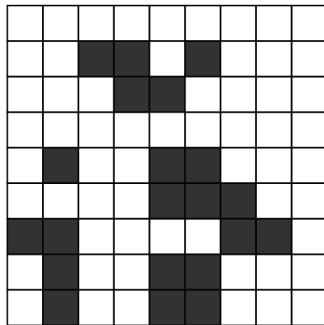
- Labels each connected component of a binary image with a separate number.



E.g. Use region growing starting from the top left corner of the image, set it to label L=1. Then find the first unlabelled pixel, set to L=2, use region growing, and continue in this way. Here, region growing algo, growing criteria: Neighbor pixel has the same label as the current pixel.

## Foreground Connected Components Labeling

- Only extract the connected components of the foreground



1	1	1	1	1	1	1	1	1
1	1	0	0	1	0	1	1	1
1	1	1	0	0	1	1	1	1
1	1	1	1	1	1	1	1	1
1	0	1	1	0	0	1	1	1
1	1	1	1	0	0	0	1	1
0	0	1	1	1	1	0	0	1
2	0	1	1	0	0	1	1	1
2	0	1	1	0	0	1	1	1

Assuming that dark pixels are the background, others are foreground

## Check this algorithm on connected component labeling

```
% B is the binary image input. L is the labelled
% image output.

function L = ConnectedComponents(B)
[X,Y] = size(B);
L = zeros(X,Y);
n=1;
For each (x,y) in B
    if(B(x,y) & L(x,y)==0)
        label(x,y,n,B,L);
        n=n+1;
    end
end
```

```

function label(x_start, y_start, n, B, L)
    % Recursively give label n to this pixel
    % and all its foreground neighbours.

    L(x_start,y_start)=n;
    for each (x,y) in N(x_start, y_start)
        if(L(x,y)==0 & B(x, y))
            label(x,y,n,B,L);
        end
    end

```

You need to define your neighborhood function N(..). E.g. 4 nbhd: x,y should be one of: (xs+1,ys), (xs-1,ys), (xs,ys+1), (xs,ys-1)

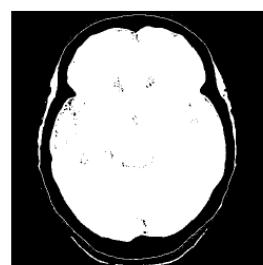
### Recall Segmentation based on Thresholding



... needs to be cleaned up -> e.g., morphological operations.



Background.



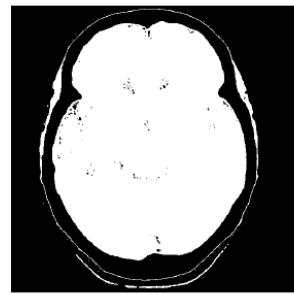
Brain.



Skull.

M. Niethammer

## Extracting Connected Component



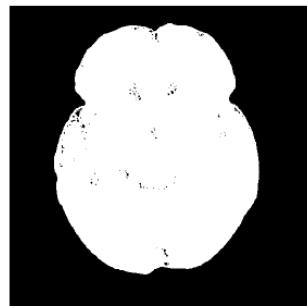
Original brain mask.



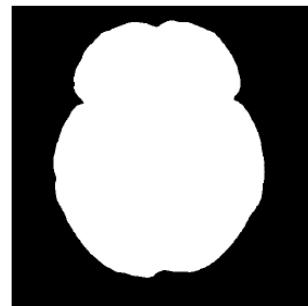
Largest connected component.

M. Niethammer

## Dilation



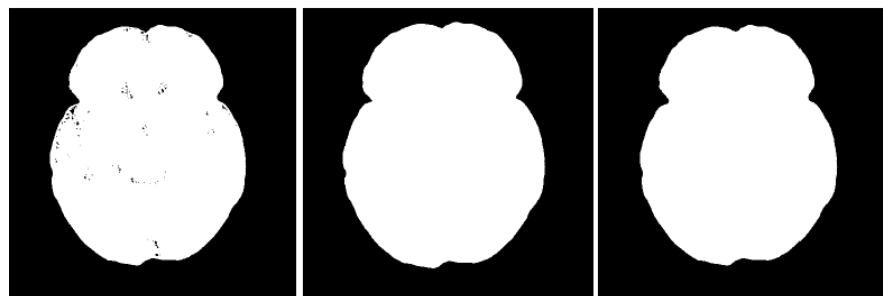
Original brain mask.



Dilated brain mask.  
Fills in holes (5x5, SE).

M. Niethammer

## Erode to Recover Original Size



Original.

Dilated.

Closed.

Dilation followed by Erosion = Closing

M. Niethammer

## END OF LECTURE

Note that Segmentation has a vast literature, there are many more methods currently used in Computer Vision.

We just studied the basic methods, but they are important in understanding the idea of segmentation and data clustering.

Recall Learning objectives of the week: Students are able to:

3. Define and construct segmentation, feature extraction, and visual motion estimation algorithms to extract relevant information from images

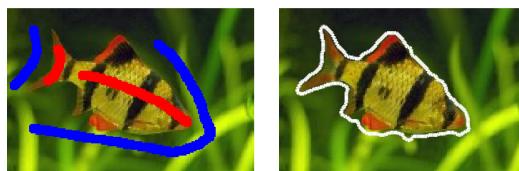
Reading Assignments:  
[Klette Book]

[Gonzalez and Woods] 10.3 : very limited  
R. Szeliski Comp Vision Book: Section 5.3

Extra Material for those interested

## Interactive segmentation

- Recently a number of interactive segmentation methods have been presented in the literature. These methods often ask the user to provide some strokes providing seeds.

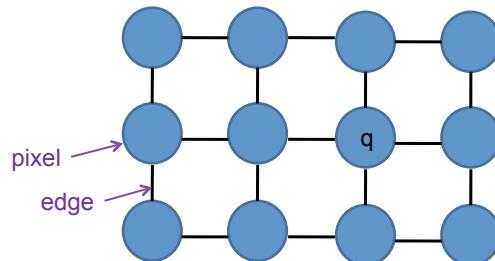


<http://jgmalcolm.com/pubs/research.html>

- The strokes:
  - Are used to form a colour model of different regions.
  - Also provide spatial context.

## Markov Random Field

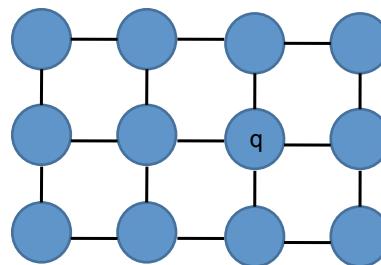
- Often, one employs a Markov Random Field to solve this problem.
- In a Markov Random Field (MRF), each pixel in the image is considered a random variable. It is connected to its adjacent pixels through edges.
- The segmentation label for a pixel depends on two terms:
  - A *unary* term, the cost of assigning a label to a pixel, independent of the neighbours.
  - A *pairwise* term, the cost of assigning a label to a pixel based on a neighbour in the neighbourhood.



The cost of assigning a label  $l$  to pixel  $q$  depends on the image and the values of labels of the connected pixels as well.

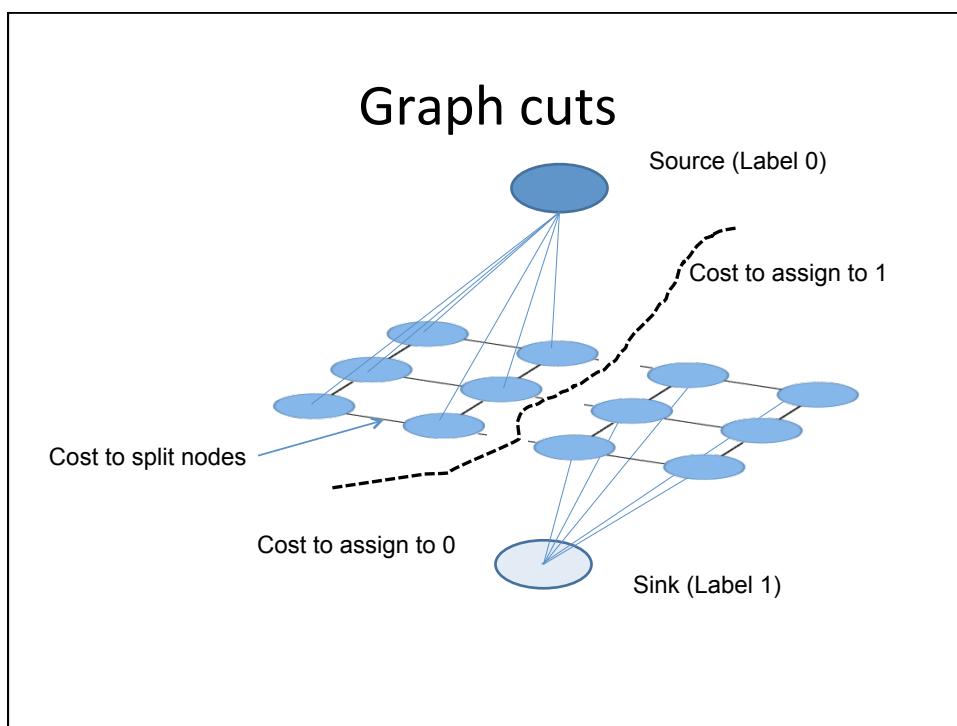
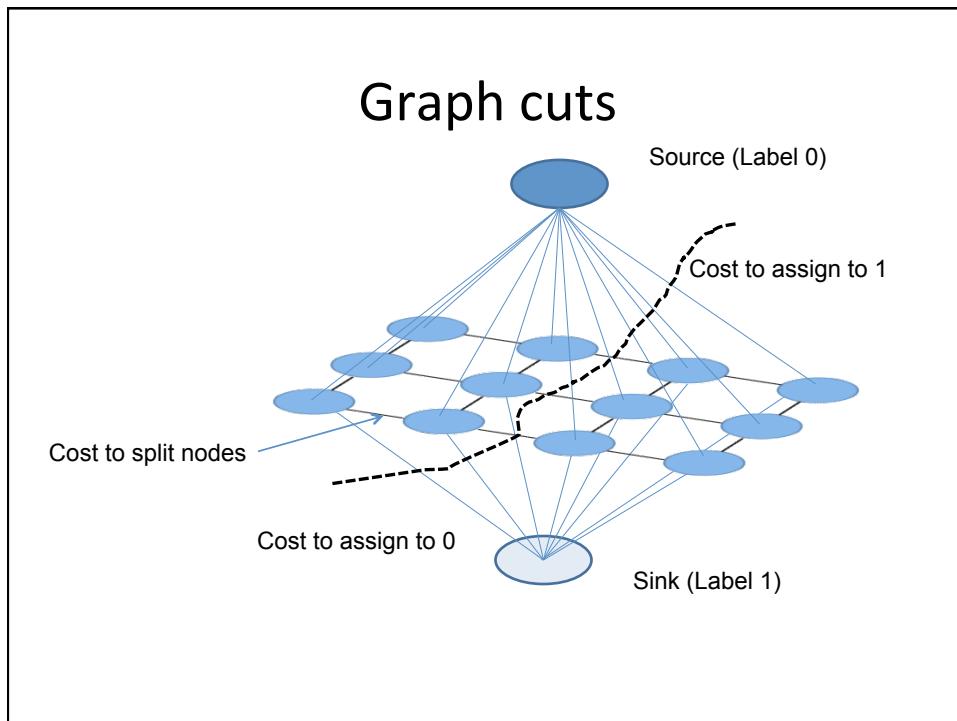
## Markov Random Field

- Example



- Unary
  - Label 0:  $-\log p(l(q) = 0 | \text{image})$
  - Label 1:  $-\log p(l(q) = 1 | \text{image})$
- Pairwise

$$\begin{array}{c|cc} & 0 & 1 \\ \hline 0 & 0 & K \\ 1 & K & 0 \end{array} \quad K > 0$$



## Graph cuts

- There is no graph cuts code available built-in to Matlab, but there are various toolboxes that you can download and use.
- [http://vision.csd.uwo.ca/wiki/vision/upload/d/d7/Bk\\_matlab.zip](http://vision.csd.uwo.ca/wiki/vision/upload/d/d7/Bk_matlab.zip)

## Superpixels

- A popular approach currently in image segmentation is to first group pixels together into superpixels to form an oversegmentation of the image.
- A superpixel consists of a connected group of pixels that have similar properties, like colour.
- Then, one can group superpixels together to form the final segmentation. This can be more efficient than processing each pixel in the image.



## SLIC

- [SLIC](#) (Simple Linear Iterative Clustering) is a popular superpixel segmentation technique, recently published by [Achanta et al. 2012]
- It performs a local grouping of pixels in 5D space defined by the LAB colours and x, y positions of the pixels [LABXY]. A distance measure in this 5D space combines distance measured in colour and the image itself
- It defines K regularly spaced cluster centres, and moves them to locations where the edge response is smallest, and assigns pixels to clusters based on distance.

## Example

- Using
  - `slic.m`
  - `drawregionboundaries.m`
  - `maskImage.m`
  - from <http://www.peterkovesi.com/projects/segmentation/>
- The syntax is

```
[L, A, S] = slic(I, K, m)
```

where L are the labels, A is an adjacency matrix, and S contains the superpixel attributes. I is the image, K is the desired number of superpixels, m is the weighting factor between colour and spatial distances, and r

```
I = imread('Success-Kid.jpg');
[rows, cols, planes] = size(I);

[L, A, S] = slic(I, 3000, 10, 1);
imshow(drawregionboundaries(L, I, [255 255 255]));
```