BBM 413
Fundamentals of Image Processing
Dec. 11, 2012

Erkut Erdem
Dept. of Computer Engineering
Hacettepe University

Segmentation – Part I
Image segmentation

• Goal: identify groups of pixels that go together

Slide credit: S. Seitz, K. Grauman
The goals of segmentation

- Separate image into coherent “objects”

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

Slide credit: S. Lazebnik
The goals of segmentation

- Separate image into coherent “objects”
- Group together similar-looking pixels for efficiency of further processing


Slide credit: S. Lazebnik
Segmentation

- Compact representation for image data in terms of a set of components
- Components share “common” visual properties
- Properties can be defined at different level of abstractions
What is segmentation?

• Clustering image elements that “belong together”
  – **Partitioning**
    • Divide into regions/sequences with coherent internal properties
  – **Grouping**
    • Identify sets of coherent tokens in image

Slide credit: Fei-Fei Li
Segmentation is a global process

What are the occluded numbers?

Slide credit: B. Freeman and A. Torralba
Segmentation is a global process

What are the occluded numbers?

Occlusion is an important cue in grouping.

Slide credit: B. Freeman and A. Torralba
... but not too global
Magritte, 1957

Slide credit: B. Freeman and A. Torralba
Groupings by Invisible Completions

A

B

C

D

* Images from Steve Lehar’s Gestalt papers

Slide credit: B. Freeman and A. Torralba
Groupings by Invisible Completions

1970s: R. C. James

Slide credit: B. Freeman and A. Torralba
Groupings by Invisible Completions

2000s: Bev Doolittle

Slide credit: B. Freeman and A. Torralba
Perceptual organization

“…the processes by which the bits and pieces of visual information that are available in the retinal image are structured into the larger units of perceived objects and their interrelations”

Stephen E. Palmer, Vision Science, 1999

Slide credit: B. Freeman and A. Torralba
Gestalt Psychology

• German: *Gestalt* - "form" or "whole"
• Berlin School, early 20th century
  – Kurt Koffka, Max Wertheimer, and Wolfgang Köhler

• Gestalt: whole or group
  – Whole is greater than sum of its parts
  – Relationships among parts can yield new properties/features

• Psychologists identified series of factors that predispose set of elements to be grouped (by human visual system)

"I stand at the window and see a house, trees, sky. Theoretically I might say there were 327 brightnesses and nuances of colour. Do I have “327”? No. I have sky, house, and trees."

Max Wertheimer (1880-1943)
Gestalt Psychology

Wolfgang Metzger

Laws of Seeing

Laws of Seeing, Wolfgang Metzger, 1936
(English translation by Lothar Spillmann,
MIT Press, 2006)
Similarity


Slide credit: K. Grauman
Symmetry


Slide credit: K. Grauman
Common fate

Image credit: Arthus-Bertrand (via F. Durand)

Slide credit: K. Grauman
Proximity
Familiarity
Familiarity
Influences of grouping

Grouping influences other perceptual mechanisms such as lightness perception


Slide credit: B. Freeman and A. Torralba
Emergence

http://en.wikipedia.org/wiki/Gestalt_psychology

Slide credit: S. Lazebnik
Grouping phenomena in real life

Images: Forsyth and Ponce, Computer Vision: A Modern Approach

Slide credit: K. Grauman
Grouping phenomena in real life

Images: Forsyth and Ponce, Computer Vision: A Modern Approach

Slide credit: K. Grauman
**Gestalt cues**

- Good intuition and basic principles for grouping
- Basis for many ideas in segmentation and occlusion reasoning
- Some (e.g., symmetry) are difficult to implement in practice
Segmentation methods

- Segment foreground from background
- Histogram-based segmentation
- Segmentation as clustering
  - K-means clustering
  - Mean-shift segmentation
- Graph-theoretic segmentation
  - Min cut
  - Normalized cuts
- Interactive segmentation
A simple segmentation technique: Background Subtraction

• If we know what the background looks like, it is easy to identify “interesting bits

• Applications
  – Person in an office
  – Tracking cars on a road
  – surveillance

• Approach:
  – use a moving average to estimate background image
  – subtract from current frame
  – large absolute values are interesting pixels
  • trick: use morphological operations to clean up pixels

Slide credit: B. Freeman
Movie frames from which we want to extract the foreground subject

Images: Forsyth and Ponce, Computer Vision: A Modern Approach
Two different background removal models

- Background estimate
- Foreground estimate
- Average over frames

EM background estimate

Images: Forsyth and Ponce, Computer Vision: A Modern Approach

Slide credit: B. Freeman
Segmentation methods

• Segment foreground from background

• Histogram-based segmentation

• Segmentation as clustering
  – K-means clustering
  – Mean-shift segmentation

• Graph-theoretic segmentation
  – Min cut
  – Normalized cuts

• Interactive segmentation
• These intensities define the three groups.
• We could label every pixel in the image according to which of these primary intensities it is.
  • i.e., segment the image based on the intensity feature.
• What if the image isn’t quite so simple?
• Now how to determine the three main intensities that define our groups?
• We need to *cluster*. 
• Goal: choose three “centers” as the representative intensities, and label every pixel according to which of these centers it is nearest to.

• Best cluster centers are those that minimize SSD between all points and their nearest cluster center $c_i$:

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

- Segment foreground from background
- Histogram-based segmentation
- Segmentation as clustering
  - K-means clustering
  - Mean-shift segmentation
- Graph-theoretic segmentation
  - Min cut
  - Normalized cuts
- Interactive segmentation
Clustering

• With this objective, it is a “chicken and egg” problem:
  – If we knew the **cluster centers**, we could allocate points to groups by assigning each to its closest center.

  ![Diagram showing allocation of points to clusters based on closest center]

  – If we knew the **group memberships**, we could get the centers by computing the mean per group.

  ![Diagram showing calculation of cluster centers from group means]
Segmentation as clustering

• Cluster together (pixels, tokens, etc.) that belong together...

• Agglomerative clustering
  – attach closest to cluster it is closest to – repeat

• Divisive clustering
  – split cluster along best boundary – repeat

• Dendrograms
  – yield a picture of output as clustering process continues
Greedy Clustering Algorithms

Algorithm 15.3: Agglomerative clustering, or clustering by merging

Make each point a separate cluster
Until the clustering is satisfactory
    Merge the two clusters with the smallest inter-cluster distance
end

Algorithm 15.4: Divisive clustering, or clustering by splitting

Construct a single cluster containing all points
Until the clustering is satisfactory
    Split the cluster that yields the two components with the largest inter-cluster distance
end
Agglomerative clustering

1. Say "Every point is its own cluster"
Agglomerative clustering

1. Say “Every point is its own cluster”
2. Find “most similar” pair of clusters
Agglomerative clustering

1. Say “Every point is its own cluster”
2. Find “most similar” pair of clusters
3. Merge it into a parent cluster
Agglomerative clustering

1. Say “Every point is its own cluster”
2. Find “most similar” pair of clusters
3. Merge it into a parent cluster
4. Repeat
Agglomerative clustering

1. Say “Every point is its own cluster”
2. Find “most similar” pair of clusters
3. Merge it into a parent cluster
4. Repeat
Common similarity/distance measures

- **P-norms**
  - City Block (L1)
  - Euclidean (L2)
  - L-infinity

\[
\|x\|_p := \left( \sum_{i=1}^{n} |x_i|^p \right)^{1/p}
\]

\[
\|x\|_1 := \sum_{i=1}^{n} |x_i|
\]

\[
\|x\| := \sqrt{x_1^2 + \cdots + x_n^2}
\]

\[
\|x\|_\infty := \max (|x_1|, \ldots, |x_n|)
\]

- **Mahalanobis**
  - Scaled Euclidean

\[
d(\bar{x}, \bar{y}) = \sqrt{\sum_{i=1}^{N} \frac{(x_i - y_i)^2}{\sigma_i^2}}
\]

- **Cosine distance**

\[
similarity = \cos(\theta) = \frac{A \cdot B}{\|A\|\|B\|}
\]

Here \(x_i\) is the distance btw. two points

Slide credit: D. Hoiem
Dendograms

Dendrogram formed by agglomerative clustering using single-link clustering.
Agglomerative clustering

How to define cluster similarity?
- Average distance between points, maximum distance, minimum distance
- Distance between means or medoids

How many clusters?
- Clustering creates a dendrogram (a tree)
- Threshold based on max number of clusters or based on distance between merges

Slide credit: D. Hoiem
Agglomerative clustering

Good

• Simple to implement, widespread application
• Clusters have adaptive shapes
• Provides a hierarchy of clusters

Bad

• May have imbalanced clusters
• Still have to choose number of clusters or threshold
• Need to use an “ultrametric” to get a meaningful hierarchy

Slide credit: D. Hoiem
Segmentation methods

• Segment foreground from background
• Histogram-based segmentation

• Segmentation as clustering
  – K-means clustering
  – Mean-shift segmentation

• Graph-Theoretic Segmentation
  – Min cut
  – Normalized cuts
K-means clustering

- Basic idea: randomly initialize the $k$ cluster centers, and iterate between the two steps we just saw.

1. Randomly initialize the cluster centers, $c_1, \ldots, c_K$
2. Given cluster centers, determine points in each cluster
   - For each point $p$, find the closest $c_i$. Put $p$ into cluster $i$
3. Given points in each cluster, solve for $c_i$
   - Set $c_i$ to be the mean of points in cluster $i$
4. If $c_i$ have changed, repeat Step 2

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

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

Slide credit: S. Seitz
K-means

1. Ask user how many clusters they’d like. *(e.g. k=5)*
K-means

1. Ask user how many clusters they’d like. *(e.g. k=5)*

2. Randomly guess k cluster Center locations
**K-means**

1. Ask user how many clusters they’d like. *(e.g. $k=5$)*

2. Randomly guess $k$ cluster Center locations

3. Each datapoint finds out which Center it’s closest to. (Thus each Center “owns” a set of datapoints)
**K-means**

1. Ask user how many clusters they’d like. *(e.g. $k=5$)*
2. Randomly guess $k$ cluster Center locations
3. Each datapoint finds out which Center it’s closest to.
4. Each Center finds the centroid of the points it owns

Slide credit: K Grauman, A. Moore
**K-means**

1. Ask user how many clusters they’d like. *(e.g. k=5)*
2. Randomly guess k cluster Center locations
3. Each datapoint finds out which Center it’s closest to.
4. Each Center finds the centroid of the points it owns...
5. ...and jumps there
6. ...Repeat until terminated!

Slide credit: K Grauman, A. Moore
K-means clustering

• Java demo:
  
  http://kovan.ceng.metu.edu.tr/~maya/kmeans/index.html

  http://home.dei.polimi.it/matteucc/Clustering/tutorial_html/AppletKM.html

Slide credit: K Grauman
K-means: pros and cons

Pros
• Simple, fast to compute
• Converges to local minimum of within-cluster squared error

Cons/issues
• Setting k?
• Sensitive to initial centers
• Sensitive to outliers
• Detects spherical clusters
• Assuming means can be computed

Slide credit: K Grauman
An aside: Smoothing out cluster assignments

- Assigning a cluster label per pixel may yield outliers:
  
  ![Original and labeled images](image)

  - How to ensure they are spatially smooth?

Slide credit: K Grauman
Segmentation as clustering

Depending on what we choose as the feature space, we can group pixels in different ways.

Grouping pixels based on intensity similarity

Feature space: intensity value (I-d)
quantization of the feature space; segmentation label map

Slide credit: K Grauman
Segmentation as clustering

Depending on what we choose as the feature space, we can group pixels in different ways.

Grouping pixels based on color similarity

Feature space: color value (3-d)

Slide credit: K Grauman
Segmentation as clustering

Depending on what we choose as the feature space, we can group pixels in different ways.

Grouping pixels based on intensity similarity

Clusters based on intensity similarity don’t have to be spatially coherent.

Slide credit: K Grauman
Segmentation as clustering

Image          Clusters on intensity (K=5)          Clusters on color (K=5)

K-means clustering using intensity alone and color alone

Slide credit: B. Freeman
Segmentation as clustering

K-means using color alone, 11 segments

Slide credit: B. Freeman
Segmentation as clustering

K-means using color alone, 11 segments.

*Color alone often will not yeild salient segments!*

Slide credit: B. Freeman
Segmentation as clustering

Depending on what we choose as the *feature space*, we can group pixels in different ways.

Grouping pixels based on *intensity*+*position* similarity

Both regions are black, but if we also include *position* \((x,y)\), then we could group the two into distinct segments; way to encode both similarity & proximity.

Slide credit: K Grauman
Segmentation as clustering

- Color, brightness, position alone are not enough to distinguish all regions…

Slide credit: K Grauman
Segmentation as clustering

Depending on what we choose as the *feature space*, we can group pixels in different ways.

Grouping pixels based on **texture** similarity

Feature space: filter bank responses (e.g., 24-d)

Slide credit: K Grauman
Recall: texture representation example

Windows with primarily horizontal edges

Windows with small gradient in both directions

Windows with primarily vertical edges

Both

Dimension 1 (mean d/dx value)

Dimension 2 (mean d/dy value)

statistics to summarize patterns in small windows

Slide credit: K Grauman
Segmentation with texture features

- Find “textons” by clustering vectors of filter bank outputs
- Describe texture in a window based on texton histogram


Slide credit: K Grauman, L. Lazebnik
Image segmentation example

Texture-based regions

Color-based regions

Slide credit: K Grauman
Pixel properties vs. neighborhood properties

These look very similar in terms of their color distributions (histograms).

How would their texture distributions compare?

Slide credit: K Grauman
Material classification example

For an image of a single texture, we can classify it according to its global (image-wide) texton histogram.

Figure from Varma & Zisserman, IJCV 2005

Slide credit: K Grauman
Material classification example

Nearest neighbor classification: label the input according to the nearest known example’s label.

$$\chi^2(h_i, h_j) = \frac{1}{2} \sum_{k=1}^{K} \frac{[h_i(k) - h_j(k)]^2}{h_i(k) + h_j(k)}$$

Manik Varma
http://www.robots.ox.ac.uk/~vgg/research/texclass/with.html

Slide credit: K Grauman
Segmentation methods

• Segment foreground from background
• Histogram-based segmentation
• Segmentation as clustering
  – K-means clustering
  – Mean-shift segmentation
• Graph-theoretic segmentation
  – Min cut
  – Normalized cuts
• Interactive segmentation

Next week