BBM 413
Fundamentals of Image Processing

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Segmentation – Part 1
Image segmentation

- Goal: identify groups of pixels that go together
The goals of segmentation

- Separate image into coherent “objects”
The goals of segmentation

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

The goals of segmentation

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

“superpixels”

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
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

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

* 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
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

Laws of Seeing, Wolfgang Metzger, 1936
(English translation by Lothar Spillmann, MIT Press, 2006)
Slide credit: B. Freeman and A. Torralba
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

Slide credit: B. Freeman and A. Torralba
Familiarity

Slide credit: B. Freeman and A. Torralba
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
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

Slide credit: B. Freeman
Two different background removal models

Background estimate
Average over frames

Foreground estimate

EM background estimate

low thresh

high thresh

Images: Forsyth and Ponce, Computer Vision: A Modern Approach
Slide credit: B. Freeman
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• 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?
input image

input image

pixel count

pixel count

intensity

intensity

Slide credit: K. Grauman
• 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 $c_i$:

$$\sum_{\text{clusters } i} \sum_{\text{points } p \text{ in cluster } i} \|p - c_i\|^2$$
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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.
  – If we knew the **group memberships**, we could get the centers by computing the mean per group.
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

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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

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K-means and Hierarchical Clustering: Slide 43
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

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Slide credit: D. Hoiem
Common similarity/distance measures

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

- Mahalanobis
  - Scaled Euclidean

- Cosine distance

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

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

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

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

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

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

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

Slide credit: D. Hoiem
Dendograms

Data set

Dendogram formed by agglomerative clustering using single-link clustering.

Slide credit: B. Freeman
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
Segmentation methods

• Segment foreground from background

• Histogram-based segmentation

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

• Graph-Theoretic Segmentation
  – Min cut
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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:

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

labeled by cluster center’s intensity

• How to ensure they are spatially smooth?
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)
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.
Segmentation as clustering

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 yield salient segments!
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…
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
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**

**Image**

**Texton map**


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?
Material classification example

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

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

\[ \chi^2(h_i, h_j) = \frac{1}{2} \sum_{k=1}^{K} \frac{[h_i(k) - h_j(k)]^2}{h_i(k) + h_j(k)} \]
Reading Assignment #5

• E. Borenstein and S. Ullman, Class-specific, top-down segmentation, ECCV 2002

• Due on 27th of January 2015
Segmentation methods

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Next week