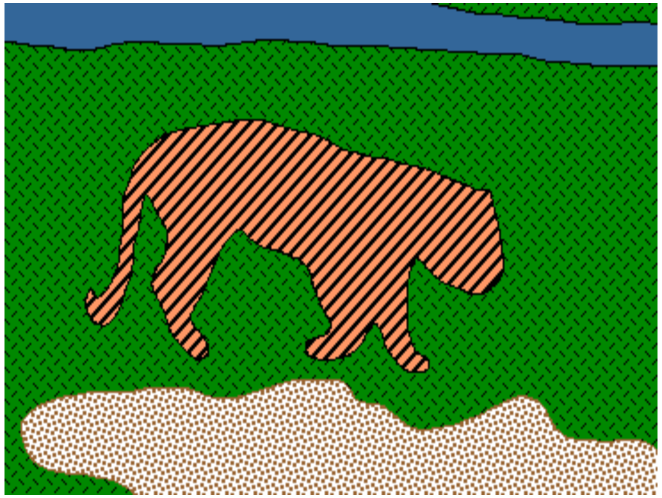
Image Processing

Segmentation – Part 1

Image segmentation

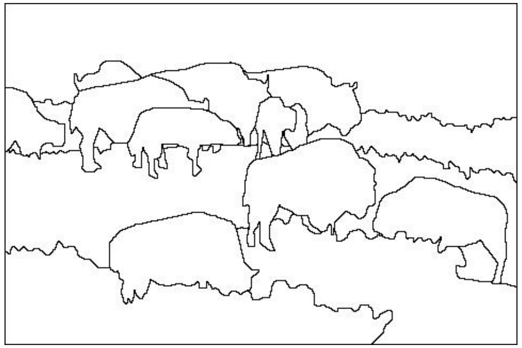
- Goal: identify groups of pixels that go together



Slide credit: S. Seitz, K. Grauman

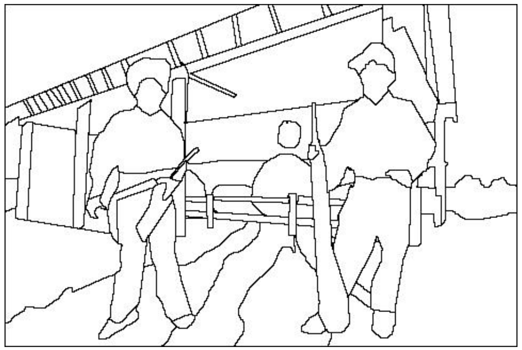
The goals of segmentation

- Separate image into coherent “objects”



image

human segmentation



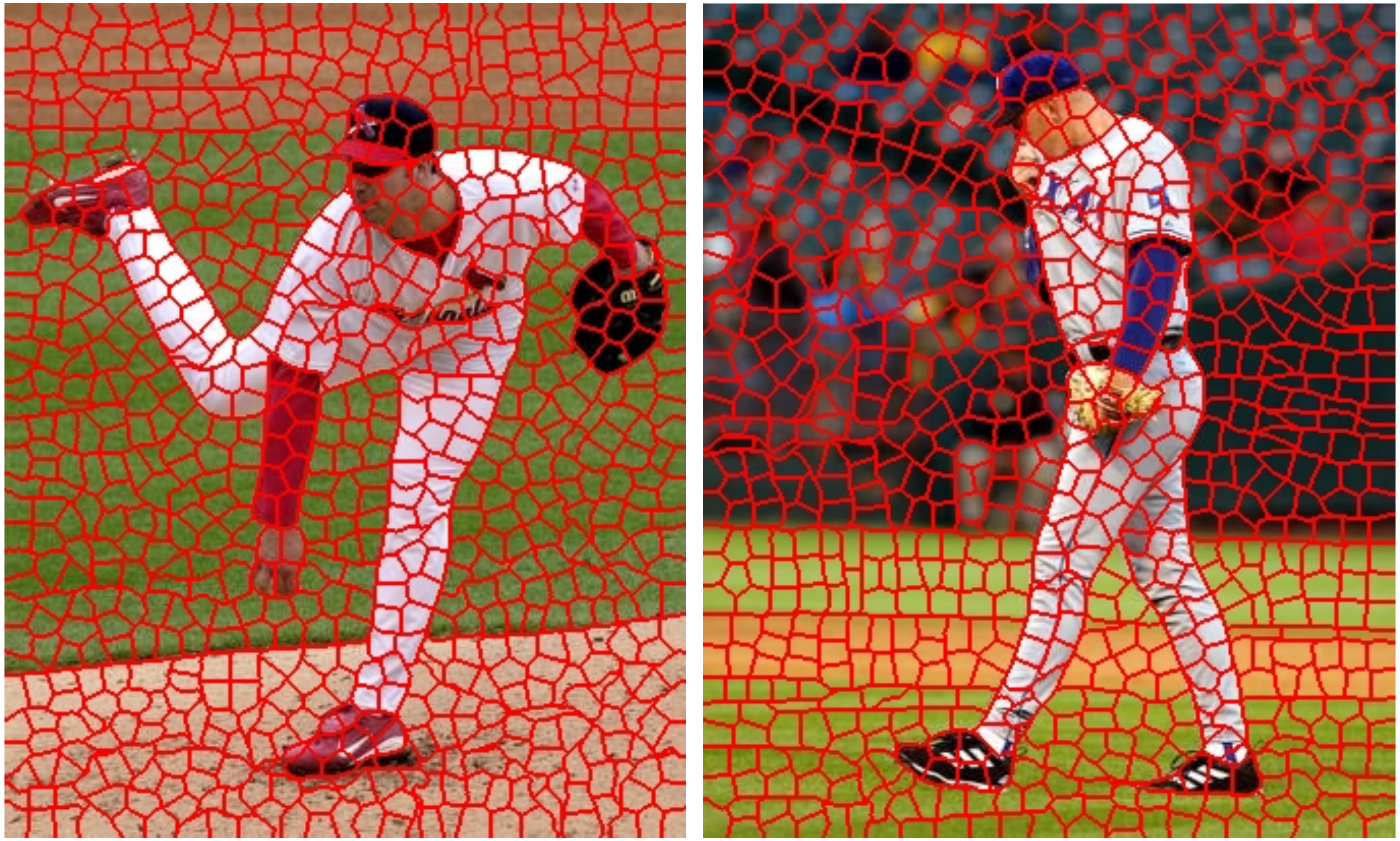
http://www.eecs.berkeley.edu/Research/Projects/CS/vision/grouping/segbench/

Slide credit: S. Lazebnik

The goals of segmentation

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

"superpixels"



X. Ren and J. Malik. [Learning a classification model for segmentation.] ICCV 2003.

Slide credit: S. Lazebnik

The goals of segmentation

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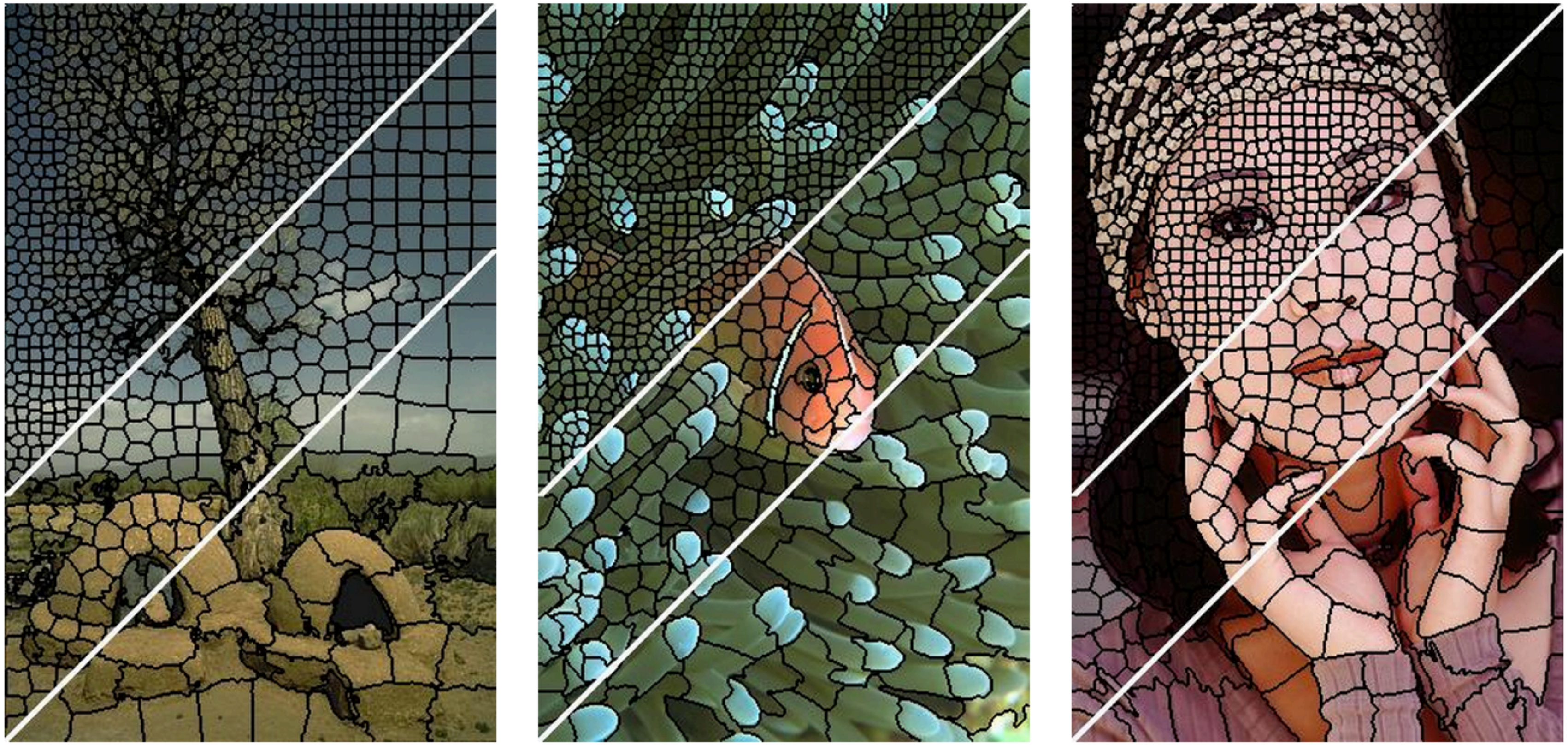
"superpixels"



R. Achanta et al.. SLIC Superpixels Compared to State-of-the-art Superpixel Methods. TPAMI 2012.

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

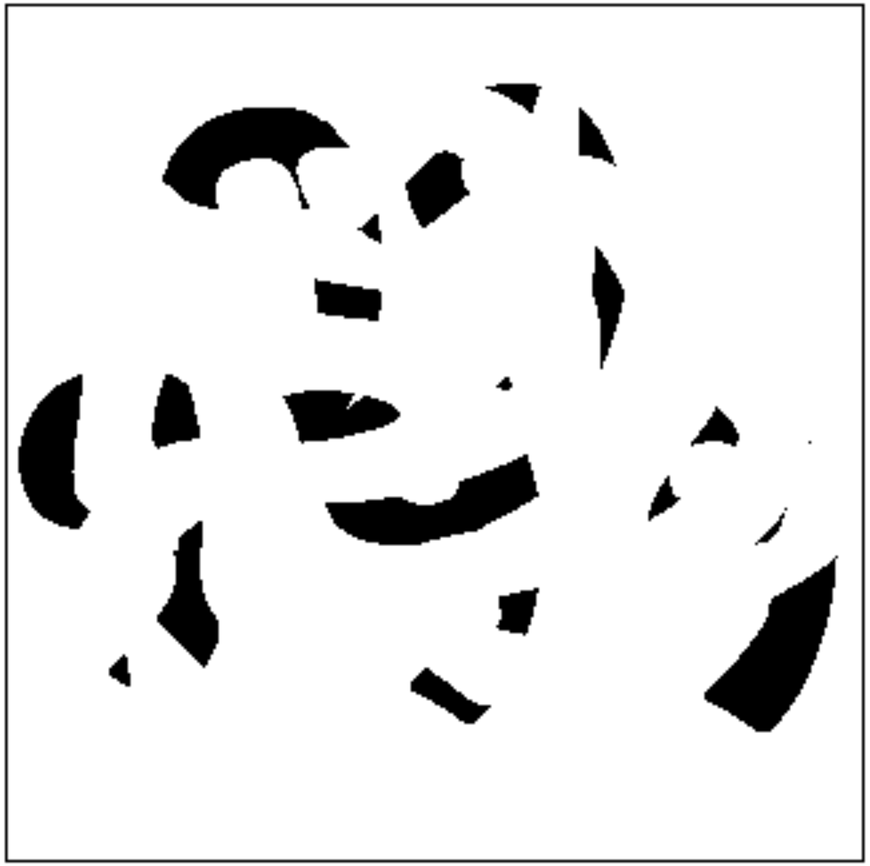
Slide credit: Fei-Fei Li

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

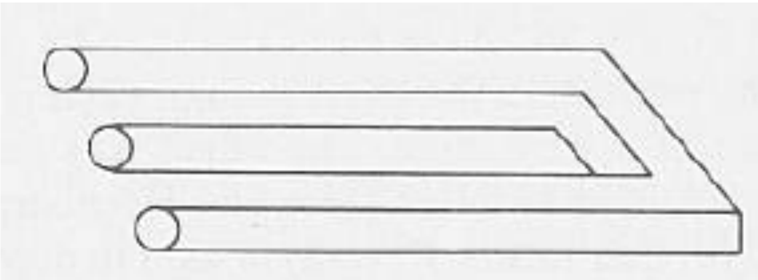
Segmentation is a global process

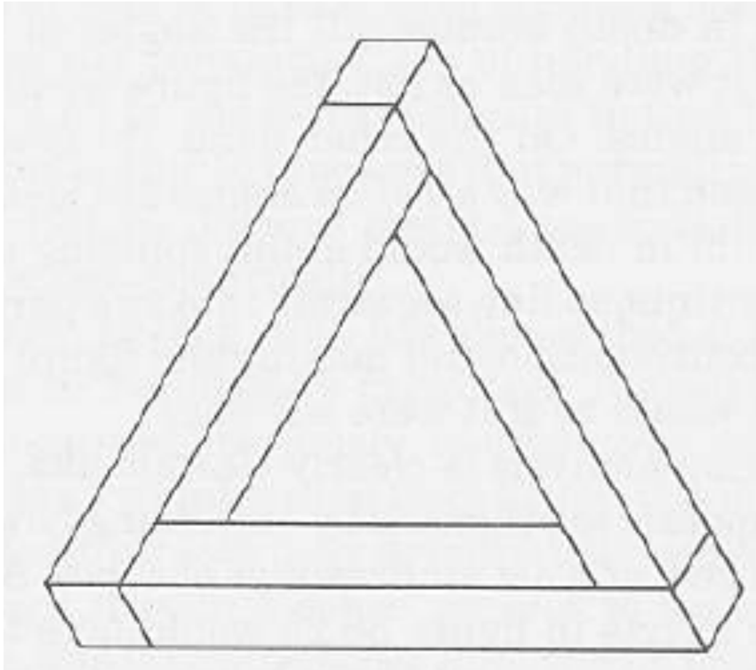
What are the occluded numbers?

Occlusion is an important cue in grouping.

Slide credit: B. Freeman and A. Torralba

… but not too global

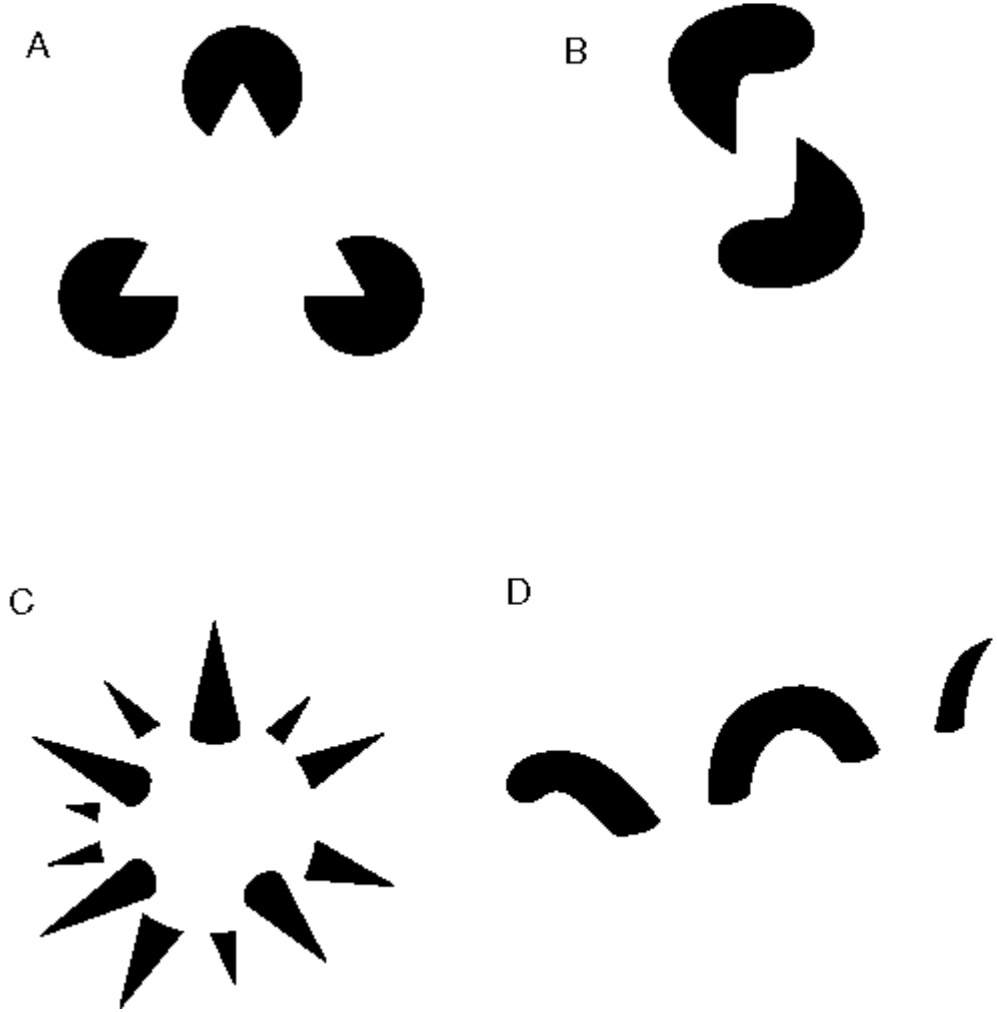




Slide credit: B. Freeman and A. Torralba

Magritte, 1957

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

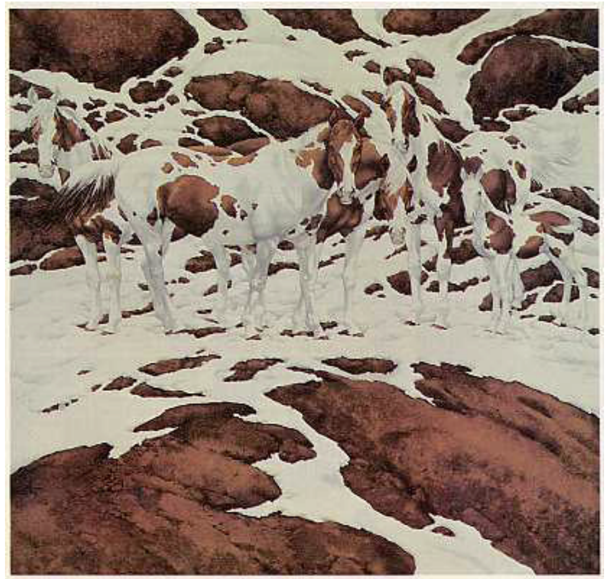
2000s: Bev Doolittle

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*



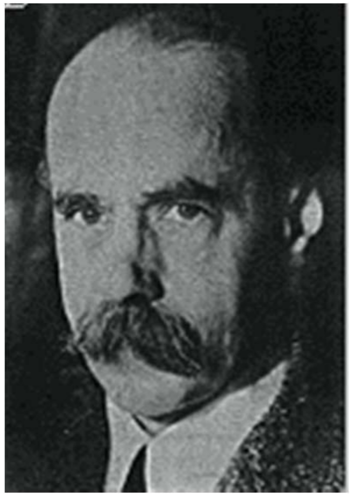
Slide credit: B. Freeman and A. Torralba

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)

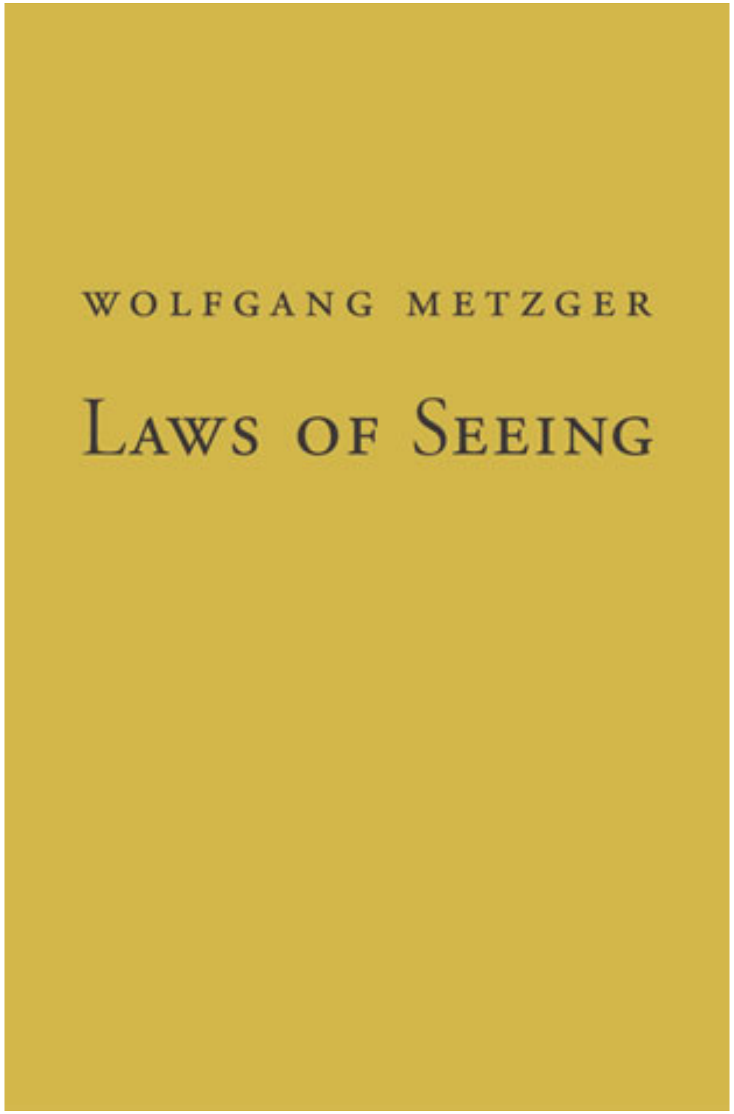
"I stand at the window and see a house, trees, sky. Theoretically I might say there were 327 brightnesses and nuances of colour. Do I have "327"? No. I have sky, house, and trees."

Max Wertheimer (1880-1943)

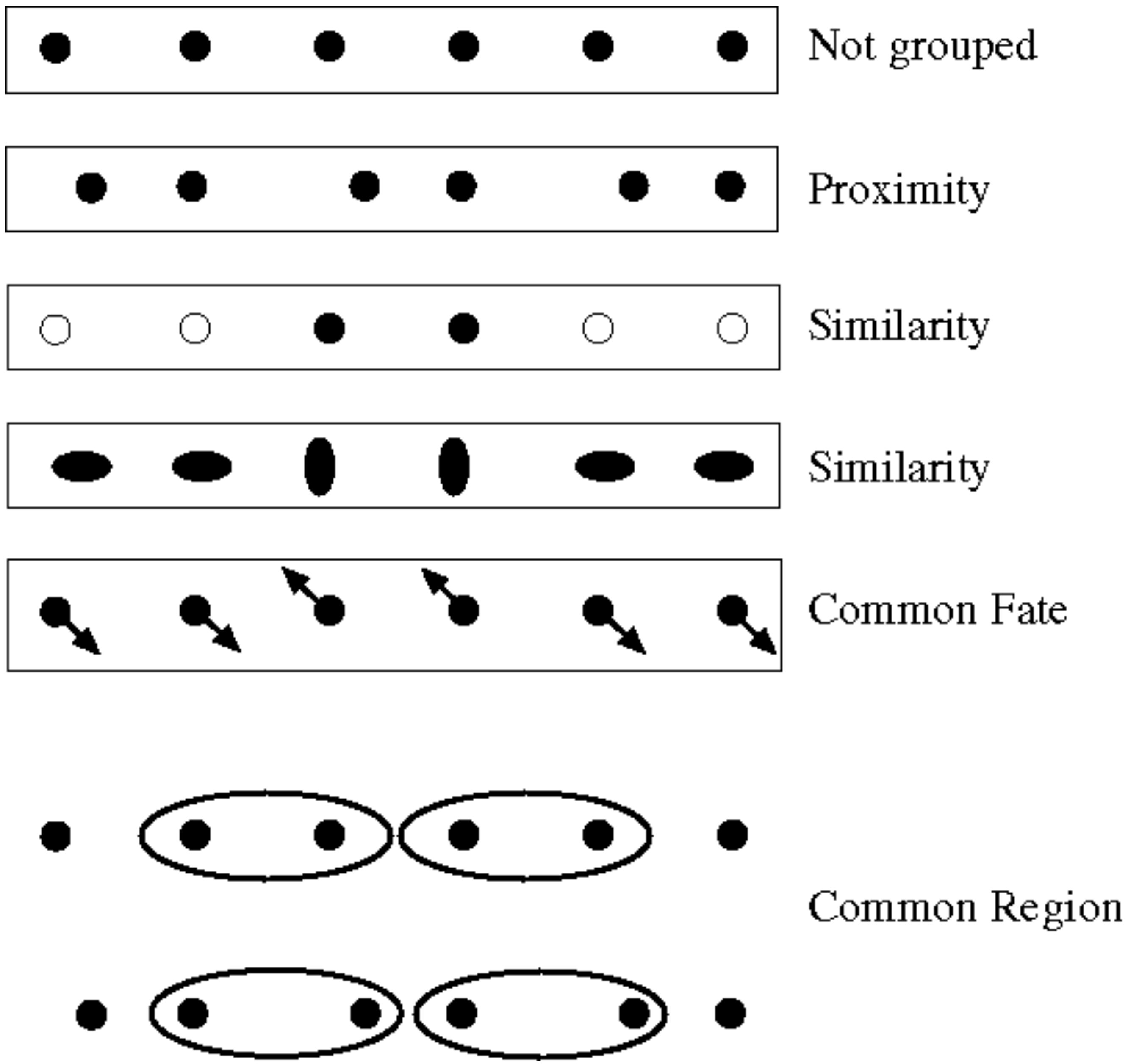


Slide credit: J. Hays and Fei-Fei Li

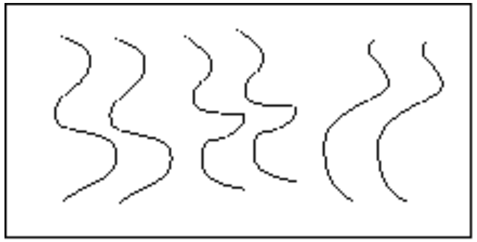
Gestalt Psychology



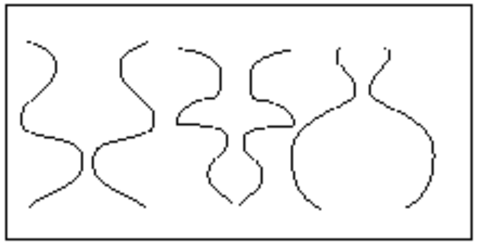
Laws of Seeing, Wolfgang Metzger, 1936
(English translation by Lothar Spillmann, MIT Press, 2006)



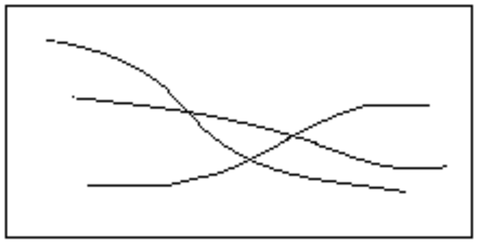
Slide credit: B. Freeman and A. Torralba



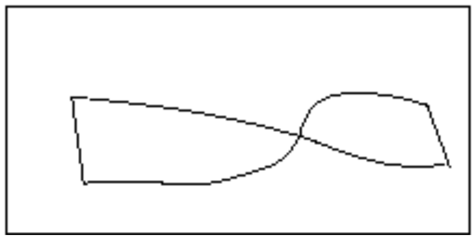
Parallelism



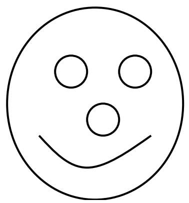
Symmetry



Continuity



Closure



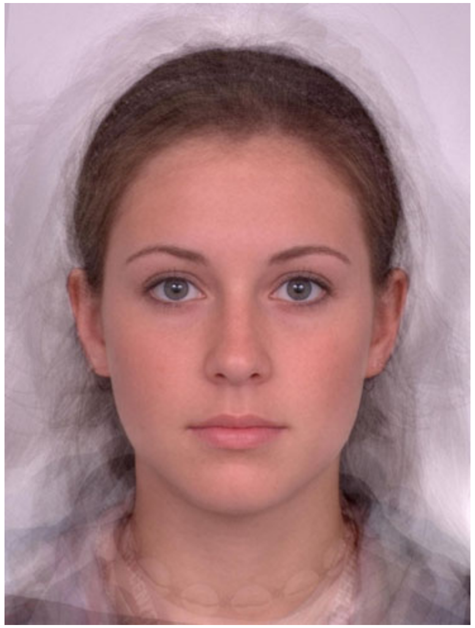
Familiarity

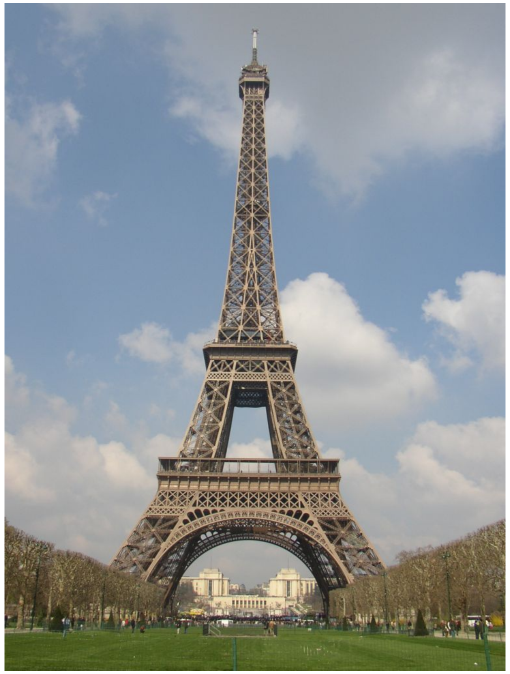
Slide credit: B. Freeman and A. Torralba

Similarity

http://chicagoist.com/attachments/chicagoist_alicia/GEESE.jpg, http://wwwdelivery.superstock.com/WI/223/1532/PreviewComp/SuperStock_1532R-0831.jpg Slide credit: K. Grauman

Symmetry





http://seedmagazine.com/news/2006/10/beauty_is_in_the_processingtim.php

Slide credit: K. Grauman

Common fate 共同性，共同运动规律

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

Slide credit: K. Grauman

Proximity

http://www.capital.edu/Resources/Images/outside6_035.jpg

Slide credit: K. Grauman

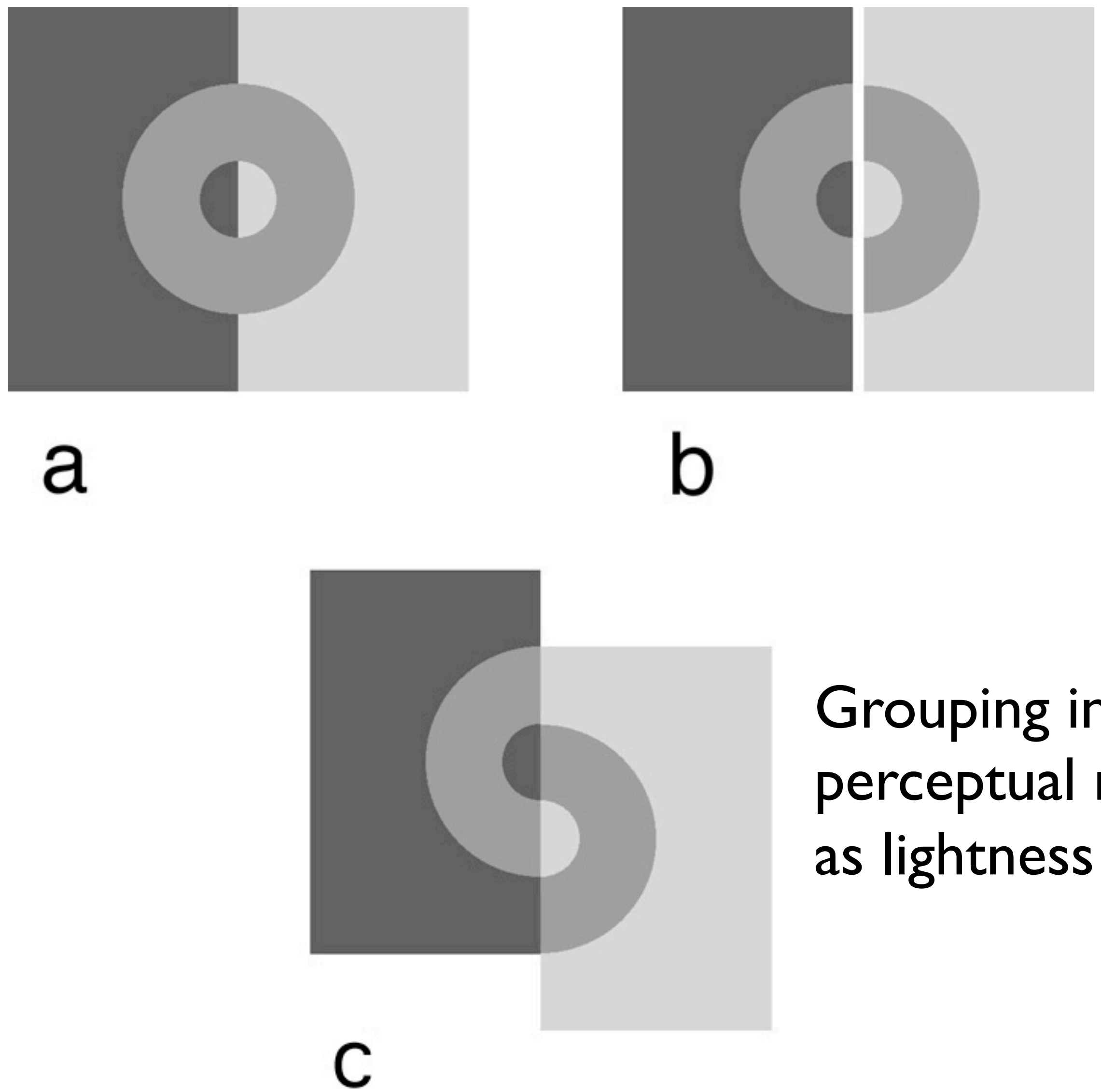
Familiarity

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

http://web.mit.edu/persci/people/adelson/publications/gazzan.dir/koffka.html

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

Slide credit: J. Hays

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

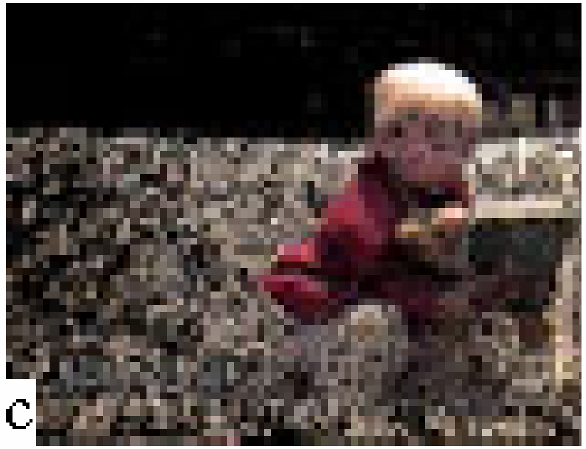
Slide credit: B. Freeman

Two different background removal models

Background estimate
Average over frames

Foreground estimate

Foreground estimate



EM background estimate

low thresh

high thresh

EM

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

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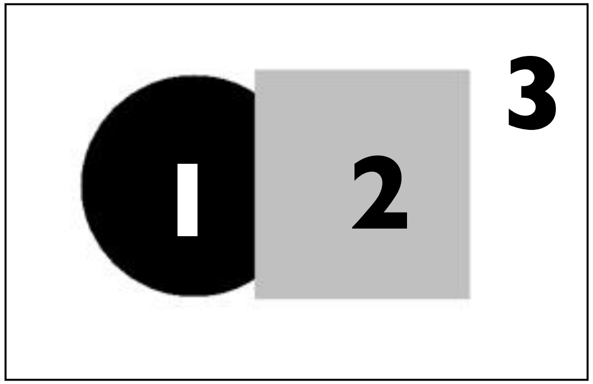
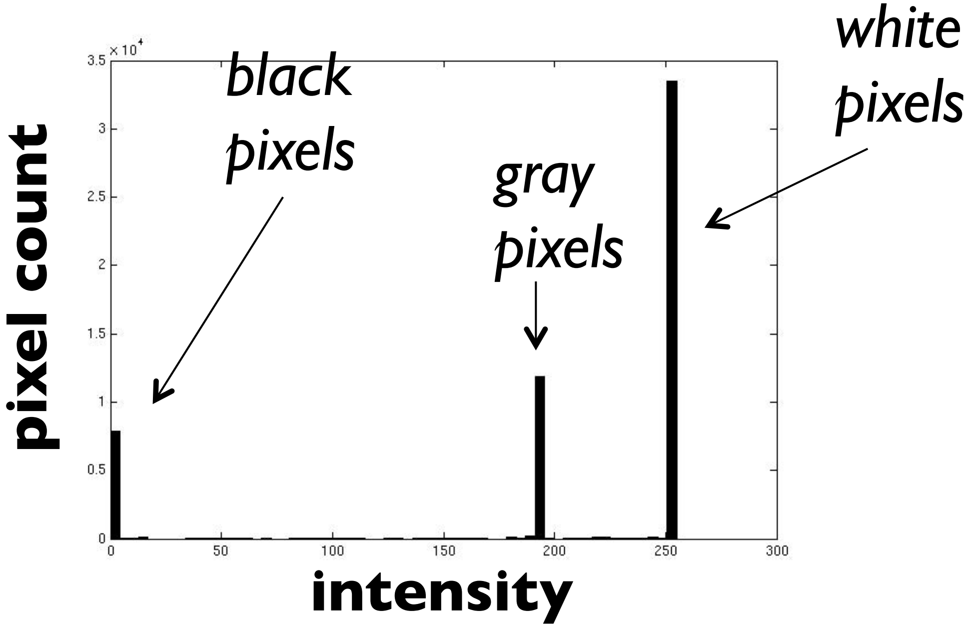
Image segmentation: toy example

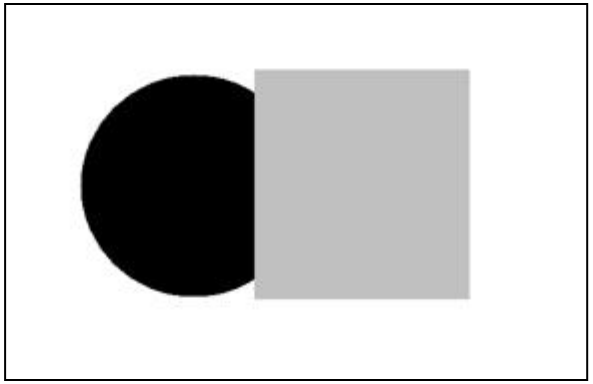


input image

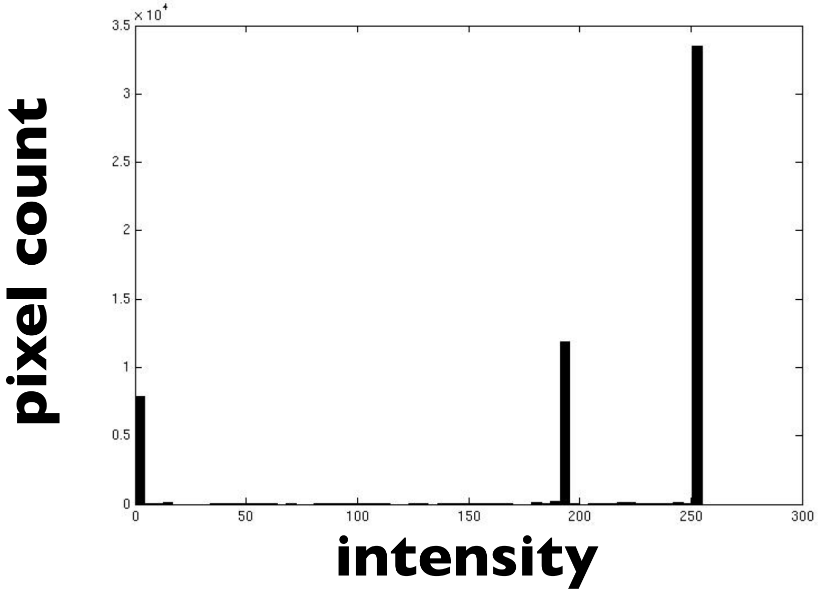


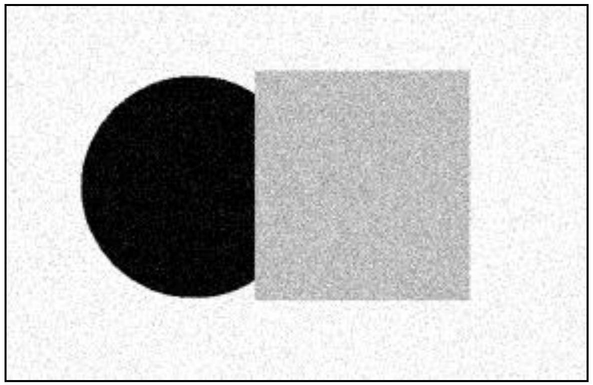
- These intensities define the three groups.
- We could label every pixel in the image according to which of these primary intensities it is.
  - i.e., *segment* the image based on the intensity feature.
- What if the image isn't quite so simple?

Slide credit: K. Grauman

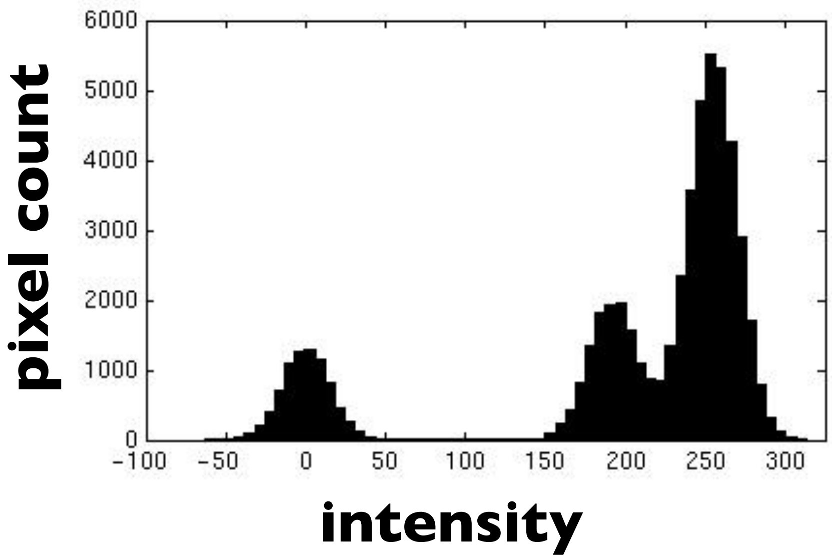


input image

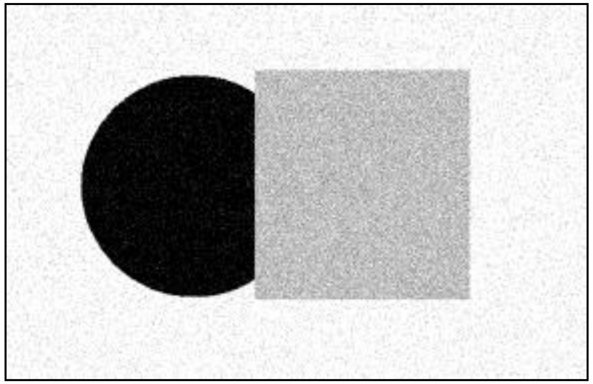




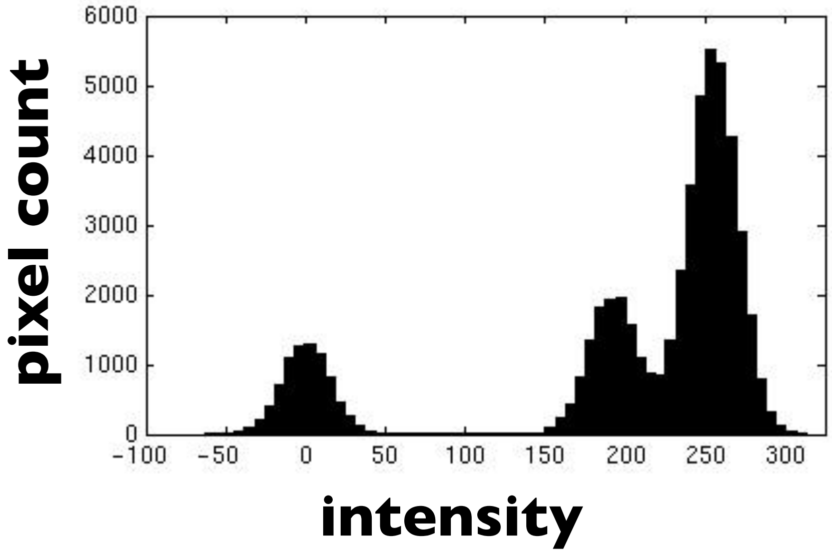
input image



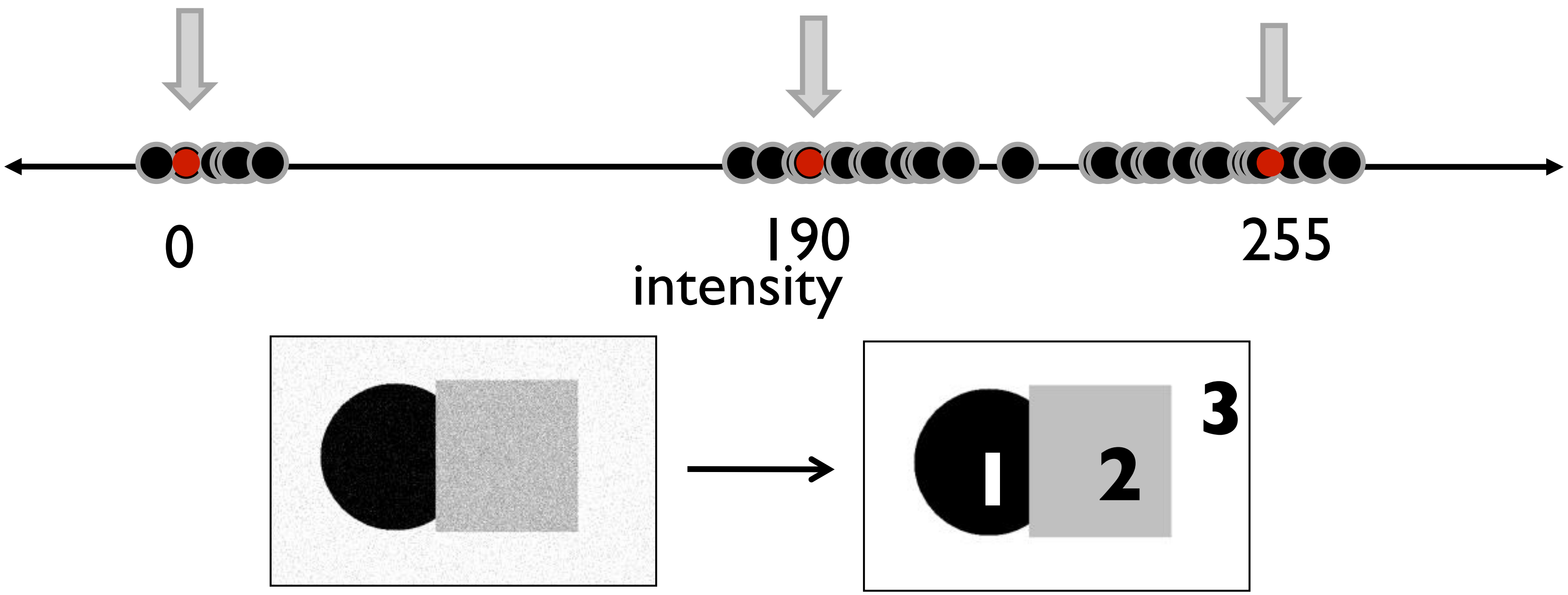
Slide credit: K. Grauman



input image



- 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:

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

Slide credit: K. Grauman

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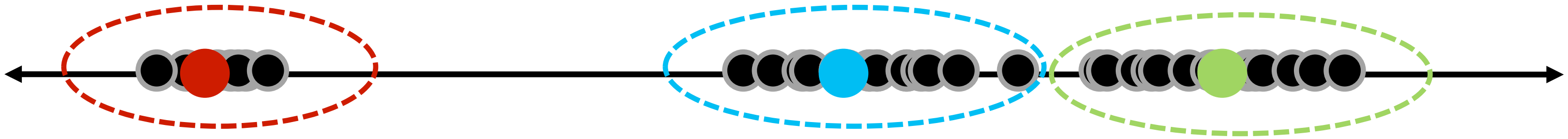
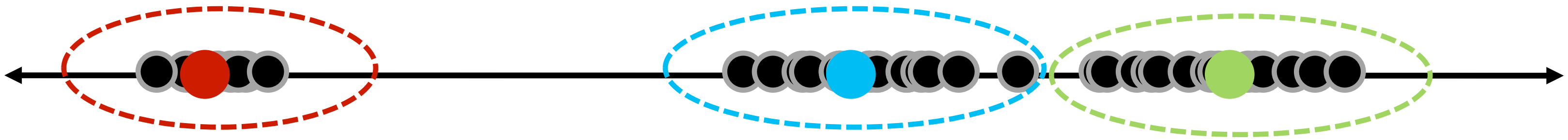
Clustering

- 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.



Slide credit: K. Grauman

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 树状图
  - yield a picture of output as clustering process continues

Slide credit: B. Freeman

Greedy Clustering Algorithms

Algorithm 15.3: Agglomerative clustering, or clustering by merging

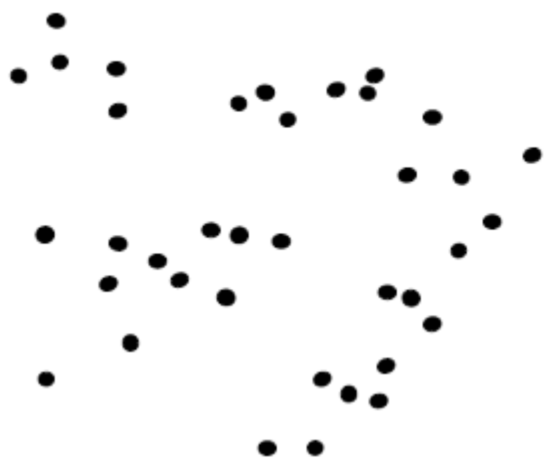
```
Make each point a separate cluster
Until the clustering is satisfactory
      Merge the two clusters with the
        smallest inter-cluster distance
end
```

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
```

Slide credit: B. Freeman

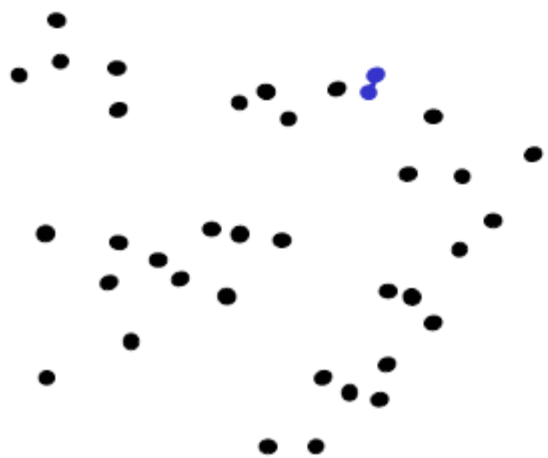
Agglomerative clustering



1. Say "Every point is its own cluster"

Slide credit: D. Hoiem

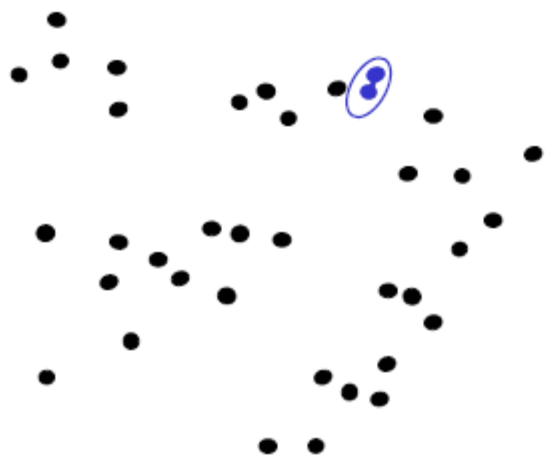
Agglomerative clustering



1. Say "Every point is its own cluster"
2. Find "most similar" pair of clusters

Slide credit: D. Hoiem

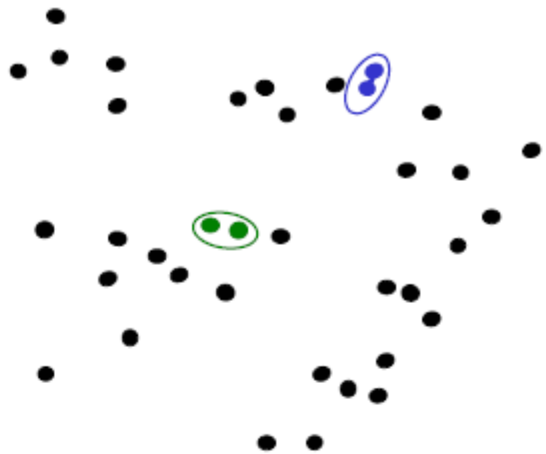
Agglomerative clustering



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

Slide credit: D. Hoiem

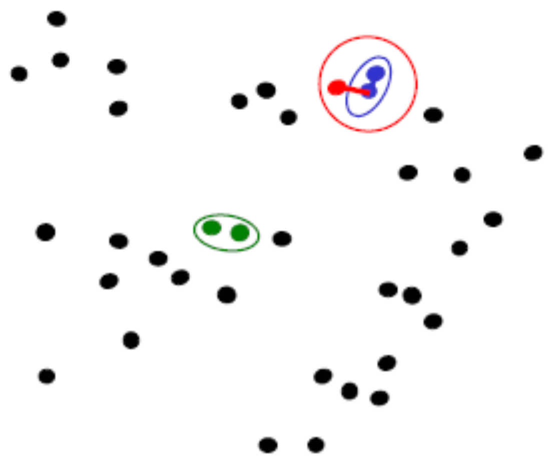
Agglomerative clustering



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

Slide credit: D. Hoiem

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

Slide credit: D. Hoiem

Common similarity/distance measures

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

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

$$\|\boldsymbol{x}\|_1 := \sum_{i=1}^{n} |x_i|$$

$$\|\boldsymbol{x}\| := \sqrt{x_1^2 + \cdots + x_n^2}$$

$$\|\mathbf{x}\|_\infty := \max\left(|x_1|, \ldots, |x_n|\right)$$

Here x_i is the distance btw. two points

- Mahalanobis
  - Scaled Euclidean

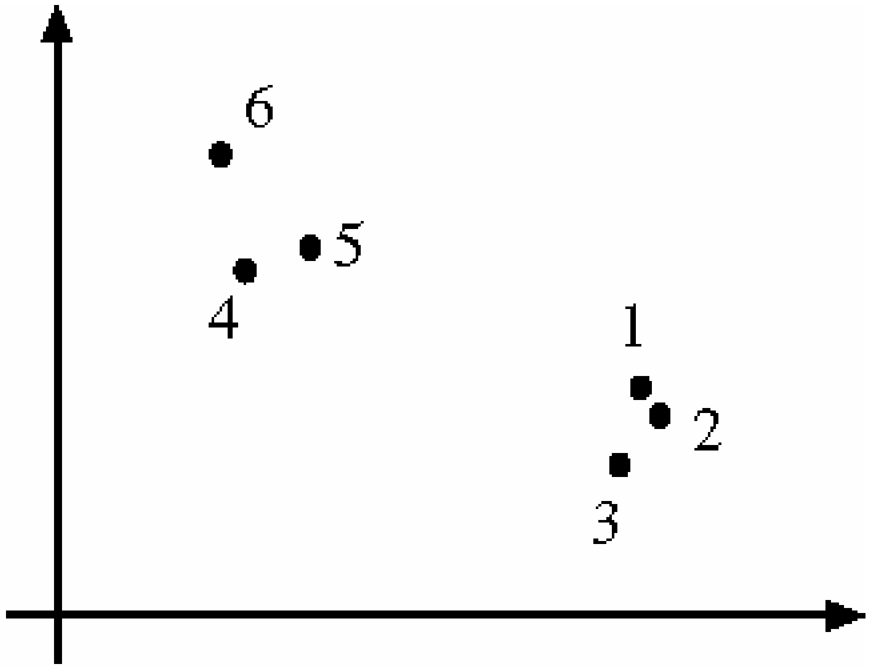
$$d(\vec{x}, \vec{y}) = \sqrt{\sum_{i=1}^{N} \frac{(x_i - y_i)^2}{\sigma_i^2}}$$

- Cosine distance

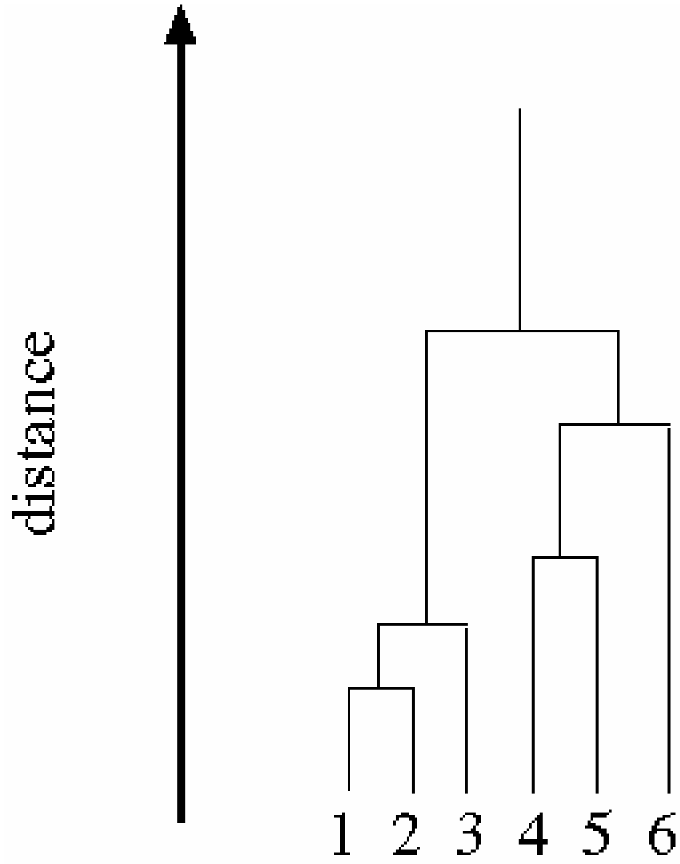
$$\text{similarity} = \cos(\theta) = \frac{A \cdot B}{\|A\| \|B\|}$$

Slide credit: D. Hoiem

Dendograms



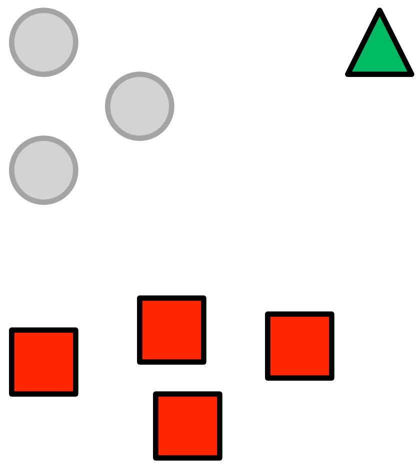
Data set



Dendogram formed by agglomerative clustering using single-link clustering.

Slide credit: B. Freeman

Agglomerative clustering

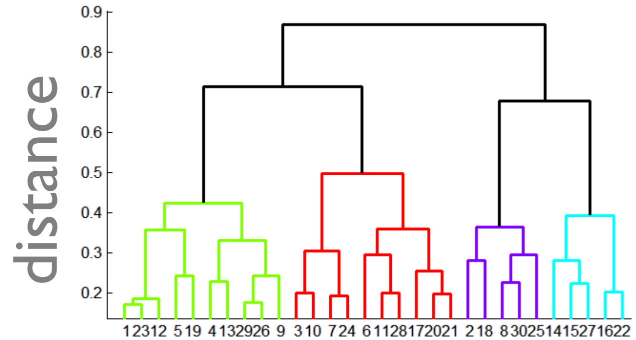


How to define cluster similarity?

- 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

Slide credit: D. Hoiem

Segmentation methods

- Segment foreground from background
- Histogram-based segmentation
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  - 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

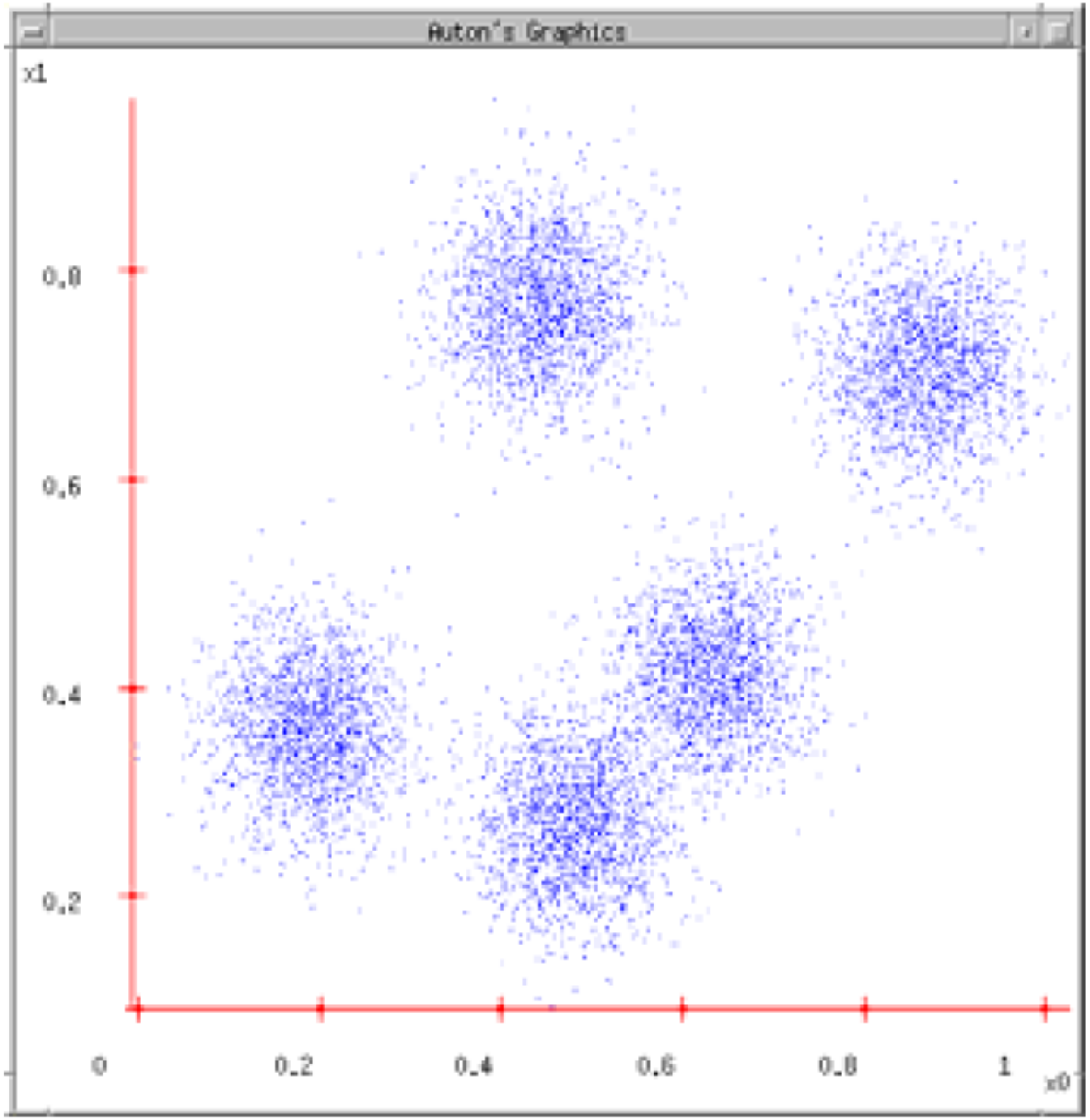
- Will always converge to *some* solution
- Can be a "local minimum"
  - does not always find the global minimum of objective function:

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

Slide credit: S. Seitz

K-means

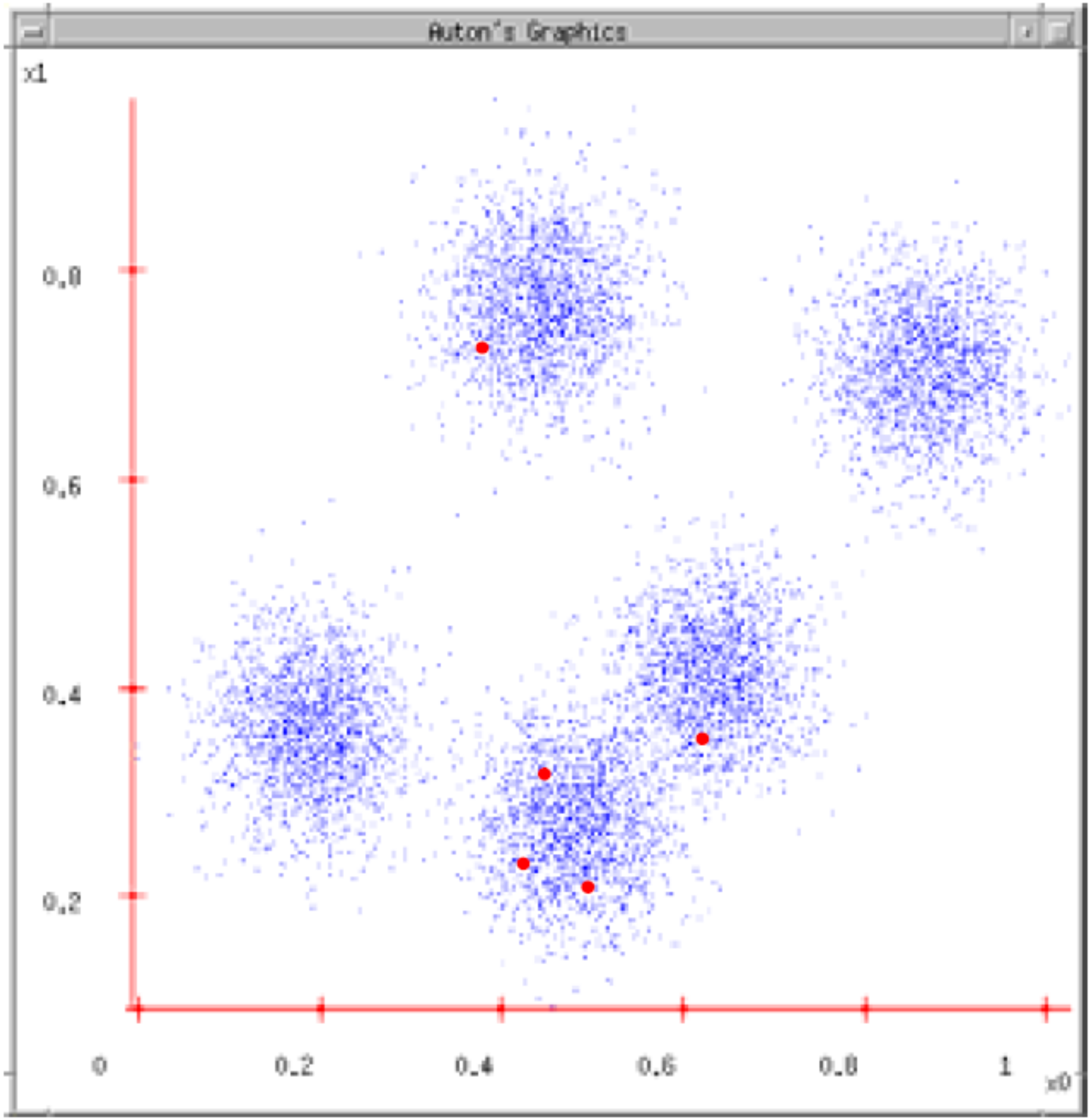
1. Ask user how many clusters they'd like. *(e.g. k=5)*



Slide credit: K Grauman, A. Moore

K-means

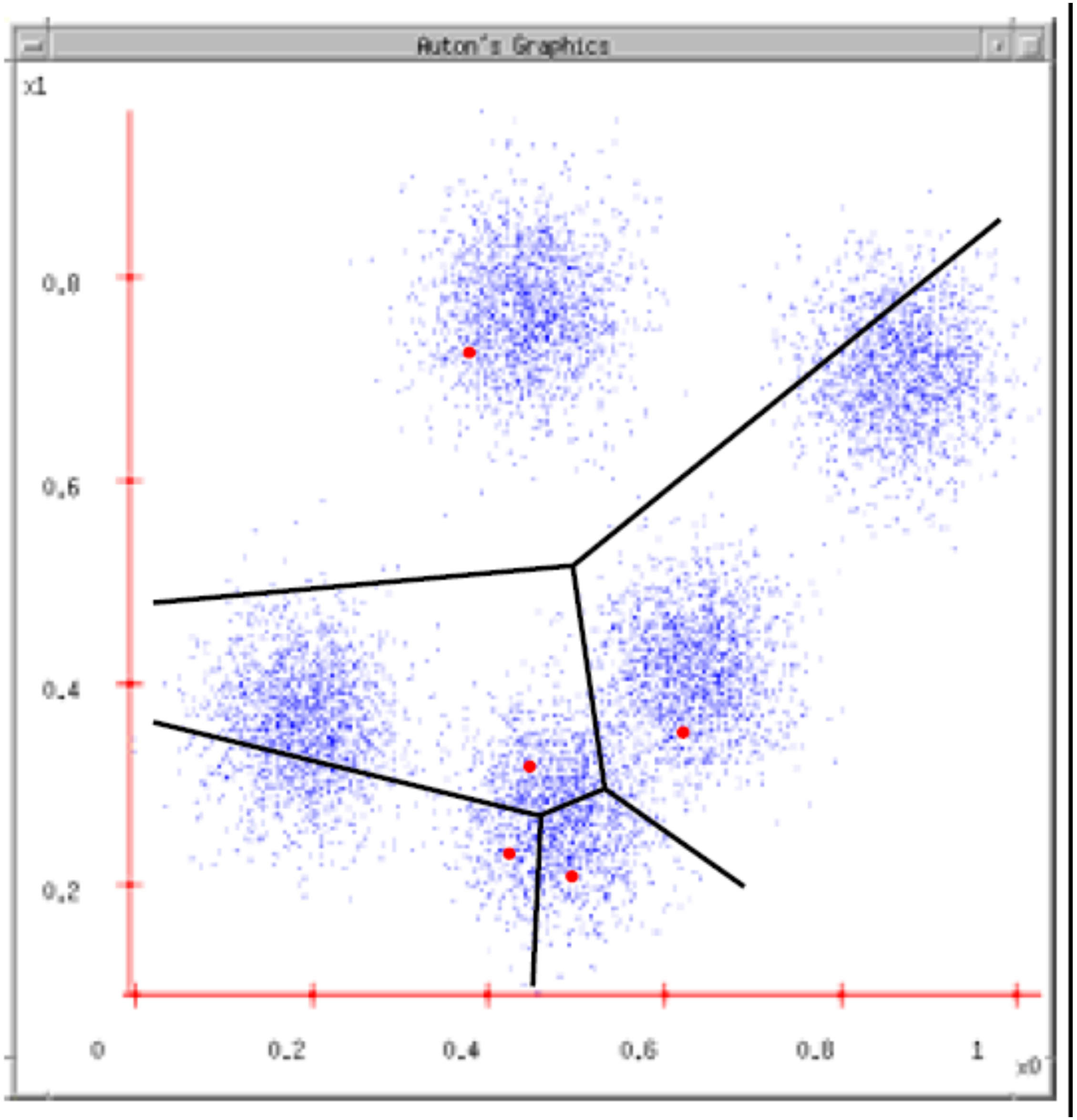
1. Ask user how many clusters they'd like. *(e.g. k=5)*
2. Randomly guess k cluster Center locations



Slide credit: K Grauman, A. Moore

K-means

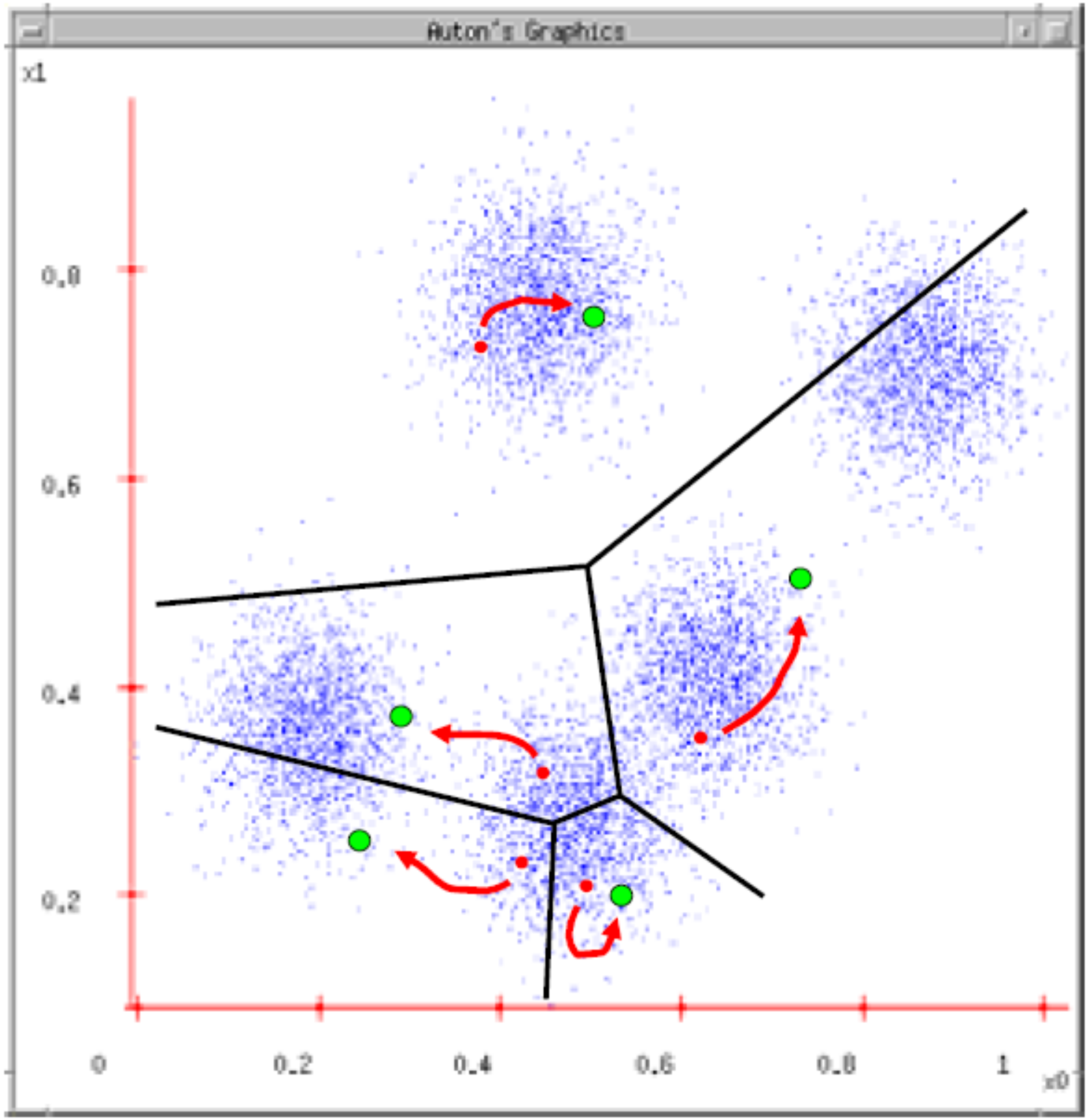
1. Ask user how many clusters they'd like. *(e.g. k=5)*
2. Randomly guess k cluster Center locations
3. Each datapoint finds out which Center it's closest to. (Thus each Center "owns" a set of datapoints)



Slide credit: K Grauman, A. Moore

K-means

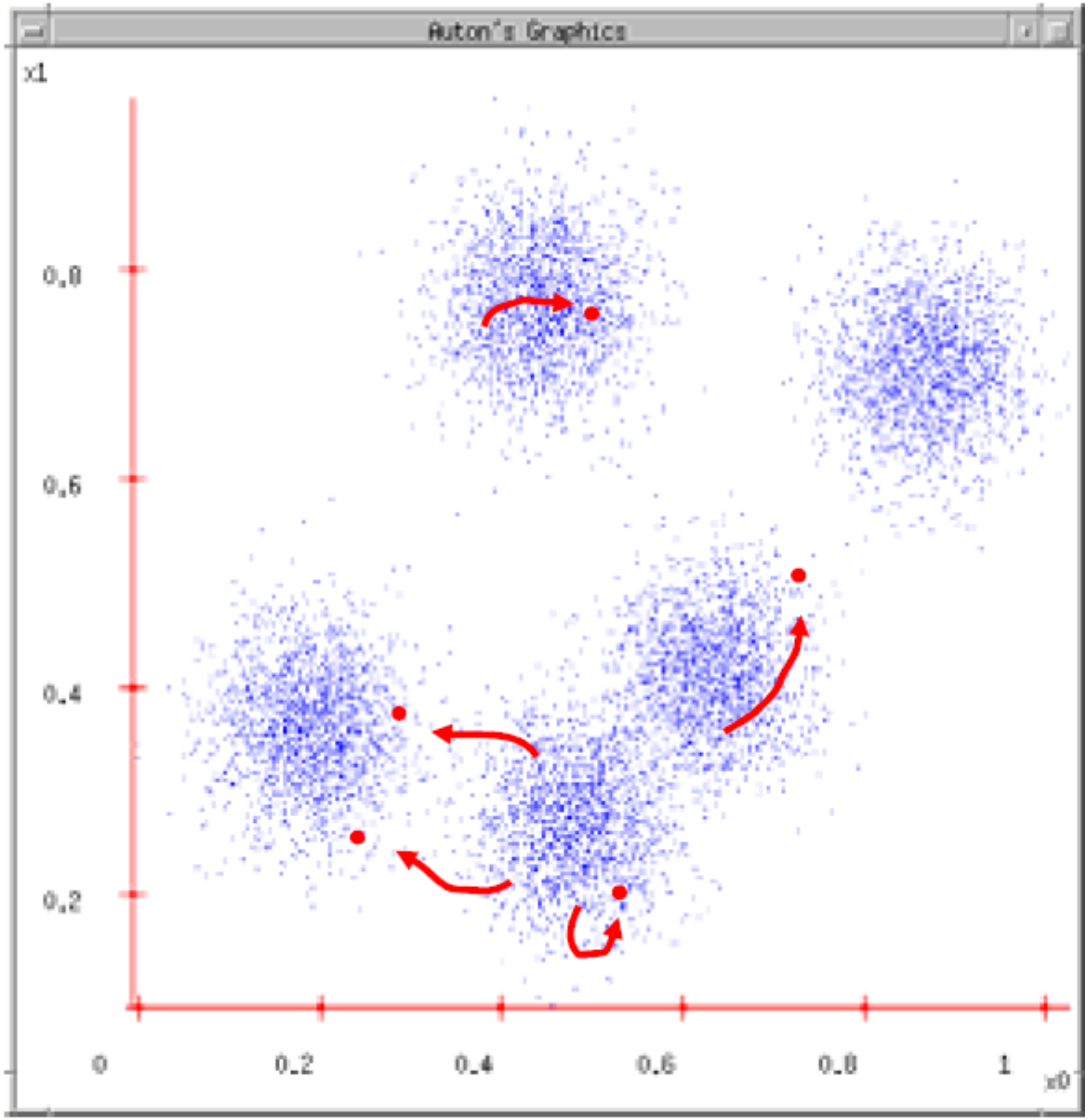
1. Ask user how many clusters they'd like. *(e.g. k=5)*
2. Randomly guess k cluster Center locations
3. Each datapoint finds out which Center it's closest to.
4. Each Center finds the centroid of the points it owns



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

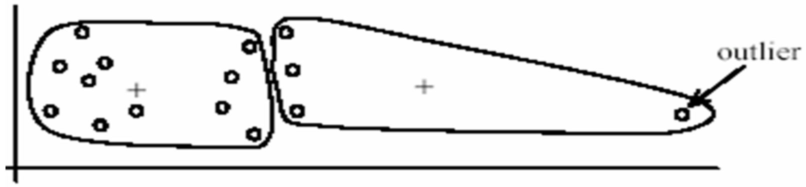
K-means: pros and cons

<u>Pros</u>

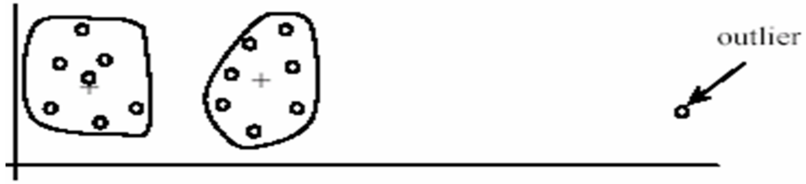
- Simple, fast to compute
- Converges to local minimum of within-cluster squared error

<u>Cons/issues</u>

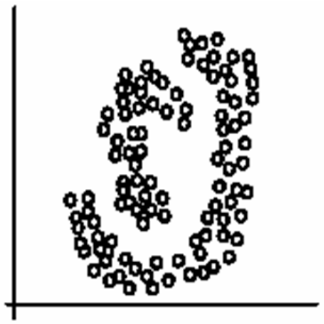
- Setting k?
- Sensitive to initial centers
- Sensitive to outliers
- Detects spherical clusters
- Assuming means can be computed

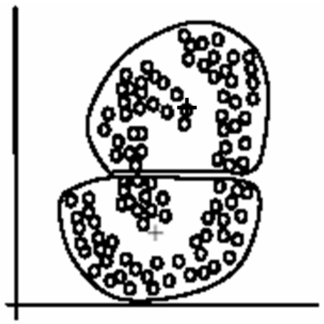


(A): Undesirable clusters



(B): Ideal clusters

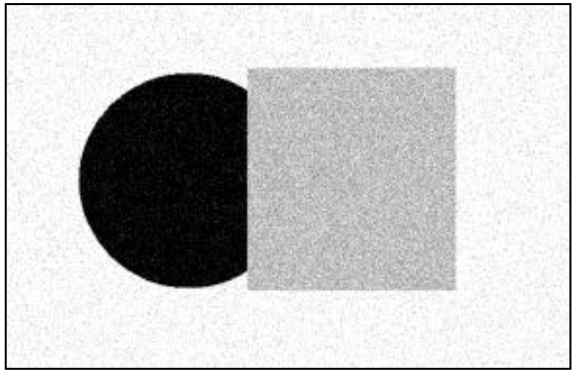

(A): Two natural clusters


(B): *k*-means clusters

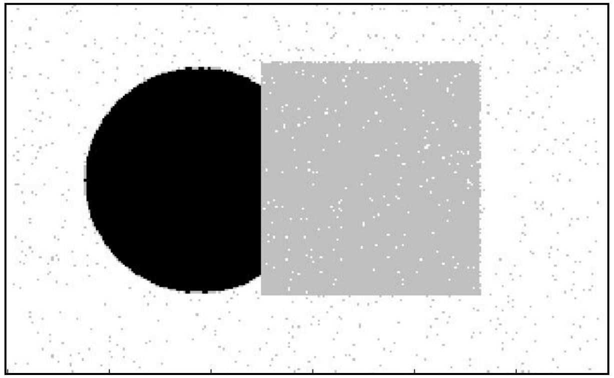
Slide credit: K Grauman

An aside: Smoothing out cluster assignments

- Assigning a cluster label per pixel may yield outliers:

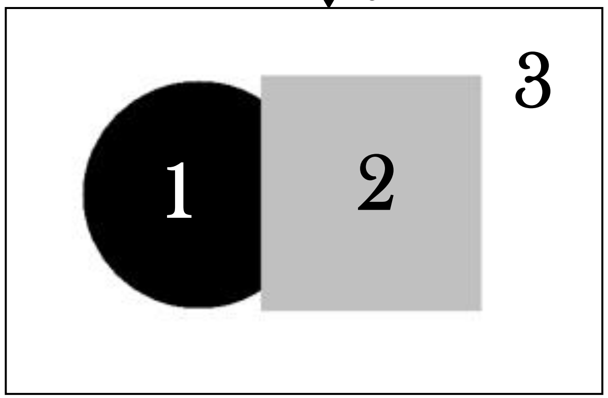


original



labeled by cluster center's intensity

?



- How to ensure they are spatially smooth?

Slide credit: K Grauman

Segmentation as clustering

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

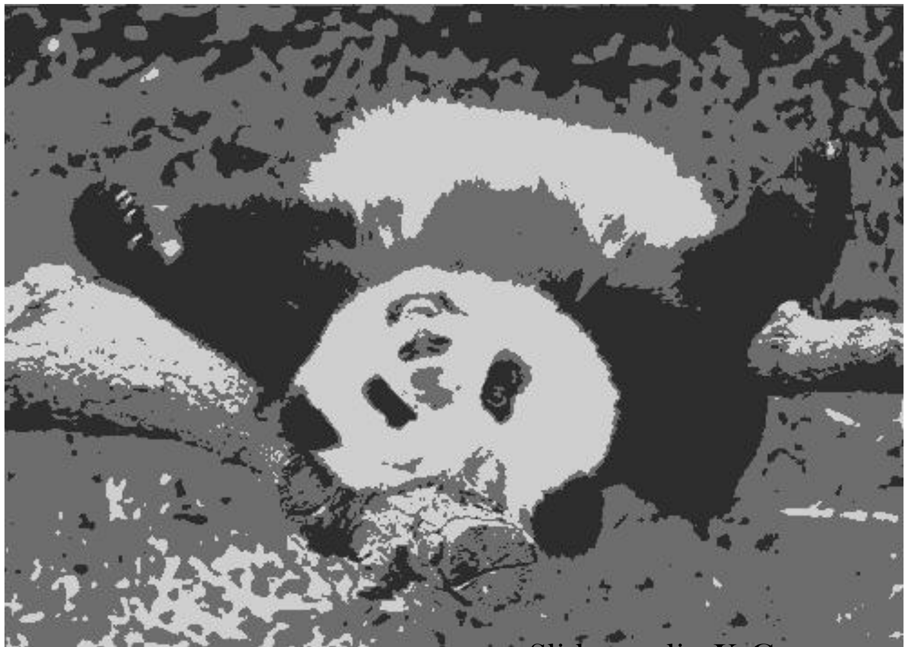
Grouping pixels based on <u>intensity</u> similarity

Feature space: intensity value (1-d)

Slide credit: K Grauman

K=2

K=3



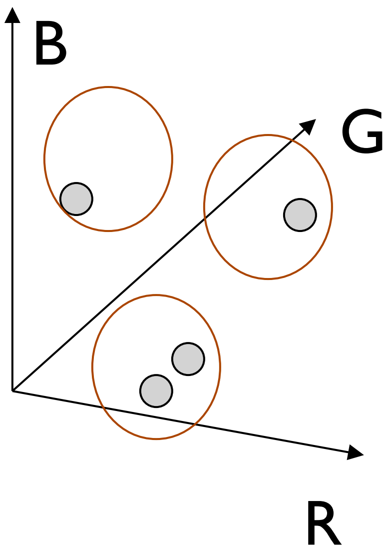
quantization of the feature space;
segmentation label map

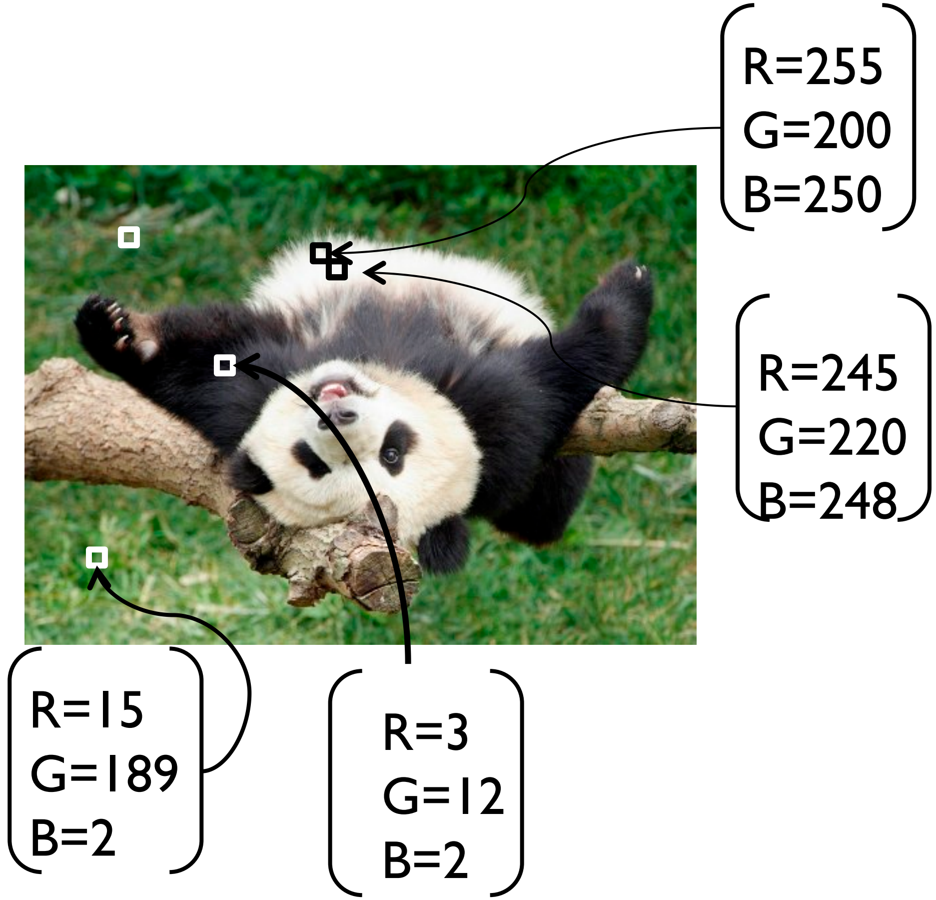
Slide credit: K Grauman

Segmentation as clustering

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

Grouping pixels based on <u>color</u> 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.

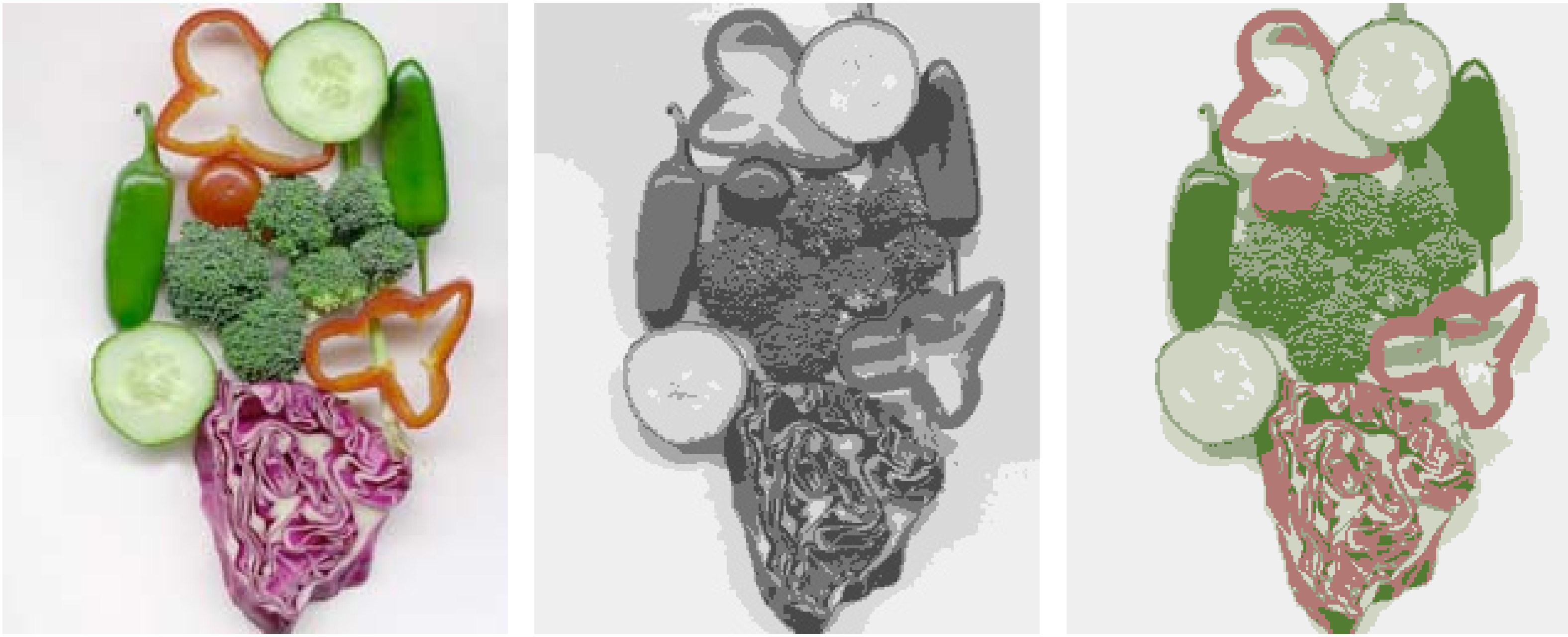
Grouping pixels based on **intensity** similarity

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

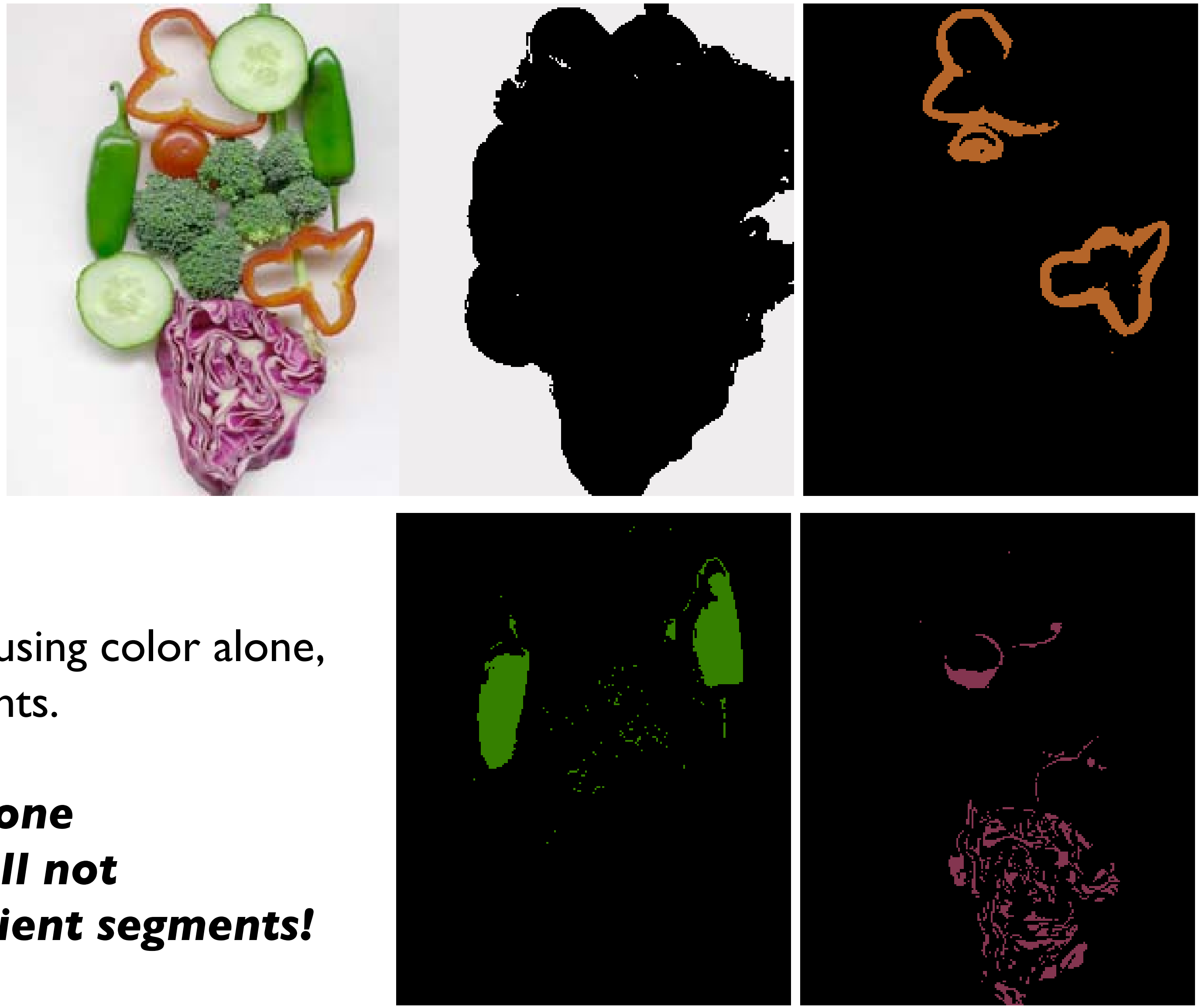
Image

Clusters on color

K-means using color alone, 11 segments

Slide credit: B. Freeman

Segmentation as clustering



K-means using color alone,
11 segments.

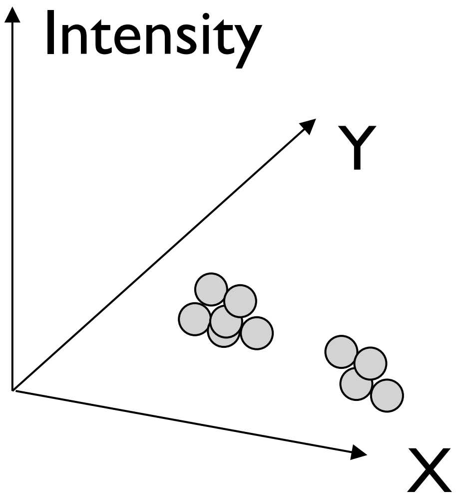
Color alone often will not yield salient segments!

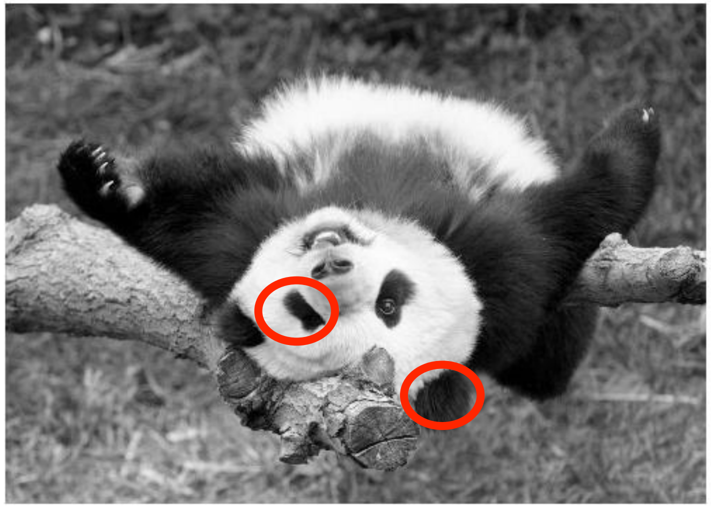
Slide credit: B. Freeman

Segmentation as clustering

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

Grouping pixels based on <u>intensity+position</u> similarity





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

Slide credit: K Grauman

Segmentation as clustering

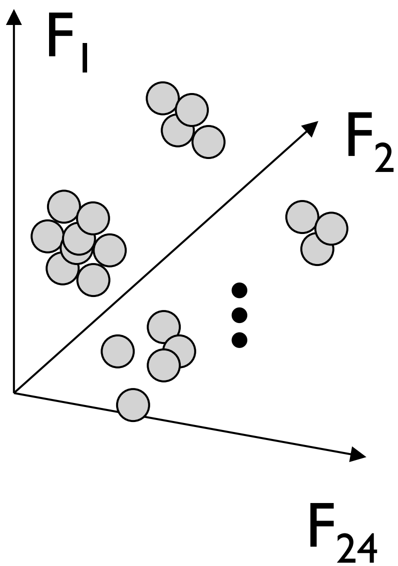
- Color, brightness, position alone are not enough to distinguish all regions…

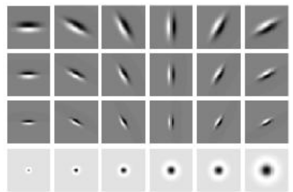
Slide credit: K Grauman

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



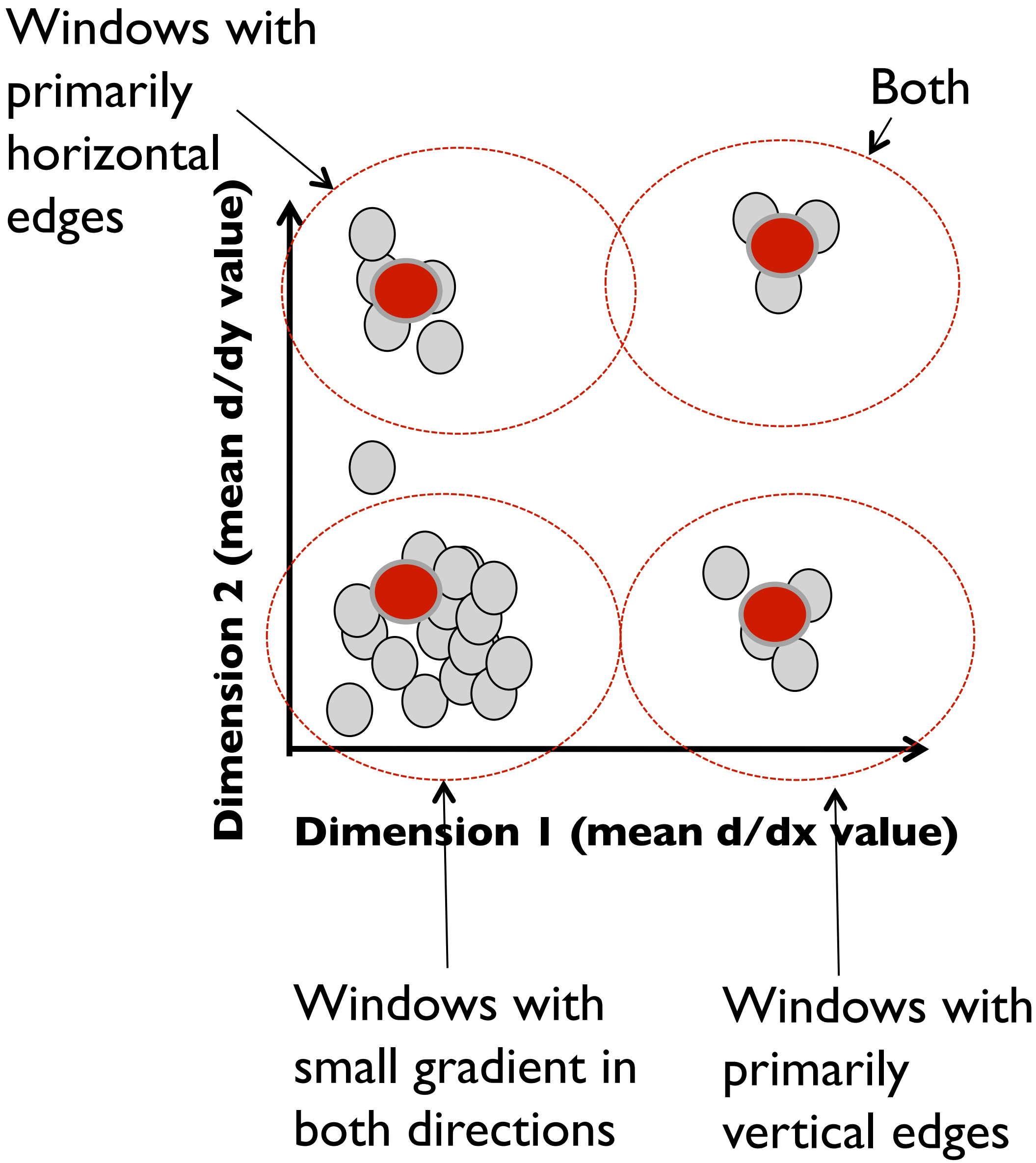


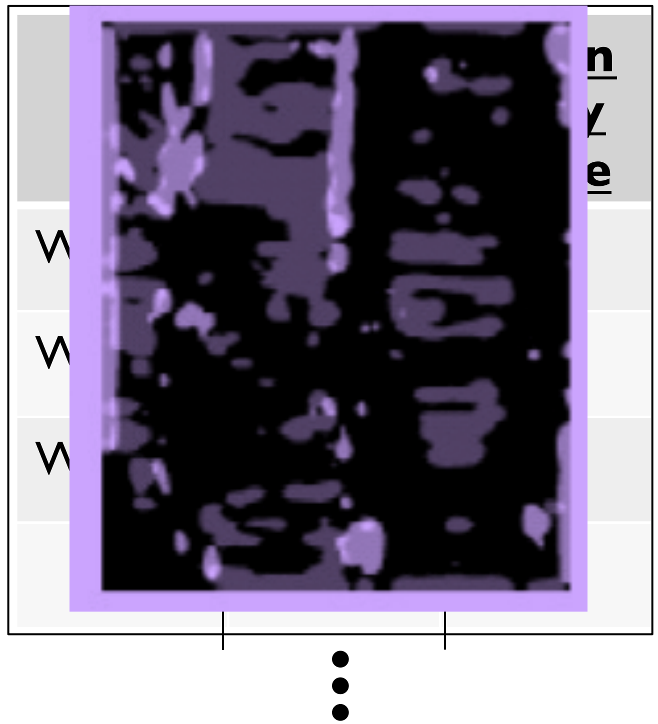
Filter bank of 24 filters

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

Slide credit: K Grauman

Texture representation example





statistics to summarize patterns in small windows

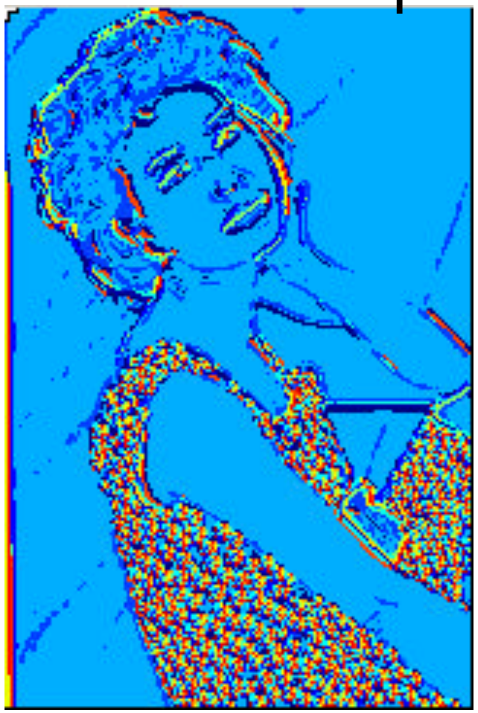
Slide credit: K Grauman

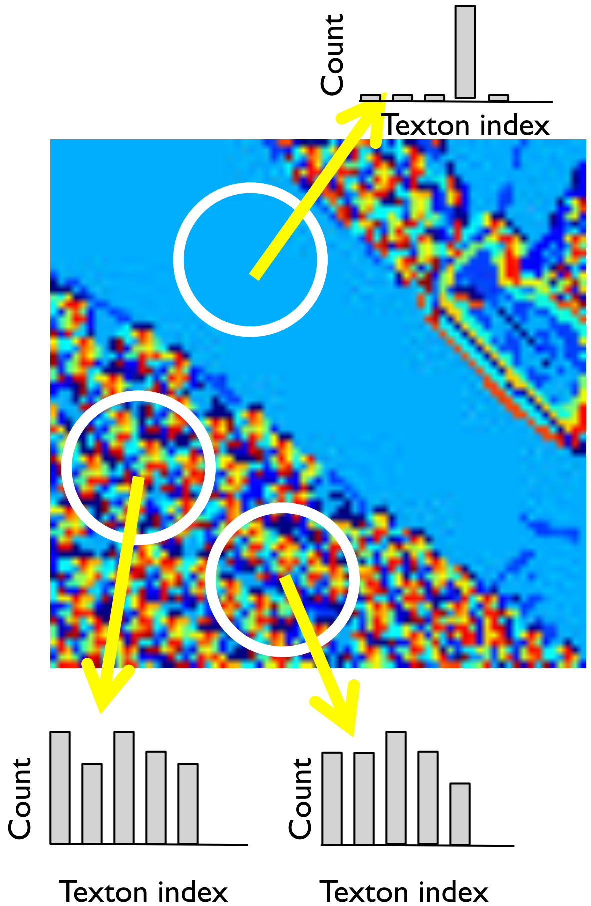
Segmentation with texture features

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

Image

Texton map

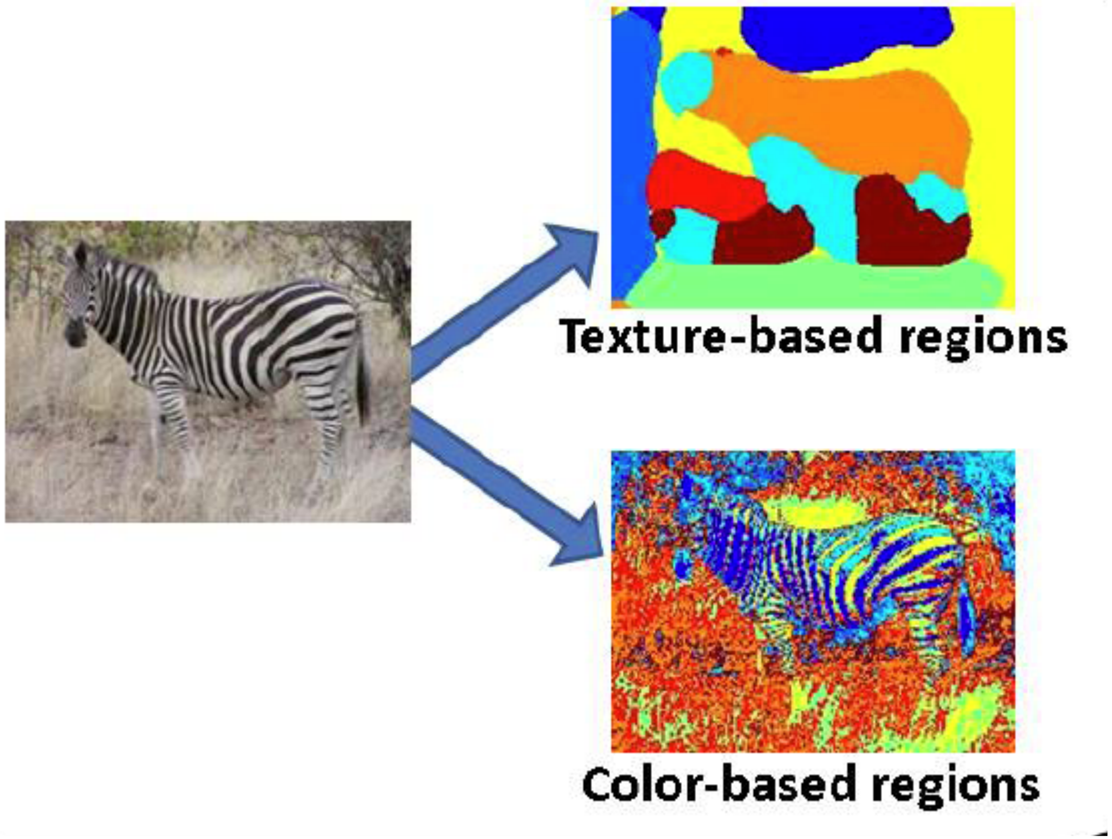




Malik, Belongie, Leung and Shi. IJCV 2001.

Slide credit: K Grauman, L. Lazebnik

Image segmentation example



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.

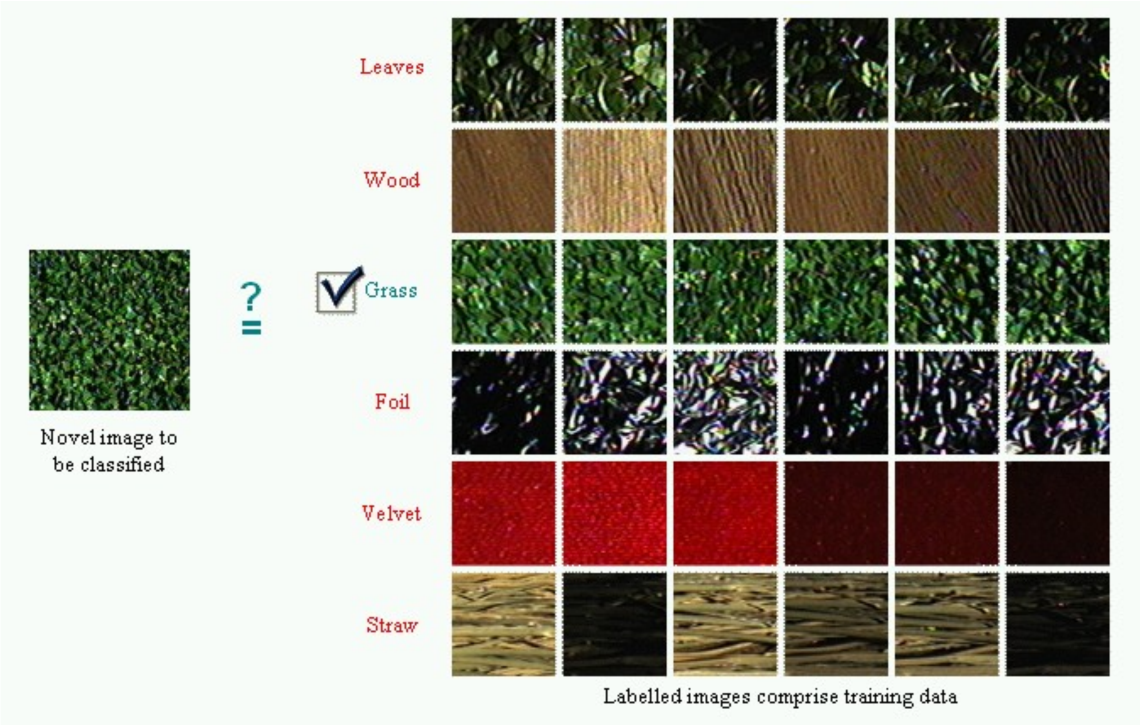
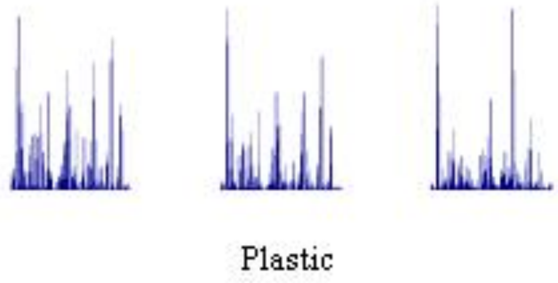


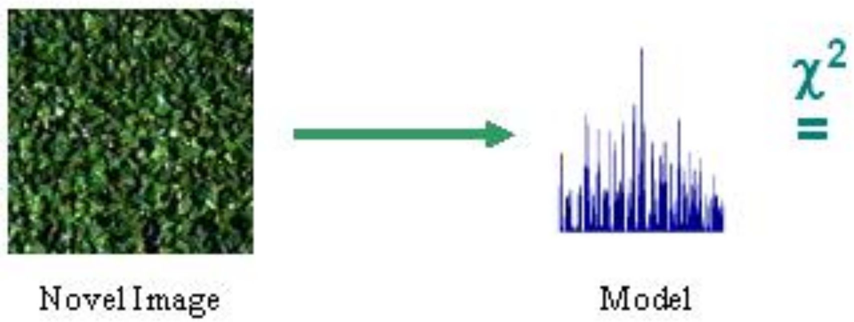
Figure from Varma & Zisserman, IJCV 2005

Slide credit: K Grauman

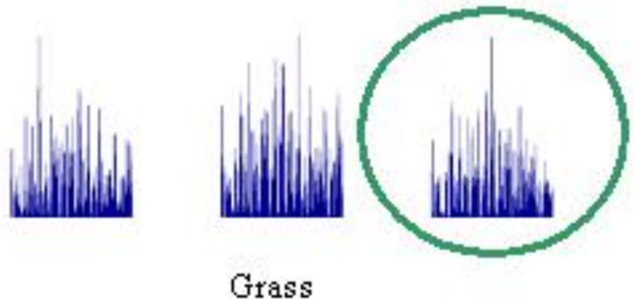
Material classification example

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