

## Clustering: K-Means and Mixtures of Gaussians

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Reading: Manning/Raghavan/Schuetze,  
Chapters 16 (not 16.3) and 17  
(<http://nlp.stanford.edu/IR-book/>)

## Outline

- Supervised vs. Unsupervised Learning
- Hierarchical Clustering
  - Hierarchical Agglomerative Clustering (HAC)
- Non-Hierarchical Clustering
  - K-means
  - Mixtures of Gaussians and EM-Algorithm

## Non-Hierarchical Clustering

- K-means clustering (“hard”)
- Mixtures of Gaussians and training via Expectation maximization Algorithm (“soft”)

## Clustering Criterion

- Evaluation function that assigns a (usually real-valued) value to a clustering
  - Clustering criterion typically function of
    - within-cluster similarity and
    - between-cluster dissimilarity
- Optimization
  - Find clustering that maximizes the criterion
    - Global optimization (often intractable)
    - Greedy search
    - Approximation algorithms

## Centroid-Based Clustering

- Assumes instances are real-valued vectors.
- Clusters represented via *centroids* (i.e. average of points in a cluster)  $c$ :

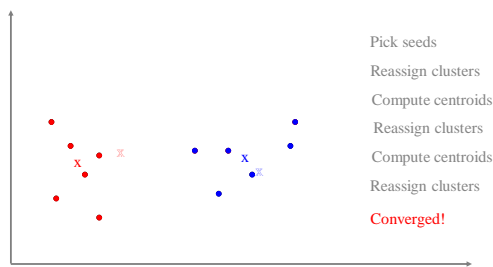
$$\bar{\mu}(c) = \frac{1}{|c|} \sum_{\vec{x} \in c} \vec{x}$$

- Reassignment of instances to clusters is based on **distance** to the current cluster centroids.

## K-Means Algorithm

- Input:  $k$  = number of clusters, distance measure  $d$
- Select  $k$  random instances  $\{s_1, s_2, \dots, s_k\}$  as seeds.
- Until clustering converges or other stopping criterion:
  - For each instance  $x_i$ :
    - Assign  $x_i$  to the cluster  $c_j$  such that  $d(x_i, s_j)$  is min.
  - For each cluster  $c_j$  //update the centroid of each cluster
    - $s_j = \mu(c_j)$

## K-means Example (k=2)



Pick seeds  
Reassign clusters  
Compute centroids  
Reassign clusters  
Compute centroids  
Reassign clusters  
**Converged!**

## Time Complexity

- Assume computing distance between two instances is  $O(N)$  where  $N$  is the dimensionality of the vectors.
- Reassigning clusters for  $n$  points:  $O(kn)$  distance computations, or  $O(knN)$ .
- Computing centroids: Each instance gets added once to some centroid:  $O(nN)$ .
- Assume these two steps are each done once for  $i$  iterations:  $O(iknN)$ .
- Linear in all relevant factors, assuming a fixed number of iterations, more efficient than HAC.

## Buckshot Algorithm

### Problem

- Results can vary based on random seed selection, especially for high-dimensional data.
- Some seeds can result in poor convergence rate, or convergence to sub-optimal clusterings.

Idea: Combine HAC and K-means clustering.

- First randomly take a sample of instances of size  $n^{1/2}$
- Run group-average HAC on this sample  $n^{1/2}$
- Use the results of HAC as initial seeds for K-means.
- Overall algorithm is efficient and avoids problems of bad seed selection.

## Clustering as Prediction

### • Setup

- Learning Task:  $P(X)$
- Training Sample:  $S = (\vec{x}_1, \dots, \vec{x}_n)$
- Hypothesis Space:  $H = \{h_1, \dots, h_{|H|}\}$  each describes  $P(X|h_i)$  where  $h_i$  are parameters
- Goal: learn which  $P(X|h_i)$  produces the data

### • What to predict?

- Predict where new points are going to fall

## Gaussian Mixtures and EM

### • Gaussian Mixture Models

– Assume

$$P(X = \vec{x}|h_i) = \sum_{j=1}^k P(X = \vec{x}|Y = j, h_i)P(Y = j)$$

where  $P(X = \vec{x}|Y = j, h) = N(X = \vec{x}|\vec{\mu}_j, \Sigma_j)$

and  $h = (\vec{\mu}_1, \dots, \vec{\mu}_k, \Sigma_1, \dots, \Sigma_k)$ .

### • EM Algorithm

– Assume  $P(Y)$  and  $k$  known and  $\Sigma_i = 1$ .

– REPEAT

$$\vec{\mu}_j = \frac{\sum_{i=1}^n P(Y=j|X=\vec{x}_i, \vec{\mu}_1, \dots, \vec{\mu}_k) \vec{x}_i}{\sum_{i=1}^n P(Y=j|X=\vec{x}_i, \vec{\mu}_1, \dots, \vec{\mu}_k)}$$

$$P(Y = j|X = \vec{x}_i, \vec{\mu}_1, \dots, \vec{\mu}_k) = \frac{P(X=\vec{x}_i|Y=j, \vec{\mu}_1, \dots, \vec{\mu}_k)P(Y=j)}{\sum_{l=1}^k P(X=\vec{x}_i|Y=l, \vec{\mu}_1, \dots, \vec{\mu}_k)P(Y=l)} = \frac{e^{-0.5(\vec{x}_i - \vec{\mu}_j)^2} P(Y=j)}{\sum_{l=1}^k e^{-0.5(\vec{x}_i - \vec{\mu}_l)^2} P(Y=l)}$$