CS540 Introduction to Artificial Intelligence

Lecture 15

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Midterm

Admin

Midterm

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Unsupervised Learning

Motivation

- Supervised learning: $\left(x_1, y_1\right), \left(x_2, y_2\right), ..., \left(x_n, y_n\right)$.
- Unsupervised learning: $x_1, x_2, ..., x_n$.
- There are a few common tasks without labels.

1. Clustering: separate instances into groups.
2. Novelty (outlier) detection: find instances that are different.
3. Dimensionality reduction: represent each instance with a lower dimensional feature vector while maintaining key characteristics.

Unsupervised Learning Applications

Motivation

1. Google News
2. Google Photo
3. Image Segmentation
4. Text Processing

Hierarchical Clustering

Description

- Start with each instance as a cluster.
- Merge clusters that are closest to each other.
- Result in a binary tree with close clusters as children.

Hierarchical Clustering Diagram

Description

Single Linkage Distance

Definition

- Usually, the distance between two clusters is measured by the single-linkage distance.

$$d\left(C_k, C_{k'}\right) = \min\left\{d\left(x_i, x_{i'}\right) : x_i \in C_k, x_{i'} \in C_{k'}\right\}$$

- It is the shortest distance from any instance in one cluster to any instance in the other cluster.

Complete Linkage Distance

Definition

- Another measure is complete-linkage distance,
$$d\left(C_k, C_{k'}\right) = \max\left\{d\left(x_i, x_{i'}\right) : x_i \in C_k, x_{i'} \in C_{k'}\right\}$$
- It is the longest distance from any instance in one cluster to any instance in the other cluster.

Average Linkage Distance Diagram

Definition

- Another measure is average-linkage distance.

$$d\left(C_k, C_{k'}\right) = \frac{1}{\left|C_k\right|\left|C_{k'}\right|} \sum_{x_i \in C_k, x_{i'} \in C_{k'}} d\left(x_i, x_{i'}\right)$$

- It is the average distance from any instance in one cluster to any instance in the other cluster.

Hierarchical Clustering 1

Quiz

Hierarchical Clustering 2

Quiz

Hierarchical Clustering 3

Quiz

Hierarchical Clustering 4

Quiz

Hierarchical Clustering 4, Diagram

Quiz

Hierarchical Clustering 5

Quiz

Number of Clusters

Discussion

- K can be chosen using prior knowledge about X.
- The algorithm can stop merging as soon as all the between-cluster distances are larger than some fixed R.
- The binary tree generated in the process is often called dendrogram, or taxonomy, or a hierarchy of data points.
- An example of a dendrogram is the tree of life in biology.

K Means Clustering

Description

- This is not K Nearest Neighbor.
- Start with random cluster centers.
- Assign each point to its closest center.
- Update all cluster centers as the center of its points.

K Means Clustering Demo

Description

Distortion

Distortion

- Distortion for a point is the distance from the point to its cluster center.
- Total distortion is the sum of distortion for all points.

$$D_K = \sum_{i=1}^{n} d\left(x_i, c_{k^\star(x_i)}\left(x_i\right)\right)$$

$$k^\star\left(x\right) = \operatorname*{argmin}_{k=1,2,\ldots K} d\left(x, c_k\right)$$

Objective Function Counterexample

Definition

Gradient Descent

Definition

- When d is the Euclidean distance. K Means algorithm is the gradient descent when distortion is the objective (cost) function.

$$\frac{\partial}{\partial c_k} \sum_{k=1}^{K} \sum_{x \in C_k} \|x - c_k\|_2^2 = 0$$

$$\Rightarrow -2 \sum_{x \in C_k} (x - c_k) = 0$$

$$\Rightarrow c_k = \frac{1}{|C_k|} \sum_{x \in C_k} x$$

K Means Clustering 1

Quiz

K Means Clustering 2

Quiz

Total Distortion 2

Quiz

Number of Clusters

Discussion

- There are a few ways to pick the number of clusters K.

1. K can be chosen using prior knowledge about X.
2. K can be the one that minimizes distortion? No, when $K = n$, distortion $= 0$.
3. K can be the one that minimizes distortion + regularizer.

$$K^{\star} = \underset{k}{\operatorname{argmin}} \left(D_k + \lambda \cdot m \cdot k \cdot \log n \right)$$

- λ is a fixed constant chosen arbitrarily.

Initial Clusters

Discussion

- There are a few ways to initialize the clusters.

1. K uniform random points in $\{x_i\}_{i=1}^{n}$.
2. 1 uniform random point in $\{x_i\}_{i=1}^{n}$ as $c_1^{(0)}$, then find the farthest point in $\{x_i\}_{i=1}^{n}$ from $c_1^{(0)}$ as $c_2^{(0)}$, and find the farthest point in $\{x_i\}_{i=1}^{n}$ from the closer of $c_1^{(0)}$ and $c_2^{(0)}$ as $c_3^{(0)}$, and repeat this K times.

Gaussian Mixture Model

Discussion

- In K means, each instance belong to one cluster with certainty.
- One continuous version is called the Gaussian mixture model: each instance belongs to one of the clusters with a positive probability.
- The model can be trained using Expectation Maximization Algorithm (EM Algorithm).

Gaussian Mixture Model Demo

Discussion

Summary

Description