Machine Learning 101

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Mean Shift Clustering

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Mean Shift Clustering is an unsupervised machine learning algorithm used for clustering data points by finding dense areas in the feature space. It is a non-parametric algorithm that does not require prior knowledge of the number of clusters.

How Mean Shift Works

- **Initialize Points:** Start with each data point as a cluster center.
- **Kernel Density Estimation (KDE):** Use a kernel function (e.g., Gaussian) to estimate the density of data points in the feature space.
- **Mean Shift Step:** For each point, compute the weighted mean of points within a given bandwidth and shift the point to this mean.
- **Convergence:** Repeat the mean shift step until points no longer move significantly or a maximum number of iterations is reached.
- **Cluster Formation:** Points that converge to the same position are grouped into the same cluster.

Mathematical Formulation

The mean shift vector is calculated as:

$$m(x) = \frac{\sum_{x_i \in N(x)} K(x_i - x) x_i}{\sum_{x_i \in N(x)} K(x_i - x)} \tag{1}$$

Where:

- $m(x)$ = mean shift vector

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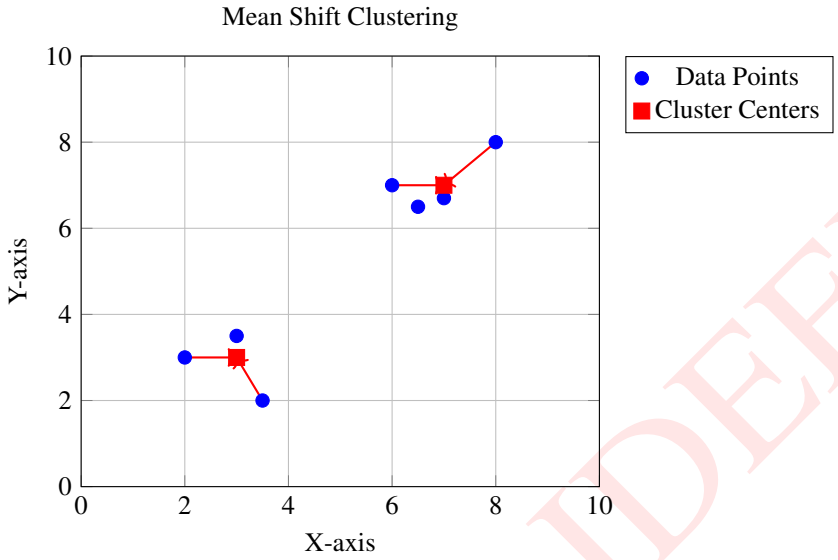
- K = kernel function (often Gaussian)
- $N(x)$ = neighborhood points within the bandwidth

Visualization

Below is a visual representation of Mean Shift clustering applied to a sample dataset.



Mean Shift is a **non-parametric**, **unsupervised** clustering algorithm that finds dense areas in a feature space. Unlike k-means, it does not require the number of clusters to be pre-specified.

1 Algorithm Steps

1. **Initialize Points:** Each data point is treated as a cluster center.
2. **Define a Kernel Density Estimator (KDE) Window:**
   - A circular window of radius h (bandwidth) is placed around each point.
   - The window size determines the search area for nearby points.
3. **Compute Mean Shift Vector:** The mean of all points within the window is computed:

$$m(x) = \frac{\sum_i K(x_i - x)x_i}{\sum_i K(x_i - x)} \tag{2}$$

   where $K(x)$ is a kernel function (e.g., Gaussian, Flat, or Epanechnikov).
4. **Shift Window:** Move the window to the computed mean.
5. **Repeat Until Convergence:** Continue shifting until movement is negligible.
6. **Assign Clusters:** All points converging to the same mode belong to the same cluster.

2 Characteristics of Mean Shift

- No need to specify the number of clusters in advance.
- Detects arbitrarily shaped clusters.
- Computationally expensive for large datasets.
- The choice of bandwidth (h) significantly affects clustering results.

3 Applications

- Image Segmentation
- Object Tracking in Computer Vision
- Anomaly Detection
- Density Estimation

4 Mean Shift Algorithm in Pseudocode

Algorithm 1 Mean Shift Clustering

```
Initialize each data point as a cluster center.
while not converged do
    for each data point x do
        Find all points within bandwidth h.
        Compute mean of these points.
        Shift x toward the mean.
    end for
end while
Assign clusters based on final convergence points.
```

5 Merits and Demerits

5.1 Merits

- Does not require prior knowledge of the number of clusters.
- Can detect arbitrarily shaped clusters.
- Works well in high-dimensional spaces.
- Robust to outliers and noise in the data.

5.2 Demerits

- Computationally expensive, especially for large datasets.
- The choice of bandwidth (h) is crucial and affects performance.
- May converge to local optima, depending on initialization.
- Difficult to scale to very large datasets due to repeated density estimation.