CS47300: Web Information Search and Management

Text Clustering
Prof. Chris Clifton
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Borrows slides from Chris Manning, Ray Mooney and Soumen Chakrabarti

Midterm 1: All Aspects of AD-hoc IR
October 14 9am – October 15 9am, Gradescope

Pagerank, HITS, and relevance feedback saved for Midterm 2
Clustering

• Document clustering
  – Motivations
  – Document representations
  – Success criteria

• Clustering algorithms
  – K-means
  – Model-based clustering (EM clustering)
  – Hierarchical clustering

What is clustering?

• Clustering is the process of grouping a set of physical or abstract objects into classes of similar objects
  – It is the commonest form of unsupervised learning
    • Unsupervised learning = learning from raw data, as opposed to supervised data where the correct classification of examples is given
  – It is a common and important task that finds many applications in IR and other places
Why cluster documents?

- Whole corpus analysis/navigation
  - Better user interface
- For improving recall in search applications
  - Better search results
- For better navigation of search results
- For speeding up vector space retrieval
  - Faster search

Navigating document collections

- Standard IR is like a book index
- Document clusters are like a table of contents
- People find having a table of contents useful

<table>
<thead>
<tr>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aardvark, 15</td>
</tr>
<tr>
<td>Blueberry, 200</td>
</tr>
<tr>
<td>Capricorn, 1, 45-55</td>
</tr>
<tr>
<td>Dog, 79-99</td>
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<tr>
<td>Egypt, 65</td>
</tr>
<tr>
<td>Falafel, 78-90</td>
</tr>
<tr>
<td>Giraffes, 45-59</td>
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   2.a. The Nervous System
   2.b. Organization of the Brain
   2.c. The Visual System
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Corpus analysis/navigation

• Given a corpus, partition it into groups of related docs
  – Recursively, can induce a tree of topics
  – Allows user to browse through corpus to find information
  – Crucial need: meaningful labels for topic nodes.

• Yahoo!: manual hierarchy
  – Often not available for new document collection
For improving search recall

• **Cluster hypothesis** - Documents with similar text are related.

• Therefore, to improve search recall:
  – Cluster docs in corpus a priori
  – When a query matches a doc $D$, also return other docs in the cluster containing $D$

• Hope if we do this: The query “car” will also return docs containing **automobile**
  – Because clustering grouped together docs containing car with those containing **automobile**.

Why might this happen?

For better navigation of search results

• Grouping search results thematically
  – clusty.com / Vivisimo
Navigating search results (2)

- One can also view grouping documents with the same sense of a word as clustering
- Given the results of a search (e.g., jaguar, NLP), partition into groups of related docs
- Can be viewed as a form of word sense disambiguation
- E.g., jaguar may have multiple senses:
  - The car company
  - The animal
  - The football team
  - The video game
- Recall query reformulation/expansion discussion
For better navigation of search results

- And more visually: Kartoo.com

For speeding up vector space retrieval

- In vector space retrieval, we must find nearest doc vectors to query vector
- This entails finding the similarity of the query to every doc – slow (for some applications)
- By clustering docs in corpus a priori
  – find nearest docs in cluster(s) close to query
  – inexact but avoids exhaustive similarity computation
What Is A Good Clustering?

- **Internal criterion**: A good clustering will produce high quality clusters in which:
  - the intra-class (that is, intra-cluster) similarity is high
  - the inter-class similarity is low
  - The measured quality of a clustering depends on both the document representation and the similarity measure used

- **External criterion**: The quality of a clustering is also measured by its ability to discover some or all of the hidden patterns or latent classes
  - Assessable with gold standard data

External Evaluation of Cluster Quality

- Assesses clustering with respect to ground truth
- Assume that there are C gold standard classes, while our clustering algorithms produce k clusters, \( \pi_1, \pi_2, \ldots, \pi_k \) with \( n_i \) members.
- Simple measure: purity, the ratio between the dominant class in the cluster \( \pi_i \) and the size of cluster \( \pi_i \)
  \[
  \text{Purity}_{\pi_i} = \frac{1}{n_i} \max_j (n_{ij}) \text{ for } j \in \mathcal{C}
  \]
- Others are entropy of classes in clusters (or mutual information between classes and clusters)
Cluster I: Purity = 1/6 (max(5, 1, 0)) = 5/6

Cluster II: Purity = 1/6 (max(1, 4, 1)) = 4/6

Cluster III: Purity = 1/5 (max(2, 0, 3)) = 3/5

Issues for clustering

- Representation for clustering
  - Document representation
    - Vector space? Normalization?
  - Need a notion of similarity/distance
- How many clusters?
  - Fixed a priori?
  - Completely data driven?
    - Avoid “trivial” clusters - too large or small
      - In an application, if a cluster's too large, then for navigation purposes you've wasted an extra user click without whittling down the set of documents much.
What makes docs “related”? 

• Ideal: semantic similarity.
• Practical: statistical similarity
  – We will use cosine similarity, Docs as vectors
  – We will describe algorithms in terms of cosine similarity:
    Cosine similarity of normalized $D_j, D_k$:
    \[
    \text{sim}(D_j, D_k) = \sum_{i=1}^{m} w_{ij} \times w_{ik}
    \]
    Also known as normalized inner product
  – For many algorithms, easier to think in terms of a distance (rather than similarity) between docs.

Recall doc as vector

• Each doc $j$ is a vector of $tf \times idf$ values, one component for each term.
• Can normalize to unit length.
• So we have a vector space
  – terms are axis - aka features
  – $n$ docs live in this space
  – even with stemming, may have 20,000+ dimensions
  – do we really want to use all terms?
    • Different from using vector space for search. Why?
Intuition

Postulate: Documents that are “close together” in vector space talk about the same things.

Clustering Algorithms

• Partitioning “flat” algorithms
  – Usually start with a random (partial) partitioning
  – Refine it iteratively
    • $k$ means/medoids clustering
    • Model based clustering

• Hierarchical algorithms
  – Bottom-up, agglomerative
  – Top-down, divisive
Partitioning Algorithms

• Partitioning method: Construct a partition of n documents into a set of k clusters
• Given: a set of documents and the number k
• Find: a partition of k clusters that optimizes the chosen partitioning criterion
  – Globally optimal: exhaustively enumerate all partitions
  – Effective heuristic methods: k-means and k-medoids algorithms

How hard is clustering?

• One idea is to consider all possible clusterings, and pick the one that has best inter and intra cluster distance properties
• Suppose we are given n points, and would like to cluster them into k-clusters
  – How many possible clusterings? \( \frac{k^n}{k!} \)
• Too hard to do it brute force or optimally
• Solution: Iterative optimization algorithms
  – Start with a clustering, iteratively improve it (e.g., K-means)