9. Relevance Feedback and Query Expansion

These notes are based, in part, on notes by Dr. Raymond J. Mooney at the University of Texas at Austin.
Relevance Feedback

• After initial retrieval results are presented, allow the user to provide feedback on the relevance of one or more of the retrieved documents.

• Use this feedback information to reformulate the query.

• Produce new results based on reformulated query.

• Allows more interactive, multi-pass process.
Relevance Feedback Architecture

1. Doc1
2. Doc2
3. Doc3

1. Doc2
2. Doc4
3. Doc5
Query Reformulation

• Revise query to account for feedback:
  – **Query Expansion**: Add new terms to query from relevant documents.
  – **Term Reweighting**: Increase weight of terms in relevant documents and decrease weight of terms in irrelevant documents.

• Several algorithms for query reformulation.
Query Reformulation for VSR

- Change query vector using vector algebra.
- **Add** the vectors for the **relevant** documents to the query vector.
- **Subtract** the vectors for the **irrelevant** docs from the query vector.
- This both adds both positive and negatively weighted terms to the query as well as reweighting the initial terms.
Optimal Query

- Assume that the relevant set of documents $C_r$ are known.
- Then the best query that ranks all and only the relevant queries at the top is:

$$
\tilde{q}_{opt} = \frac{1}{|C_r|} \sum_{\forall \tilde{d}_j \in C_r} \tilde{d}_j - \frac{1}{N - |C_r|} \sum_{\forall \tilde{d}_j \not\in C_r} \tilde{d}_j
$$

Where $N$ is the total number of documents.
Rocchio’s Method (1971)

\[ Q_1 = Q_0 + \beta \sum_{i=1}^{n_1} \frac{R_i}{n_1} - \gamma \sum_{i=1}^{n_2} \frac{S_i}{n_2} \]

where

- \( Q_0 \) = the vector for the initial query
- \( R_i \) = the vector for the relevant document \( i \)
- \( S_i \) = the vector for the non-relevant document \( i \)
- \( n_1 \) = the number of relevant documents chosen
- \( n_2 \) = the number of non-relevant documents chosen
- \( \beta \) and \( \gamma \) tune the importance of relevant and nonrelevant terms
  (in some studies best to set \( \beta \) to 0.75 and \( \gamma \) to 0.25)
Rocchio’s Method

- Rocchio’s Method automatically
  - re-weights terms
  - adds in new terms (from relevant docs)
- Positive v. Negative feedback
  - Positive moves query closer to relevant documents
  - Negative moves query away from non-relevant documents (but, not necessary closer to relevant ones)
    - negative feedback doesn’t always improve effectiveness
    - some systems only use positive feedback
- Some machine learning methods are proving to work better than standard IR approaches like Rocchio

\[ \beta \sum_{i=1}^{n_1} \frac{R_i}{n_1} \quad \text{Positive Feedback} \]

\[ \gamma \sum_{i=1}^{n_2} \frac{S_i}{n_2} \quad \text{Negative Feedback} \]
Rocchio’s Method: Example

Term weights and relevance judgements for 3 documents returned after submitting the query $Q_0$

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_0$</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>D1 (re)</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>D2 (re)</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D3 (nr)</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Assume $\beta = 0.5$ and $\gamma = 0.25$

$$Q_1 = Q_0 + \beta \sum_{i=1}^{n_1} \frac{R_i}{n_1} - \gamma \sum_{i=1}^{n_2} \frac{S_i}{n_2}$$

$$Q_1 = (3, 0, 0, 2, 0) + \frac{[0.5 \times (2+1, 4+3, 0, 0, 2)]}{2} - 0.25 \times (0, 0, 4, 3, 2)$$

$$= (3.75, 1.75, 0, 1.25, 0)$$

(Note: negative entries are changed to zero)
Rocchio’s Method: Example

\[ Q_0 = (3, 0, 0, 2, 0) \quad \rightarrow \quad Q_1 = (3.75, 1.75, 0, 1.25, 0) \]

Using the new query and computing similarities using simple matching function, gives the following results

<table>
<thead>
<tr>
<th></th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q0</td>
<td>6</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Q1</td>
<td>14.5</td>
<td>9</td>
<td>3.75</td>
</tr>
</tbody>
</table>

Some Observations:

- Note that initial query resulted in high score for D3, though it was not relevant to the user (due to the weight of term 4)
  - In general, fewer terms in the query, the more likely a particular term could result in non-relevant results
  - New query decreased score of D3 and increased those of D1 and D2
- Also note that new query added a weight for term 2
  - Initially it may not have been in user’s vocabulary
  - It was added because it appeared as significant in enough relevant documents

2/10/2019 Q1’s values updated
Comparison of Methods

• Overall, experimental results indicate no clear preference for any one of the specific methods.

• All methods generally improve retrieval performance (recall & precision) with feedback.

• Generally just let tunable constants equal 1.
Evaluating Relevance Feedback

• By construction, reformulated query will rank explicitly-marked relevant documents higher and explicitly-marked irrelevant documents lower.
• Method should not get credit for improvement on these documents, since it was told their relevance.
• In machine learning, this error is called “testing on the training data.”
• Evaluation should focus on generalizing to other un-rated documents.
Fair Evaluation of Relevance Feedback

• Remove from the corpus any documents for which feedback was provided.
• Measure recall/precision performance on the remaining residual collection.
• Compared to complete corpus, specific recall/precision numbers may decrease since relevant documents were removed.
• However, relative performance on the residual collection provides fair data on the effectiveness of relevance feedback.
Why is Feedback Not Widely Used

• Users sometimes reluctant to provide explicit feedback.
• Results in long queries that require more computation to retrieve, and search engines process lots of queries and allow little time for each one.
• Makes it harder to understand why a particular document was retrieved.
Pseudo Feedback

• Use relevance feedback methods without explicit user input.
• Just assume the top $m$ retrieved documents are relevant, and use them to reformulate the query.
• Allows for query expansion that includes terms that are correlated with the query terms.
Pseudo Feedback Architecture

Query String

Revised Query

Ranked Documents

IR System

Document corpus

ReRanked Documents

Query Reformulation

Pseudo Feedback

1. Doc 1
2. Doc 2
3. Doc 3

1. Doc 1
2. Doc 2
3. Doc 3

1. Doc 2
2. Doc 4
3. Doc 5

PseudoFeedback Results

• Found to improve performance on TREC competition ad-hoc retrieval task.
• Works even better if top documents must also satisfy additional boolean constraints in order to be used in feedback.
Thesaurus

- A thesaurus provides information on synonyms and semantically related words and phrases.
- Example:

  physician
  
  syn: ||croaker, doc, doctor, MD, medical, mediciner, medico, ||sawbones
  rel: medic, general practitioner, surgeon,
Thesaurus-based Query Expansion

- For each term, $t$, in a query, expand the query with synonyms and related words of $t$ from the thesaurus.
- May weight added terms less than original query terms.
- Generally increases recall.
- May significantly decrease precision, particularly with ambiguous terms.
  - “interest rate” → “interest rate fascinate evaluate”
WordNet

• A more detailed database of semantic relationships between English words.
• Developed by famous cognitive psychologist George Miller and a team at Princeton University.
• About 144,000 English words.
• Nouns, adjectives, verbs, and adverbs grouped into about 109,000 synonym sets called *synsets*.
WordNet Synset Relationships

- **Antonym**: front → back
- **Attribute**: benevolence → good (noun to adjective)
- **Pertainym**: alphabetical → alphabet (adjective to noun)
- **Similar**: unquestioning → absolute
- **Cause**: kill → die
- **Entailment**: breathe → inhale
- **Holonym**: chapter → text (part to whole)
- **Meronym**: computer → cpu (whole to part)
- **Hyponym**: plant → tree (specialization)
- **Hypernym**: apple → fruit (generalization)
WordNet Query Expansion

- Add synonyms in the same synset.
- Add hyponyms to add specialized terms.
- Add hypernyms to generalize a query.
- Add other related terms to expand query.
Statistical Thesaurus

- Existing human-developed thesauri are not easily available in all languages.
- Human thesauri are limited in the type and range of synonymy and semantic relations they represent.
- Semantically related terms can be discovered from statistical analysis of corpora.
Automatic Global Analysis

• Determine term similarity through a pre-computed statistical analysis of the complete corpus.
• Compute association matrices which quantify term correlations in terms of how frequently they co-occur.
• Expand queries with statistically most similar terms.
### Association Matrix

<table>
<thead>
<tr>
<th></th>
<th>( w_1 )</th>
<th>( w_2 )</th>
<th>( w_3 )</th>
<th>\ldots</th>
<th>( w_n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w_1 )</td>
<td>( c_{11} )</td>
<td>( c_{12} )</td>
<td>( c_{13} )</td>
<td>\ldots</td>
<td>( c_{1n} )</td>
</tr>
<tr>
<td>( w_2 )</td>
<td>( c_{21} )</td>
<td></td>
<td></td>
<td>\ldots</td>
<td></td>
</tr>
<tr>
<td>( w_3 )</td>
<td>( c_{31} )</td>
<td></td>
<td></td>
<td>\ldots</td>
<td></td>
</tr>
<tr>
<td>\ldots</td>
<td>( \ldots )</td>
<td>\ldots</td>
<td></td>
<td>\ldots</td>
<td>\ldots</td>
</tr>
<tr>
<td>( w_n )</td>
<td>( c_{n1} )</td>
<td></td>
<td></td>
<td>\ldots</td>
<td></td>
</tr>
</tbody>
</table>

- **\( c_{ij} \):** Correlation factor between term \( i \) and term \( j \)

\[
\begin{align*}
    c_{ij} &= \sum_{d_k \in D} f_{ik} \times f_{jk} \\
    f_{ik} &\text{: Frequency of term } i \text{ in document } k
\end{align*}
\]
Normalized Association Matrix

- Frequency based correlation factor favors more frequent terms.
- Normalize association scores:
  \[ s_{ij} = \frac{c_{ij}}{c_{ii} + c_{jj} - c_{ij}} \]
- Normalized score is 1 if two terms have the same frequency in all documents.
Metric Correlation Matrix

- Association correlation does not account for the proximity of terms in documents, just co-occurrence frequencies within documents.
- Metric correlations account for term proximity.

\[
c_{ij} = \sum_{k_u \in V_i} \sum_{k_v \in V_j} \frac{1}{r(k_u, k_v)}
\]

- \(V_i\): Set of all occurrences of term \(i\) in any document.
- \(r(k_u, k_v)\): Distance in words between word occurrences \(k_u\) and \(k_v\) (\(\infty\) if \(k_u\) and \(k_v\) are occurrences in different documents).
Normalized Metric Correlation Matrix

- Normalize scores to account for term frequencies:

\[ s_{ij} = \frac{c_{ij}}{|V_i| \times |V_j|} \]
Query Expansion with Correlation Matrix

• For each term $i$ in query, expand query with the $n$ terms, $j$, with the highest value of $c_{ij}$ ($s_{ij}$).

• This adds semantically related terms in the “neighborhood” of the query terms.
Problems with Global Analysis

- Term ambiguity may introduce irrelevant statistically correlated terms.
  - “Apple computer” → “Apple red fruit computer”

- Since terms are highly correlated anyway, expansion may not retrieve many additional documents.
Automatic Local Analysis

- At query time, dynamically determine similar terms based on analysis of top-ranked retrieved documents.
- Base correlation analysis on only the “local” set of retrieved documents for a specific query.
- Avoids ambiguity by determining similar (correlated) terms only within relevant documents.
  - “Apple computer” →
    “Apple computer Macbook laptop”
Global vs. Local Analysis

• Global analysis requires intensive term correlation computation only once at system development time.

• Local analysis requires intensive term correlation computation for every query at run time (although number of terms and documents is less than in global analysis).

• But local analysis gives better results.
Global Analysis Refinements

• Only expand query with terms that are similar to all terms in the query.

\[
sim(k_i, Q) = \sum_{k_j \in Q} c_{ij}
\]

– “fruit” not added to “Apple computer” since it is far from “computer.”
– “fruit” added to “apple pie” since “fruit” close to both “apple” and “pie.”

• Use more sophisticated term weights (instead of just frequency) when computing term correlations.
Query Expansion Conclusions

- Expansion of queries with related terms can improve performance, particularly recall.
- However, must select similar terms very carefully to avoid problems, such as loss of precision.