
Recommender Systems

Collaborative Filtering &
Content-Based Recommending

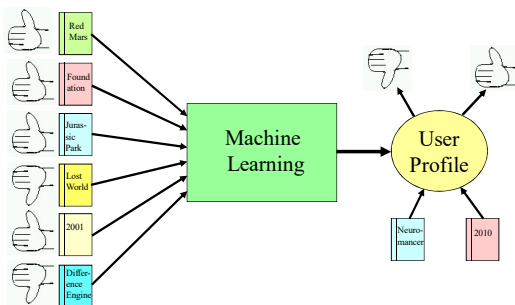
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Recommender Systems

- Systems for recommending items (e.g. books, movies, CD's, web pages, newsgroup messages) to users based on examples of their preferences.
- Many websites provide recommendations (e.g. Amazon, NetFlix, Pandora).
- Recommenders have been shown to substantially increase sales at on-line stores.
- There are two basic approaches to recommending:
 - Collaborative Filtering (a.k.a. social filtering)
 - Content-based

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Book Recommender



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Personalization

- Recommenders are instances of personalization software.
- Personalization concerns adapting to the individual needs, interests, and preferences of each user.
- Includes:
 - Recommending
 - Filtering
 - Predicting (e.g. form or calendar appt. completion)
- From a business perspective, it is viewed as part of Customer Relationship Management (CRM).

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Machine Learning and Personalization

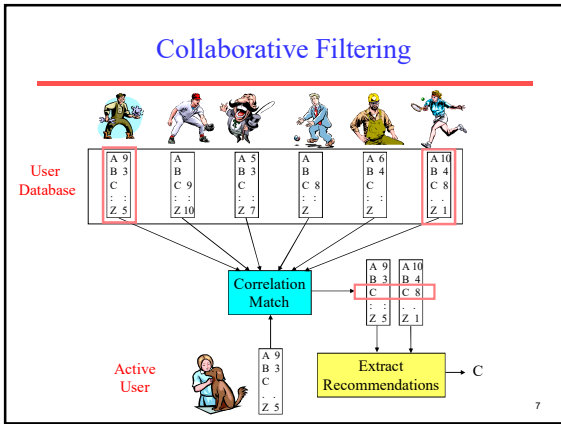
- Machine Learning can allow learning a *user model* or *profile* of a particular user based on:
 - Sample interaction
 - Rated examples
- This model or profile can then be used to:
 - Recommend items
 - Filter information
 - Predict behavior

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Collaborative Filtering

- Maintain a database of many users' ratings of a variety of items.
- For a given user, find other similar users whose ratings strongly correlate with the current user.
- Recommend items rated highly by these similar users, but not rated by the current user.
- Almost all existing commercial recommenders use this approach (e.g. Amazon).

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- ### Collaborative Filtering Method
- Weight all users with respect to similarity with the active user.
 - Select a subset of the users (*neighbors*) to use as predictors.
 - Normalize ratings and compute a prediction from a weighted combination of the selected neighbors' ratings.
 - Present items with highest predicted ratings as recommendations.

Similarity Weighting

- Typically use Pearson correlation coefficient between ratings for active user, a , and another user, u .

$$c_{a,u} = \frac{\text{covar}(r_a, r_u)}{\sigma_{r_a} \sigma_{r_u}}$$

r_a and r_u are the ratings vectors for the m items rated by **both** a and u

$r_{i,j}$ is user i 's rating for item j

Covariance and Standard Deviation

- Covariance:

$$\text{covar}(r_a, r_u) = \frac{\sum_{j=1}^m (r_{a,j} - \bar{r}_a)(r_{u,j} - \bar{r}_u)}{m}$$

$$\bar{r}_x = \frac{\sum_{j=1}^m r_{x,j}}{m}$$

- Standard Deviation:

$$\sigma_x = \sqrt{\frac{\sum_{j=1}^m (r_{x,j} - \bar{r}_x)^2}{m}}$$

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Significance Weighting

- Important not to trust correlations based on very few co-rated items.
- Include *significance weights*, $s_{a,u}$ based on number of co-rated items, m .

$$w_{a,u} = s_{a,u} c_{a,u}$$

$$s_{a,u} = \begin{cases} 1 & \text{if } m > 50 \\ \frac{m}{50} & \text{if } m \leq 50 \end{cases}$$

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Neighbor Selection

- For a given active user, a , select correlated users to serve as source of predictions.
- Standard approach is to use the most similar n users, u , based on similarity weights, $w_{a,u}$
- Alternate approach is to include all users whose similarity weight is above a given threshold.

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Rating Prediction

- Predict a rating, $p_{a,i}$, for each item i , for active user, a , by using the n selected neighbor users, $u \in \{1,2,\dots,n\}$.
- To account for users different ratings levels, base predictions on *differences* from a user's *average* rating.
- Weight users' ratings contribution by their similarity to the active user.

$$p_{a,i} = \bar{r}_a + \frac{\sum_{u=1}^n w_{a,u} (r_{u,i} - \bar{r}_u)}{\sum_{u=1}^n w_{a,u}}$$

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Problems with Collaborative Filtering

- **Cold Start:** There needs to be enough other users already in the system to find a match.
- **Sparsity:** If there are many items to be recommended, even if there are many users, the user/ratings matrix is sparse, and it is hard to find users that have rated the same items.
- **First Rater:** Cannot recommend an item that has not been previously rated.
 - New items
 - Esoteric items
- **Popularity Bias:** Cannot recommend items to someone with unique tastes.
 - Tends to recommend popular items.

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Content-Based Recommending

- Recommendations are based on information on the **content** of items rather than on other users' opinions.
- Uses a machine learning algorithm to induce a profile of the users preferences from examples based on a featural description of content.
- Some previous applications:
 - Newsweeder (Lang, 1995)
 - Syskill and Webert (Pazzani et al., 1996)

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Advantages of Content-Based Approach

- No need for data on other users.
 - No cold-start or sparsity problems.
- Able to recommend to users with unique tastes.
- Able to recommend new and unpopular items
 - No first-rater problem.
- Can provide explanations of recommended items by listing content-features that caused an item to be recommended.

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Disadvantages of Content-Based Method

- Requires content that can be encoded as meaningful features.
- Users' tastes must be represented as a learnable function of these content features.
- Unable to exploit quality judgments of other users.
 - Unless these are somehow included in the content features.

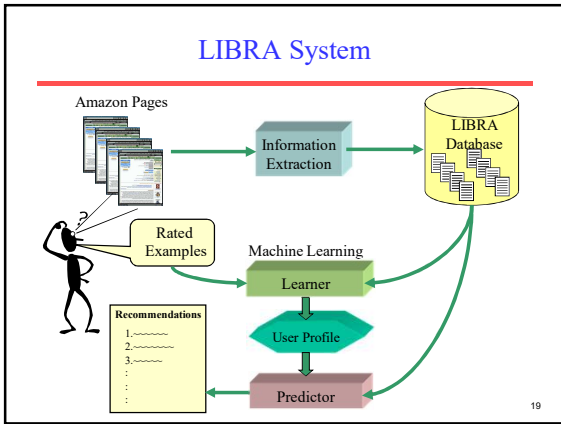
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LIBRA

Learning Intelligent Book Recommending Agent

- Content-based recommender for books using information about titles extracted from Amazon.
- Uses information extraction from the web to organize text into fields:
 - Author
 - Title
 - Editorial Reviews
 - Customer Comments
 - Subject terms
 - Related authors
 - Related titles

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Sample Amazon Page

Age of Spiritual Machines

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Sample Extracted Information

Title: <The Age of Spiritual Machines: When Computers Exceed Human Intelligence>
 Author: <Ray Kurzweil>
 Price: <11.96>
 Publication Date: <January 2000>
 ISBN: <0140282025>
 Related Titles: <Title: <Robot: Mere Machine or Transcendent Mind>
 Author: <Hans Moravec>>
 ...
 Reviews: <Author: <Amazon.com Reviews> Text: <How much do we humans...>>
 ...
 Comments: <Stars: <4> Author: <Stephen A. Haines> Text: <Kurzweil has ...>>
 ...
 Related Authors: <Hans P. Moravec> <K. Eric Drexler> ...
 Subjects: <Science/Mathematics> <Computers> <Artificial Intelligence> ...

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Libra Content Information

- Libra uses this extracted information to form “bags of words” for the following slots:
 - Author
 - Title
 - Description (reviews and comments)
 - Subjects
 - Related Titles
 - Related Authors

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Libra Overview

- User rates selected titles on a 1 to 10 scale.
- Libra uses a naïve Bayesian text-categorization algorithm to learn a profile from these rated examples.
 - Rating 6–10: Positive
 - Rating 1–5: Negative
- The learned profile is used to rank all other books as recommendations based on the computed posterior probability that they are positive.
- User can also provide explicit positive/negative keywords, which are used as priors to bias the role of these features in categorization.

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Bayesian Categorization in LIBRA

- Model is generalized to generate a **vector** of bags of words (one bag for each slot).
 - Instances of the same word in different slots are treated as separate features:
 - “Chrichton” in author vs. “Chrichton” in description
- Training examples are treated as *weighted* positive or negative examples when estimating conditional probability parameters:
 - An example with rating $1 \leq r \leq 10$ is given:
 - positive probability: $(r - 1)/9$
 - negative probability: $(10 - r)/9$

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Implementation

- Stopwords removed from all bags.
- A book's title and author are added to its own related title and related author slots.
- All probabilities are smoothed using Laplace estimation to account for small sample size.
- Lisp implementation is quite efficient:
 - Training: 20 exs in 0.4 secs, 840 exs in 11.5 secs
 - Test: 200 books per second

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Explanations of Profiles and Recommendations

- Feature strength of word w_k appearing in a slot s_j :

$$\text{strength}(w_k, s_j) = \log \frac{P(w_k | \text{positive}, s_j)}{P(w_k | \text{negative}, s_j)}$$

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Libra Demo

<http://www.cs.utexas.edu/users/libra>

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Experimental Data

- Amazon searches were used to find books in various genres.
- Titles that have at least one review or comment were kept.
- Data sets:
 - Literature fiction: 3,061 titles
 - Mystery: 7,285 titles
 - Science: 3,813 titles
 - Science Fiction: 3,813 titles

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Rated Data

- 4 users rated random examples within a genre by reviewing the Amazon pages about the title:
 - LIT1 936 titles
 - LIT2 935 titles
 - MYST 500 titles
 - SCI 500 titles
 - SF 500 titles

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Experimental Method

- 10-fold cross-validation to generate learning curves.
- Measured several metrics on independent test data:
 - Precision at top 3: % of the top 3 that are positive
 - Rating of top 3: Average rating assigned to top 3
 - Rank Correlation: Spearman's r_s between system's and user's complete rankings.
- Test ablation of related author and related title slots (LIBRA-NR).
 - Test influence of information generated by Amazon's collaborative approach.

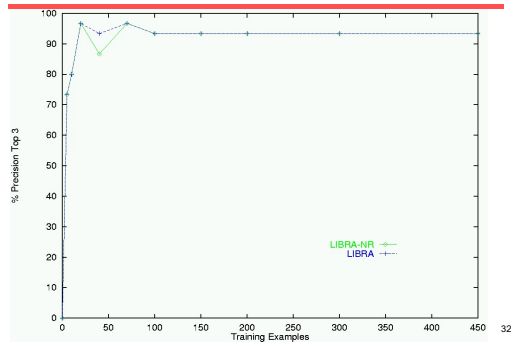
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Experimental Result Summary

- Precision at top 3 is fairly consistently in the 90's% after only 20 examples.
- Rating of top 3 is fairly consistently above 8 after only 20 examples.
- All results are always significantly better than random chance after only 5 examples.
- Rank correlation is generally above 0.3 (moderate) after only 10 examples.
- Rank correlation is generally above 0.6 (high) after 40 examples.

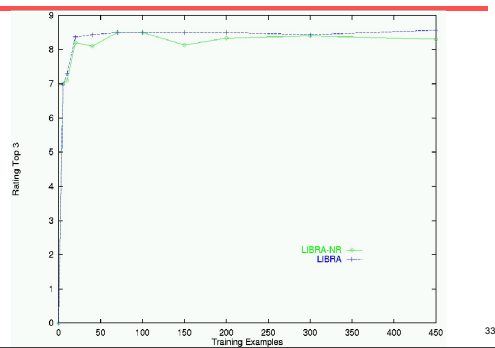
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Precision at Top 3 for Science

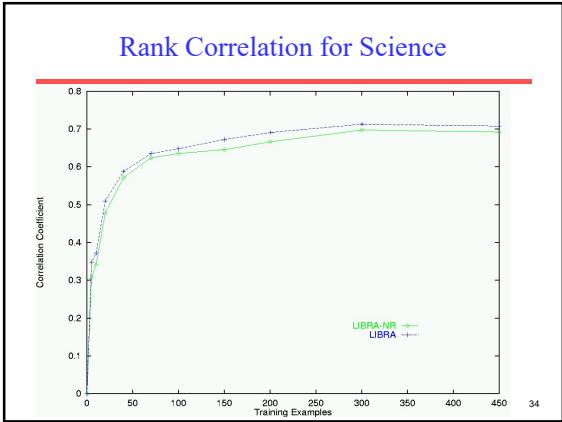


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Rating of Top 3 for Science



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- ### User Studies
- Subjects asked to use Libra and get recommendations.
 - Encouraged several rounds of feedback.
 - Rated all books in final list of recommendations.
 - Selected two books for purchase.
 - Returned reviews after reading selections.
 - Completed questionnaire about the system.

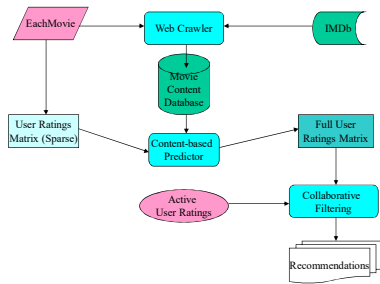
- ### Combining Content and Collaboration
- Content-based and collaborative methods have complementary strengths and weaknesses.
 - Combine methods to obtain the best of both.
 - Various hybrid approaches:
 - Apply both methods and combine recommendations.
 - Use collaborative data as content.
 - Use content-based predictor as another collaborator.
 - Use content-based predictor to complete collaborative data.

Movie Domain

- *EachMovie* Dataset [Compaq Research Labs]
 - Contains user ratings for movies on a 0–5 scale.
 - 72,916 users (avg. 39 ratings each).
 - 1,628 movies.
 - Sparse user-ratings matrix – (2.6% full).
- Crawled Internet Movie Database (*IMDb*)
 - Extracted content for titles in *EachMovie*.
- Basic movie information:
 - Title, Director, Cast, Genre, etc.
- Popular opinions:
 - User comments, Newspaper and Newsgroup reviews, etc.

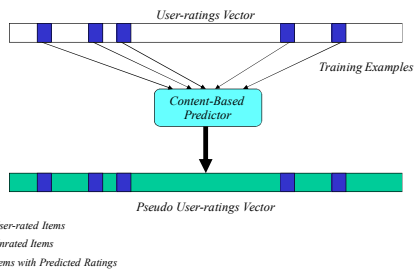
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Content-Boosted Collaborative Filtering



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Content-Boosted CF - I



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Content-Boosted CF - II



- Compute pseudo user ratings matrix
 - Full matrix – approximates actual full user ratings matrix
- Perform CF
 - Using Pearson corr. between pseudo user-rating vectors

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Experimental Method

- Used subset of *EachMovie* (7,893 users; 299,997 ratings)
- Test set: 10% of the users selected at random.
 - Test users that rated at least 40 movies.
 - Train on the remainder sets.
- Hold-out set: 25% items for each test user.
 - Predict rating of each item in the hold-out set.
- Compared CBCF to other prediction approaches:
 - Pure CF
 - Pure Content-based
 - Naive hybrid (averages CF and content-based predictions)

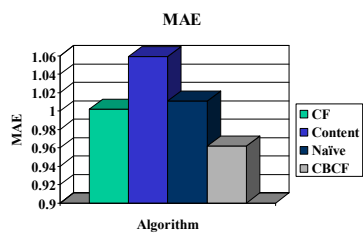
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Metrics

- Mean Absolute Error (MAE)
 - Compares numerical predictions with user ratings
- ROC sensitivity [Herlocker 99]
 - How well predictions help users select *high-quality* items
 - Ratings ≥ 4 considered “good”; < 4 considered “bad”
- Paired t-test for statistical significance

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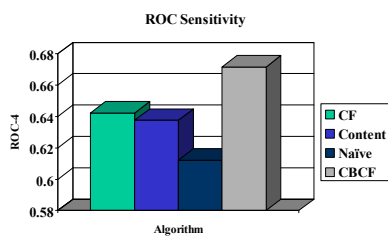
Results - I



CBCF is significantly better (4% over CF) at $p < 0.001$

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Results - II



CBCF outperforms rest (5% improvement over CF)

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Active Learning (Sample Section, Learning with Queries)

- Used to reduce the number of training examples required.
- System requests ratings for specific items from which it would learn the most.
- Several existing methods:
 - Uncertainty sampling
 - Committee-based sampling

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Semi-Supervised Learning (Weakly Supervised, Bootstrapping)

- Use wealth of unlabeled examples to aid learning from a small amount of labeled data.
- Several recent methods developed:
 - Semi-supervised EM (Expectation Maximization)
 - Co-training
 - Transductive SVM's

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Conclusions

- Recommending and personalization are important approaches to combating information over-load.
- Machine Learning is an important part of systems for these tasks.
- Collaborative filtering has problems.
- Content-based methods address these problems (but have problems of their own).
- Integrating both is best.

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