



Lecture 21: Recommendation Systems

COMP90049
Introduction to Machine Learning
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"The Web, they say, is leaving the era of search and entering one of discovery.

What's the difference? Search is what you do when you're looking for something.

Discovery is when something wonderful that you didn't know existed, or didn't know how to ask for, finds you."

Jeffrey O'Brien, Fortune Magazine, The race to create a 'smart' Google

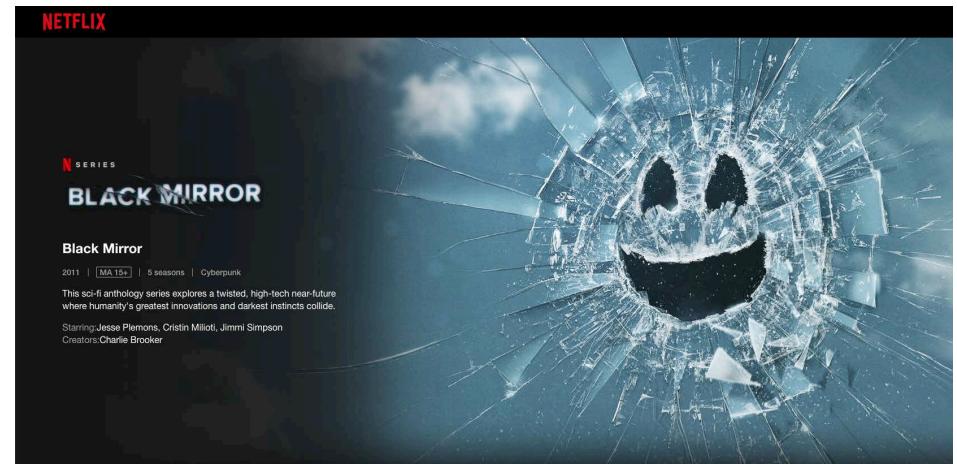
Information overload

- Consumers are overloaded with products and services
- We only need and like to consume a few



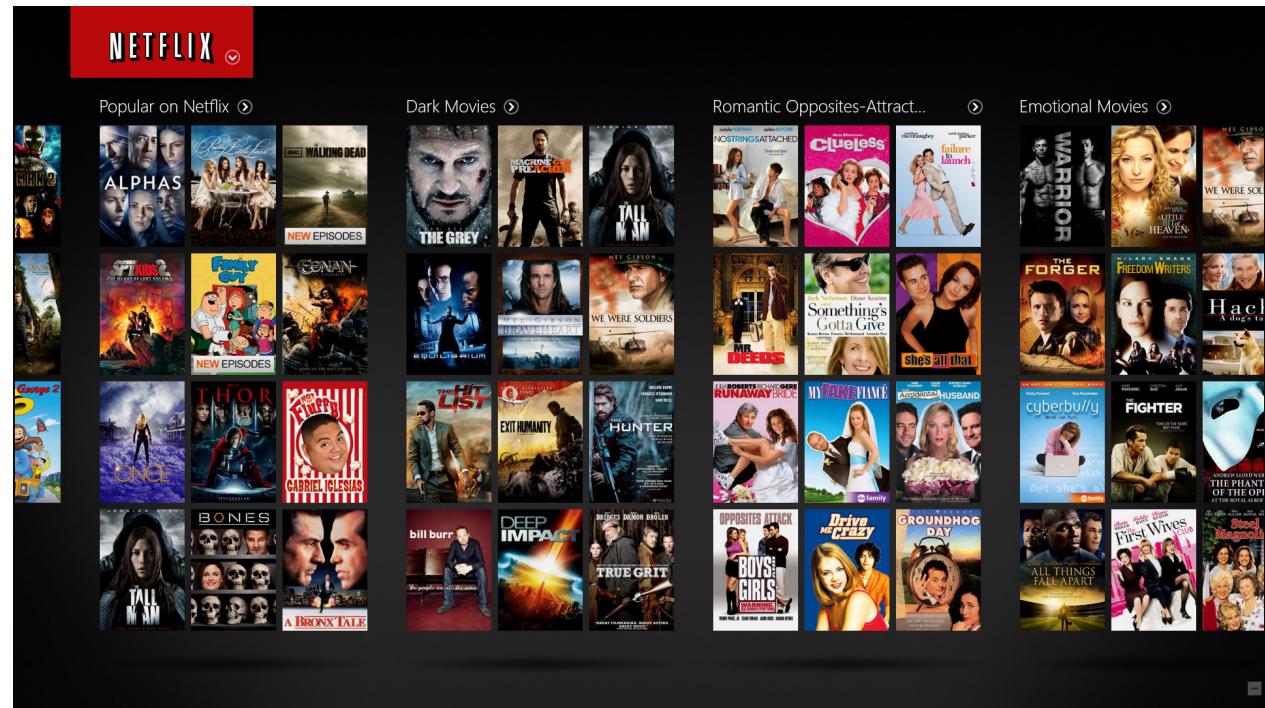
Search vs. Recommendation

- Search: when users know what to look for



Search vs. Recommendation

- Recommendation:
 - Relevant items that users don't know
 - how to look for
 - Its existence



Examples

- Movie recommendation (Netflix)
- Related product recommendation (Amazon)
- Social recommendation (Facebook, LinkedIn)
- News content recommendation (Yahoo, Google News)

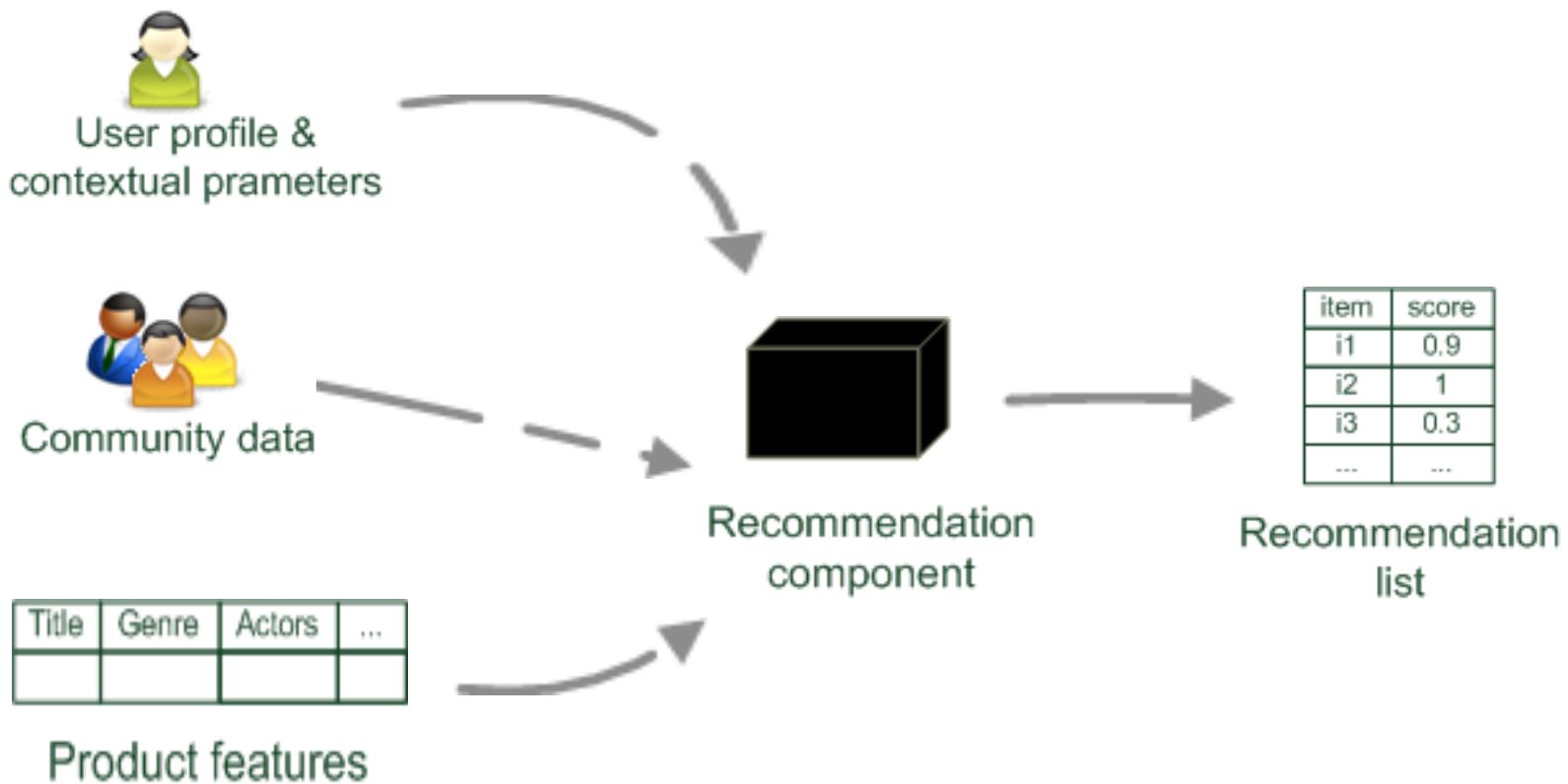


The value of recommendations

- Netflix: 2/3 of the movies watched are recommended
- Google News: recommendations generate 38% more click-throughs
- Amazon: 35% sales from recommendations

Problem Formulation

- Estimate a utility function to predict how a user will like an item



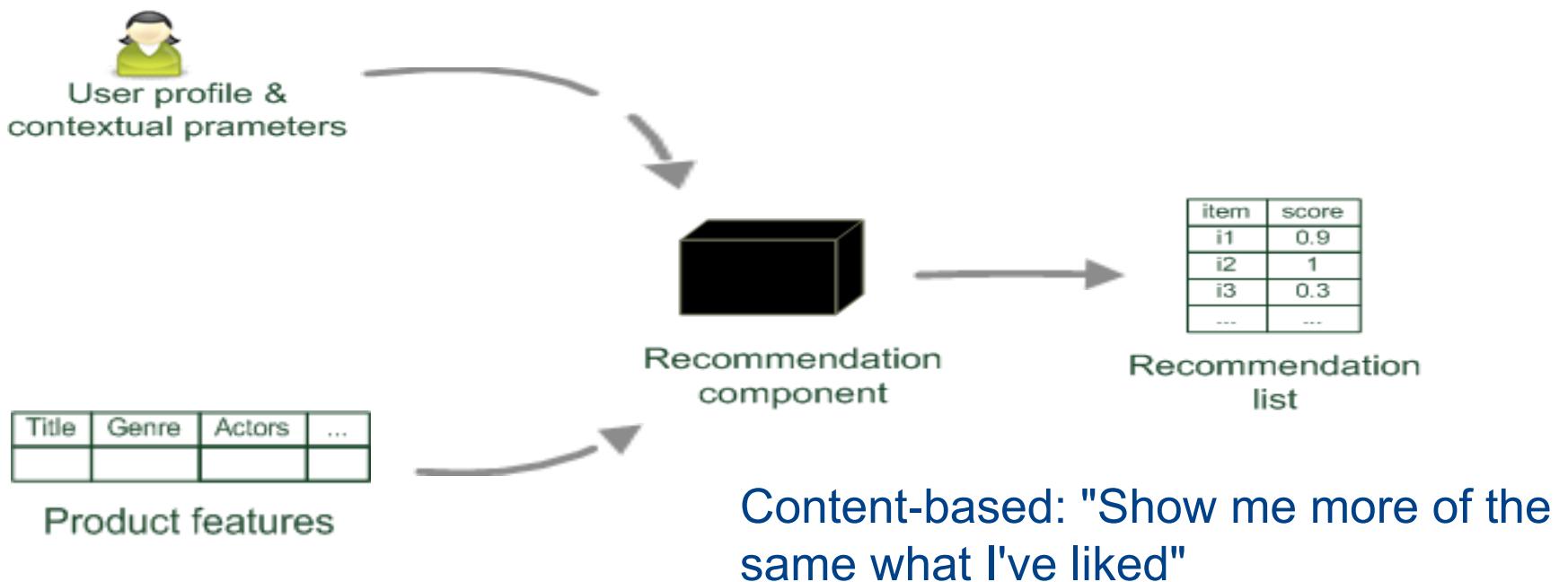
Operational goals

- **Relevance:** Users are more likely to consume items they find *Relevant*
- **Novelty:** Recommender systems are truly helpful when the recommended item is something that the user has *not seen in the past*
- **Serendipity:** the items recommended are somewhat *unexpected*
 - Recommend a new Indian restaurant opens in a neighbourhood to a user who normally eats Indian food is novel but not necessarily serendipitous.
 - Recommend Ethiopian food, and it was unknown to the user that such food might appeal to her, then the recommendation is serendipitous.
- **Increasing recommendation diversity:** Diversity has the benefit of ensuring that the user does not get bored by repeated recommendation of similar items

- Content-based recommendation
- Collaborative filtering
 - User-based CF
 - Item-based CF

1. Content-based recommendation

- Recommendations are based on the information of the **content** of items
- Uses a machine learning algorithm to induce a profile of the users preferences from examples based on a featural description of content.



1. Content-based recommendation

- **What do we need:**
 - Some information about the available items such as the genre ("content")
 - Some sort of *user profile* describing what the user likes (the preferences): items users liked in the past or explicit interests that he/she defined
- **The task:**
 - Learn user preferences
 - Locate/recommend items that are "similar" to the user preferences

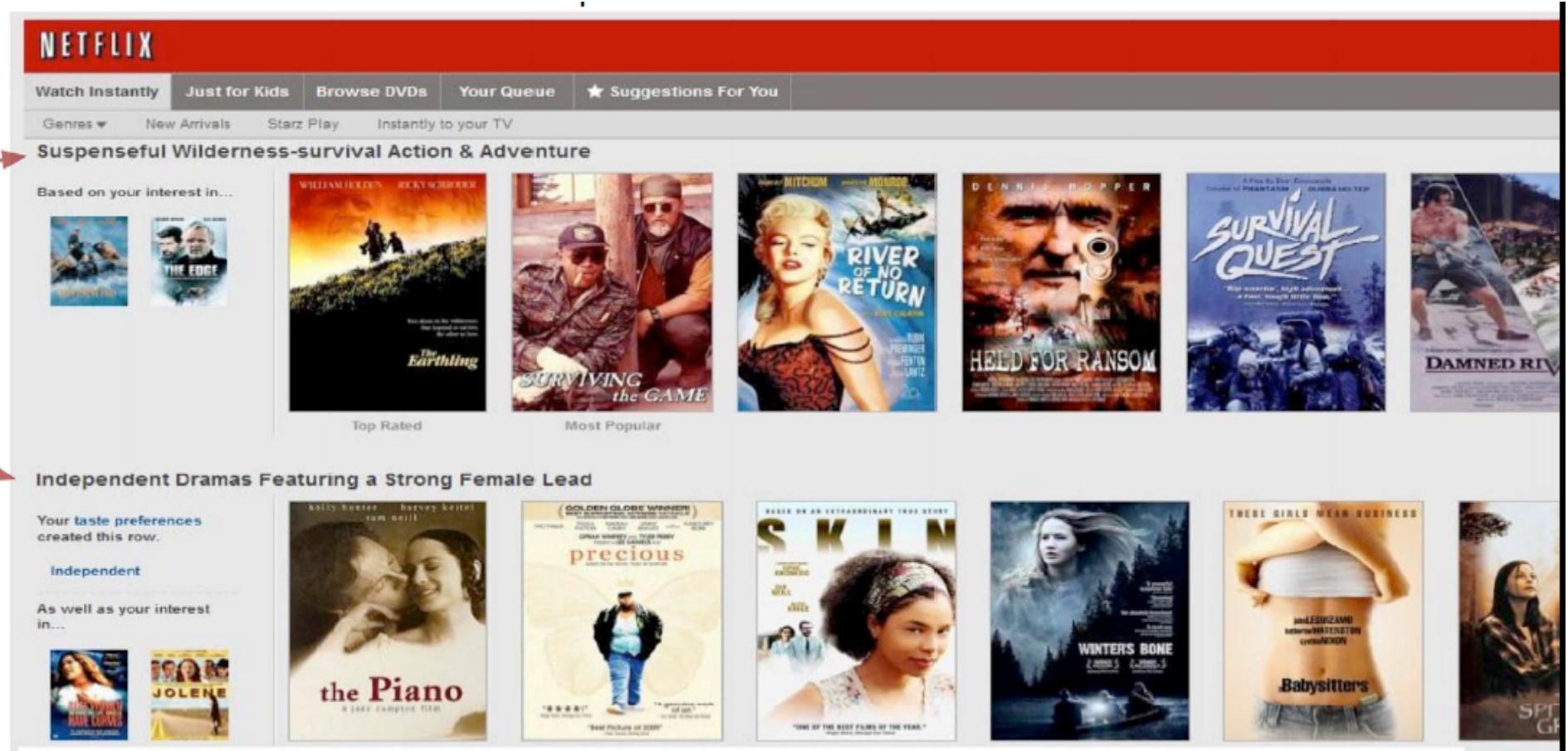
What is the "content"?

- Explicit attributes or characteristics, e.g., for a movie:
 - Genre: Action / adventure
 - Actors: Bruce Willis
 - Year: 1995
- Textual content, e.g., for a book:
 - Title,
 - Description,
 - Table of content



1. Content-Based Recommendations

- The recommended items for a user are based on the *profile* built up by analysing the content of the items the user has liked in the past



The screenshot shows the Netflix homepage with a focus on content-based recommendations. At the top, there's a navigation bar with links like "Watch Instantly", "Just for Kids", "Browse DVDs", "Your Queue", and "Suggestions For You". Below the navigation, there are sections for "Genres", "New Arrivals", "Starz Play", and "Instantly to your TV".

Suspenseful Wilderness-survival Action & Adventure

An arrow points to this section, which is titled "Based on your interest in...". It features movie posters for "The Mountain", "The Edge", "The Earthling", "SURVIVING the GAME", "RIVER OF NO RETURN", "HELD FOR RANSOM", "SURVIVAL QUEST", and "DAMNED RIV". Below these, there are "Top Rated" and "Most Popular" filters.

Independent Dramas Featuring a Strong Female Lead

An arrow points to this section, which is titled "Your taste preferences created this row.". It features movie posters for "the Piano", "precious", "SKIN", "WINTERS BONE", "Babysitters", and "SPF GIRL". To the left of this section, there's a sidebar with text about "Independent" and "As well as your interest in..." followed by small movie posters for "BROKEN", "JOLENE", and "SWEET HOME ALABAMA".

1. Content-Based Recommendations

- Suitable for text-based products (web pages, books)
- Items are “described” by their features (e.g. keywords)
- Users are described by the keywords in the items they bought
- Recommendations based on the match between the content (item keywords) and user keywords

Item profiles

- $\text{ItemProfile}(s)$:= profile of item s

$$w_s = (w_{1s}, \dots, w_{ks})$$

weight w_{is} measures the 'Importance' (or "informativeness") of word k_i in item s

- *term frequency/inverse document frequency (TF-IDF)* is a popular weighting technique in IR

User profiles

- $UserProfile(c)$:= profile of user c
$$w_c = (w_{1c}, \dots, w_{kc})$$
- a vector of weights, where w_{ic} denotes the importance of keyword k_i to user c
- profiles are obtained by analysing the content of the previous items using keyword analysis techniques

- Utility function $u(c,s)$ usually represented by some scoring heuristic defined in terms of vectors, such as the cosine similarity measure.

$$u(c, s) = \cos(w_c, w_s) = \frac{w_c \times w_s}{\|w_s\| \|w_c\|} = \frac{\sum_{i=1}^K w_{ic} w_{is}}{\sum_{i=1}^K w_{ic}^2 \sum_{i=1}^K w_{is}^2}$$

Example: How to compute Recommendations of books based only on their title?

- A customer buys the book: *Building data mining applications for CRM*
- 7 Books are possible candidates for a recommendation:
 - *Accelerating Customer Relationships: Using CRM and Relationship Technologies*
 - *Mastering Data Mining: The Art and Science of Customer Relationship Management*
 - *Data Mining Your Website*
 - *Introduction to marketing*
 - *Consumer behaviour*
 - *Marketing research, a handbook*
 - *Customer knowledge management*

Frequency count

COUNT	a	Accelerating	and	applications	art	behavior	Building	Consumer	CRM	customer	data	for	Handbook	Introduction	Knowledge	Management	Marketing	Mastering	mining	of	relationship	Research	science	technology	the	to	using	website	your
Building data mining applications for CRM				1			1		1		1							1											
Accelerating customer relationships: using CRM and relationship technologies	1	1							1	1										2			1		1				
Mastering Data Mining: the art and science of Customer Relationship Management			1	1						1	1				1		1	1	1	1	1	1	1						
Data Mining your website											1								1							1	1		
Introduction to Marketing														1			1										1		
Consumer behavior					1	1																							
Marketing Research: a Handbook	1													1			1					1							
Customer Knowledge Management										1					1	1													

TFIDF Normed Vectors	a	Accelerating	and	applications	art	behavior	Building	Consumer	CRM	customer	data	for	Handbook	Introduction	Knowledge	Management	Marketing	Mastering	mining	of	relationship	Research	science	technology	the	to	using	website	your
Building data mining applications for CRM			0.502			0.502		0.344		0.251	0.502								0.251										
Accelerating customer relationships: using CRM and relationship technologies		0.432	0.296						0.296	0.216										0.468		0.432		0.432					
Mastering Data Mining: the art and science of Customer Relationship Management		0.256	0.374						0.187	0.187						0.256	0.374	0.187	0.374	0.256	0.374	0.374							
Data Mining your website										0.316									0.316							0.632	0.632		
Introduction to Marketing														0.636		0.436									0.636				
Consumer behavior				0.707	0.707																								
Marketing Research: a Handbook	0.537												0.537			0.368				0.537									
Customer Knowledge Management										0.381					0.736	0.522													

Recommendation

- **Computes distances** between the book that the user has bought & all others
- Recommends the **closest** books:
 - #1: Data Mining Your Website
 - #2: Accelerating Customer Relationships: Using CRM and Relationship Technologies
 - #3: Mastering Data Mining: The Art and Science of Customer Relationship Management

- Advantages:
 - Can recommend new items
- Disadvantages
 - Feature extraction can be difficult (music, movies)

2. Collaborative Filtering

The task of predicting user preferences on new items (**filtering**) by collecting taste information from many users (**collaborative**).

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- **User-based models:** Similar users have similar ratings on the same item.
 - If Alice and Bob have rated movies in a similar way in the past, then one can use Alice's observed ratings on the movie *Terminator* to predict Bob's unobserved ratings on this movie.
- **Item-based models:** Similar items are rated in a similar way by the same user
 - Bob's ratings on similar science fiction movies like *Alien* and *Predator* can be used to predict his rating on *Terminator*.

Problem setting

Each user has expressed an opinion for some items:

- **Explicit opinion:** rating score
- **Implicit:** purchase records or listen to tracks



Problem setting

Target (or active) user for whom the CF recommendation task is performed.

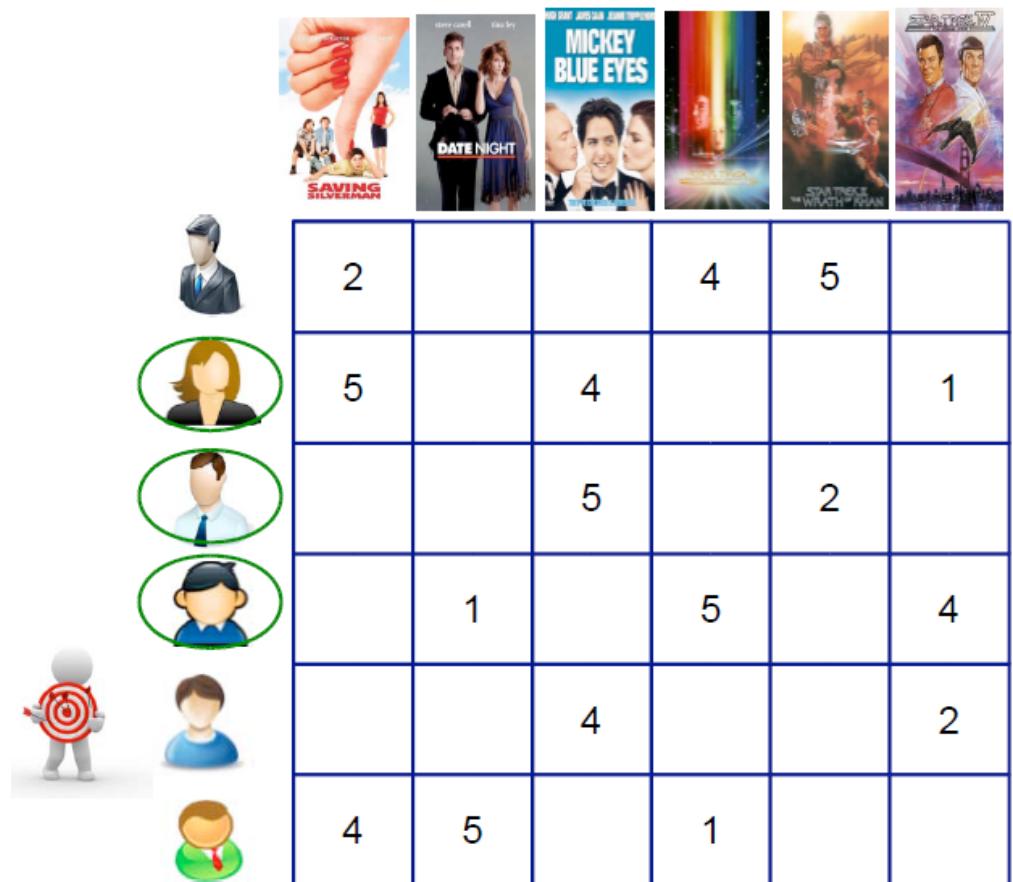


User based collaborative filtering

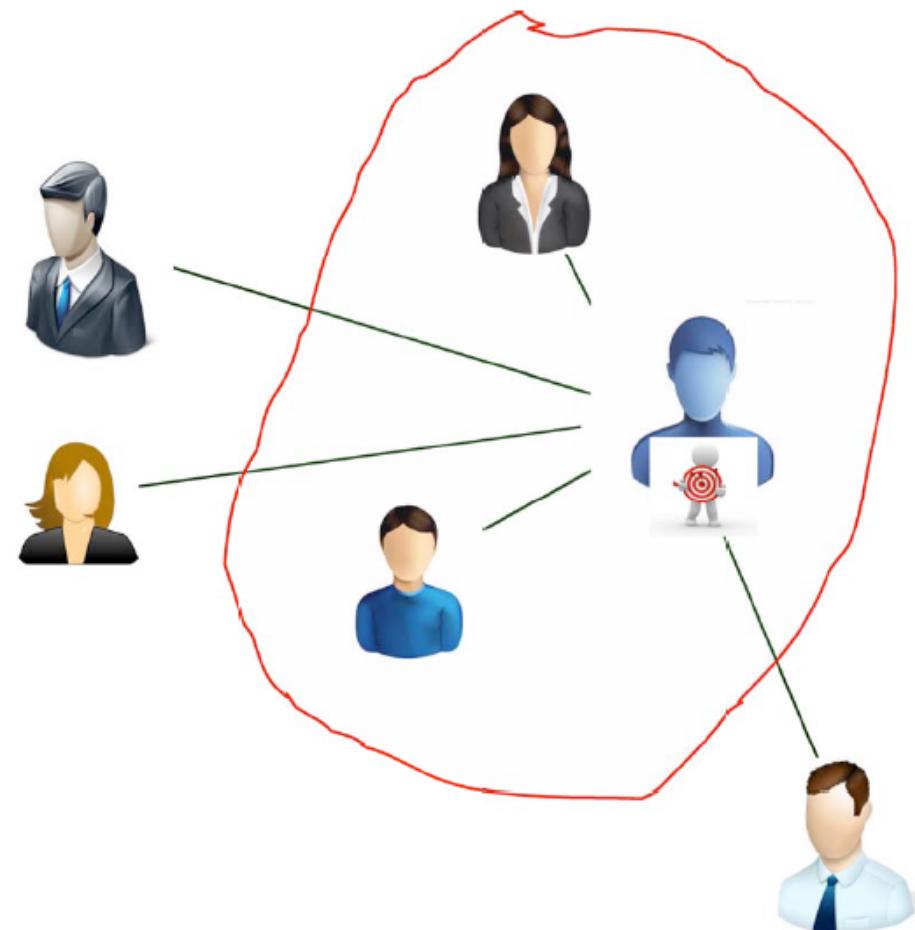
1. Identify set of items rated by the target user



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2. **Identify** which other **users** rated 1+ items in this set (neighborhood formation)



1. **Identify** set of **items** rated by the target user
2. **Identify** which other **users** rated 1+ items in this set (*neighborhood formation*)
3. **Compute** how **similar** each neighbor is to the target user (*similarity function*)
4. **Select k most similar** neighbors



Computing user similarity

- Rating matrix R : $r_{u,k}$ - rating by user u for item k
- Pearson correlation between users u & v

$$\text{Sim}(u, v) = \text{Pearson}(u, v) = \frac{\sum_{k \in I_u \cap I_v} (r_{uk} - \mu_u) \cdot (r_{vk} - \mu_v)}{\sqrt{\sum_{k \in I_u \cap I_v} (r_{uk} - \mu_u)^2} \cdot \sqrt{\sum_{k \in I_u \cap I_v} (r_{vk} - \mu_v)^2}}$$

$$\mu_u = \frac{\sum_{k \in I_u} r_{uk}}{|I_u|}$$

Mean rating of user u

$$I_u$$

Set of items rated by user u

Strictly speaking, the traditional definition of $\text{Pearson}(u, v)$ mandates that the values of μ_u and μ_v should be computed *only* over the items that are rated *both* by users u and v .

5. Predict ratings for the target user's unrated items (prediction function)

Rating of user u for item j:

$$\hat{r}_{uj} = \mu_u + \frac{\sum_{v \in P_u(j)} \text{Sim}(u, v) \cdot (r_{vj} - \mu_v)}{\sum_{v \in P_u(j)} |\text{Sim}(u, v)|}$$

$P_u(j)$ Set of nearest users of user u who rated item j

6. Recommend to the user the top N products based on predicted rating

Example: user-based CF

- Predict r_{31} and r_{36}

Item-Id \Rightarrow	1	2	3	4	5	6	Mean Rating	Cosine($i, 3$) (user-user)	Pearson($i, 3$) (user-user)
User-Id \Downarrow									
1	7	6	7	4	5	4	5.5	0.956	0.894
2	6	7	?	4	3	4	4.8	0.981	0.939
3	?	3	3	1	1	?	2	1.0	1.0
4	1	2	2	3	3	4	2.5	0.789	-1.0
5	1	?	1	2	3	3	2	0.645	-0.817

$$\text{Cosine}(1, 3) = \frac{6 * 3 + 7 * 3 + 4 * 1 + 5 * 1}{\sqrt{6^2 + 7^2 + 4^2 + 5^2} \cdot \sqrt{3^2 + 3^2 + 1^2 + 1^2}} = 0.956$$

$$\begin{aligned} \text{Pearson}(1, 3) &= \\ &= \frac{(6 - 5.5) * (3 - 2) + (7 - 5.5) * (3 - 2) + (4 - 5.5) * (1 - 2) + (5 - 5.5) * (1 - 2)}{\sqrt{1.5^2 + 1.5^2 + (-1.5)^2 + (-0.5)^2} \cdot \sqrt{1^2 + 1^2 + (-1)^2 + (-1)^2}} \\ &= 0.894 \end{aligned}$$

Prediction

$$\hat{r}_{31} = 2 + \frac{1.5 * 0.894 + 1.2 * 0.939}{0.894 + 0.939} \approx 3.35$$

$$\hat{r}_{36} = 2 + \frac{-1.5 * 0.894 - 0.8 * 0.939}{0.894 + 0.939} \approx 0.86$$

The basic steps:

- Identify set of users who rated the **target item**
- Identify which other items (**neighbours**) were rated
- Compute **similarity** between each neighbour and target item (*similarity function*)
- Select **k** most similar neighbours
- Predict ratings for the target item (*prediction function*)

Item similarity



Similarity measure

- Compute the similarity between columns (items)
- Pearson and cosine similarity can be used
- Adjusted cosine measure yields superior results

$$\text{AdjustedCosine}(i, j) = \frac{\sum_{u \in U_i \cap U_j} s_{ui} \cdot s_{uj}}{\sqrt{\sum_{u \in U_i \cap U_j} s_{ui}^2} \cdot \sqrt{\sum_{u \in U_i \cap U_j} s_{uj}^2}}$$

$$s_{uj} = r_{uj} - \mu_u$$

Mean-centred rating

Example of item based CF

- Mean-centred voting matrix

Item-Id ⇒	1	2	3	4	5	6
User-Id ↓						
1	1.5	0.5	1.5	-1.5	-0.5	-1.5
2	1.2	2.2	?	-0.8	-1.8	-0.8
3	?	1	1	-1	-1	?
4	-1.5	-0.5	-0.5	0.5	0.5	1.5
5	-1	?	-1	0	1	1
Cosine(1, j) (item-item)	1	0.735	0.912	-0.848	-0.813	-0.990
Cosine(6, j) (item-item)	-0.990	-0.622	-0.912	0.829	0.730	1

$$\text{AdjustedCosine}(1, 3) = \frac{1.5 * 1.5 + (-1.5) * (-0.5) + (-1) * (-1)}{\sqrt{1.5^2 + (-1.5)^2 + (-1)^2} \cdot \sqrt{1.5^2 + (-0.5)^2 + (-1)^2}} = 0.912$$

Item based prediction

Item-Id \Rightarrow	1	2	3	4	5	6
User-Id \Downarrow						
1	1.5	0.5	1.5	-1.5	-0.5	-1.5
2	1.2	2.2	?	-0.8	-1.8	-0.8
3	?	1	1	-1	-1	?
4	-1.5	-0.5	-0.5	0.5	0.5	1.5
5	-1	?	-1	0	1	1
Cosine(1, j) (item-item)	1	0.735	0.912	-0.848	-0.813	-0.990
Cosine(6, j) (item-item)	-0.990	-0.622	-0.912	0.829	0.730	1

$$\hat{r}_{ut} = \frac{\sum_{j \in Q_t(u)} \text{AdjustedCosine}(j, t) \cdot r_{uj}}{\sum_{j \in Q_t(u)} |\text{AdjustedCosine}(j, t)|}$$

$$\begin{aligned}\hat{r}_{31} &= \frac{3 * 0.735 + 3 * 0.912}{0.735 + 0.912} = 3 \\ \hat{r}_{36} &= \frac{1 * 0.829 + 1 * 0.730}{0.829 + 0.730} = 1\end{aligned}$$

Challenges

- Many items to choose from
- Very few recommendations to propose
- Few data per user
- No data for new user
- Very large datasets

- Bottleneck: similarity computation

Time complexity, highly time consuming with millions of users and items in the database
- Two step process:
 - Offline components/model
Similarity computation precomputed and stored
 - Online component: prediction on process

References

- Recommendation systems – The text book
(chapter 1 & 2)