

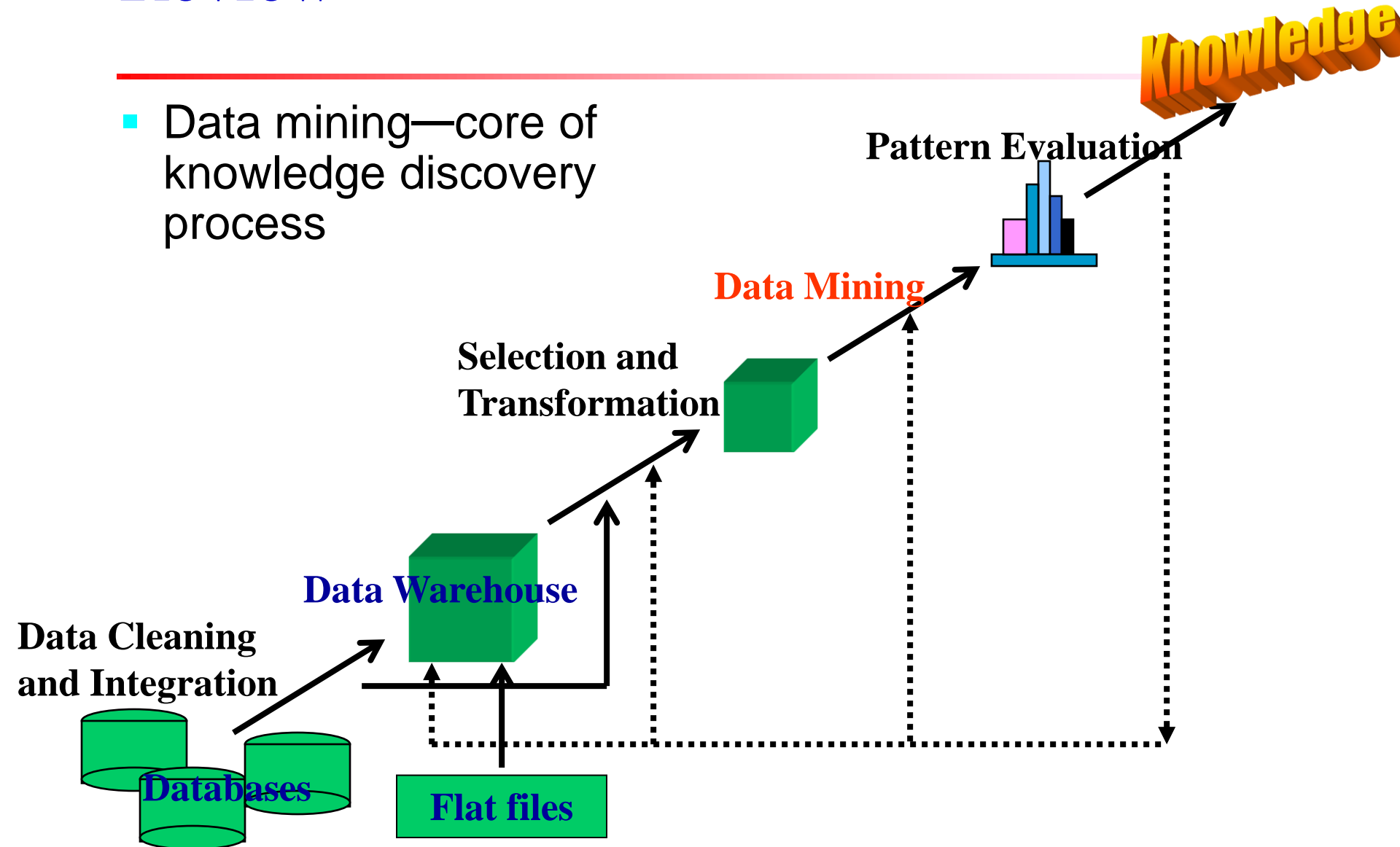
Data Mining

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Review

- Data mining—core of knowledge discovery process



Outline

- What is Recommender System?
- Recommendation Algorithms
- Evaluation of Recommender Systems

Motivation

- Which digital camera should I buy?
- Where should I spend my holiday?
- Which movie should I see?
- Whom should I follow?
- Where should I find interesting news article?

Motivation

- There are many choices
 - There are no obvious advantages among them
 - We do not have enough resources to check all options (*information overload*)
 - We do not have enough knowledge and experience to choose
- Solution
- ***Recommendation: automatically come up with a short list of items that fits user's interests!***

Examples

Book recommendation in Amazon

Amazon.com: Networks: An Introduction / Mark Newman / dp/0199206631/ref=sim_b_4

Start reading **Networks: An Introduction on your Kindle in under a minute.**
 Don't have a Kindle? [Get your Kindle here](#), or download a **FREE Kindle Reading App**.

Textbook Trade-In
 Sell Back Your Copy for \$47.10
 Receive a \$47.10 Amazon.com Gift Card for selling back this book. See other eligible items in our [Book Trade-In Program - Restrictions Apply](#).

Used Price \$51.03
 Buyback Price \$47.10
 Price after Buyback \$3.93

Here Buying Choices
 26 used & new from \$51.03

Sell your Copy
 Sell on Amazon Listings start at \$51.03
 Get a \$47.10 Amazon Gift Card
 Trade In

Share [Facebook](#) [Twitter](#) [Email](#)

Frequently Bought Together

Price For All Three: \$120.68
[Add all three to Cart](#) [Add all three to Wish List](#)
[Show availability and shipping details](#)

- ✓ **This Item:** Networks: An Introduction by Mark Newman Hardcover: \$69.40
- ✓ Networks, Crowds, and Markets: Reasoning About a Highly Connected World by David Easley Hardcover: \$41.47
- ✓ Simply Complexity: A Clear Guide to Complexity Theory by Neil Johnson Paperback: \$9.81

Customers Who Bought This Item Also Bought

Networks, Crowds, and Markets: Reasoning About a... by David Easley
 \$41.47 ★★★★★ (3)

Dynamical Processes on Complex Networks by Allen Barabási
 \$64.18 ★★★★★ (3)

Simply Complexity: A Clear Guide to Complexity Theory... by Neil Johnson
 \$9.81 ★★★★★ (6)

Social Network Analysis: Methods and Applications by Stanley Wasserman
 \$44.52 ★★★★★ (10)

Networks of the Brain by Olaf Sporns
 \$32.28 ★★★★★ (4)

Editorial Reviews

Product Recommendation in ebay

ebay | Electronics, Cars, etc. | www.ebay.com/?_ipact=false

[View recent items](#) [I need way to pay and get paid.](#) [Shop now](#) [Your eBay extras](#)

[Show activities]

Recommendations for you

<p>Dr. Seuss's Second Beginner Book Collection \$1.00 See suggestions</p>	<p>Dr. Seuss's Beginner Book Classics Fox in Socks \$1.99 See suggestions</p>	<p>Ten Apples Up On Top by Dr. Seuss (1991, Harbinger) \$1.99 See suggestions</p>	<p>Dr. Seuss's ABC by Dr. Seuss (1963, Harbinger) \$1.50 See suggestions</p>	<p>The Big Green Book of Beginner Books \$1.55 See suggestions</p>	<p>The Cat in the Hat by Dr. Seuss (1957, Harbinger) \$0.99 See suggestions</p>
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Popular on eBay

eBay stories	
<p>1x 3800mAh 18650 rechargeable battery \$14.95 See suggestions</p>	<p>AAA 1800mAh RECHARGEABLE BATTERY X4 \$2.13 See suggestion</p>
<p>3000mAh 9V Rechargeable Battery \$2.80 See suggestion</p>	<p>8x 3000mAh AAA Rechargeable Batteries \$1.99 See suggestion</p>

eBay's hidden gem: eBAY Radio

Updated Tue, Nov 20, 2013

Want to get the inside scoop on selling on ebay? Then join host Jim Griffin on eBay Radio every Tuesday and Thursday, broadcasting live from the eBay studios. Read about how this show came into being. Continue reading —

[See all stories](#)

Support Toys for Tots at the Give-A-Toy Store

[Visit now](#)

Buy direct on eBay

New! eBay Go Together
Easy way to go to events with friends

[Check it out](#)

BYE Registration
SELL Sell listing
Ebay COMPANIES
ABOUT EBAY
COMMUNITY Community

Video clip recommendation in YouTube

YouTube - Ariz. Wildfire to

www.youtube.com/watch?v=JRSJHwP9uU&feature=related

Ariz. Wildfire Near Flagstaff at 10,000 Acres

fa12grace 1,023 videos Subscribe



0:28 / 0:50

Like Add to Share

Updated by fa12grace on Jun 22, 2010

AssociatedPress — Arizona authorities say a wildfire near Flagstaff has

Show more

Uploader Comments (fa12grace)

The "station fire" in California was in my home town. They evacuated my street further north in the hills. I spent a week just gazing at it with friends... powerful stuff that mother nature.

1 subscriber 1 user av

510 views

15 likes, 0 dislikes

Suggestions

- Schultz Fire - Flagstaff, AZ - June 20, 2010 by BaktVenus 7,231 views
- Flagstaff Father's Day Fire #2 - Schuz Wildfire by GoalBusters 8,327 views
- Winds Driving Fire in Ariz., Homes Threatened by AssociatedPress 1,491 views
- Arizona wildfires rage on by NewsOnABC 141 views
- Arizona wildfires third largest in state history by CBSNewsOnline 815 views
- Arizona Governor Tours Growing Wildfire Near NM by AssociatedPress 9,118 views
- Arizona wildfire barely contained by WMAZArizNews 59 views
- Evangelism in Chicago, Ill.

Restaurant Recommendation in Yelp

[illegible]

Recommender Systems

- Idea: Use historical data such as the user's past preferences or similar users' past preferences to predict future likes
- Basic assumption
 - Users' preferences are likely to remain stable, and change smoothly over time
 - Users with similar tastes have similar ratings for an item
- By watching the past users' or groups' preferences, try to predict their future likes
 - Then we can recommend items of interest to them

Recommender Systems

- Formally, a recommender system takes a set of users U and a set of items I and *learns a function f* such that:

$$f : U \times I \rightarrow \mathbb{R}$$

Recommendation vs. Search

- One way to get answers is using search engines
- Search engines find results that match the query provided by the user
- The results are generally provided as a list ordered with respect to the relevance of the item to the given query
- Consider the query “best 2014 movie to watch”
 - The same results for an 8 year old and an adult

Search engines' results are not customized!

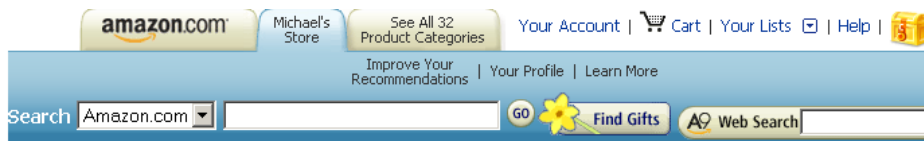
Outline

- What is Recommender System?
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- Evaluation of Recommender Systems

Content-based Methods

- Content-based methods are based on the fact that **a user's interest should match the description of the items** that she should be recommended
- The more similar the item's description to that of the user's interest, the more likely the user finds the item's recommendation interesting
- **Core idea:** Find the similarity between the user and all of the existing items

Example



Edit Favorites

Mark the categories that interest you the most.

☒ Books

Submit

Your Books Favorites

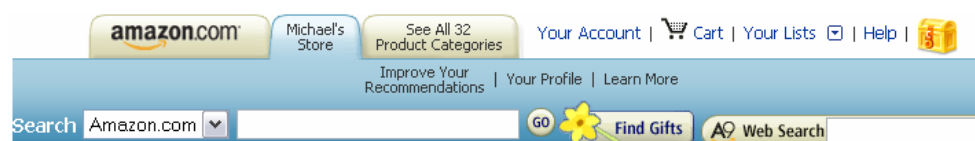
Categories

- ☒ Biographies & Memoirs
- ☒ Business & Investing
- ☒ Computers & Internet

☒ Nonfiction

Add to Your Favorites

- | | |
|--|---|
| <input type="checkbox"/> Arts & Photography | <input type="checkbox"/> Outdoors & Nature |
| <input type="checkbox"/> Children's Books | <input type="checkbox"/> Parenting & Families |
| <input type="checkbox"/> Comics & Graphic Novels | <input type="checkbox"/> Professional & Technical |
| <input type="checkbox"/> Cooking, Food & Wine | <input type="checkbox"/> Reference |
| <input type="checkbox"/> Entertainment | <input type="checkbox"/> Religion & Spirituality |



Recommended For You > Books

Recommendations by Category in Books

Your Favorites [Edit](#)

[Business & Investing](#)
[Computers & Internet](#)
[Biographies & Memoirs](#)
[Nonfiction](#)

More Categories

[Arts & Photography](#)
[Children's Books](#)
[Comics & Graphic Novels](#)
[Cooking, Food & Wine](#)
[Entertainment](#)
[Gay & Lesbian](#)
[Health, Mind & Body](#)
[History](#)
[Home & Garden](#)

These recommendations are based on [items you own](#) and more.

view: [All](#) | [New Releases](#) | [Coming Soon](#)

[More results](#)

- 

The Search: How Google and Its Rivals Rewrote the Rules of Business and Transformed Our Culture
by John Battelle
Average Customer Review: ★★★★★
Publication Date: September 8, 2005

Our Price: \$16.35
Used & new from \$10.95

[Add to cart](#)

[Add to Wish List](#)

☐ I Own It ☐ Not interested [x](#) [★ ★ ★ ★ ★](#) Rate it
Recommended because you purchased [Amazonia](#) and more ([edit](#))

- 

Writing Successful Science Proposals
by Andrew J. Friedland, Carol L. Folt
Average Customer Review: ★★★★★
Publication Date: June 10, 2000

[Add to cart](#)

Content-based Methods

■ Steps

1. Describe the items to be recommended
2. Create a profile of the user that describes the types of items the user likes
3. Compare items with the user profile to determine what to recommend

Content-based Algorithm

- 1. Represent both user profiles and item descriptions by vectorizing them using a set of k keywords
- 2. Vectorize (e.g., using TF-IDF) both users and items and compute their similarity

$$I_j = (i_{j,1}, i_{j,2}, \dots, i_{j,k})$$

$$U_i = (u_{i,1}, u_{i,2}, \dots, u_{i,k}).$$

$$\text{sim}(U_i, I_j) = \cos(U_i, I_j) = \frac{\sum_{l=1}^k u_{i,l} i_{j,l}}{\sqrt{\sum_{l=1}^k u_{i,l}^2} \sqrt{\sum_{l=1}^k i_{j,l}^2}}$$

- 3. Recommend the top most similar items to the user

Collaborative Filtering

■ Assumption

■ User-based CF

- Users with similar previous ratings for items are likely to rate future items similarly

	I1	I2	I3	I4
U1	1	2	4	4
U2	1	2	4	?
U3	2	5	2	2
U4	5	2	3	3

■ Item-based CF

- Items that have received similar ratings previously from users are likely to receive similar ratings from future users (item-based CF)

	I1	I2	I3	I4
U1	1	2	4	4
U2	1	2	4	?
U3	2	5	2	2
U4	5	2	3	3

Example

Movies You've Rated

Based on your 745 movie ratings, this is the list of movies you've seen. As you discover movies on the website that you've seen, rate them and they will show up on this list. On this page, you may change the rating for any movie you've seen, and you may remove a movie from this list by clicking the 'Clear Rating' button.

Sort by > **Star Rating**

Jump to > **5 Stars**

	TITLE	MPAA	GENRE	STAR RATING
Add	12 Angry Men (1957)	UR	Classics	5 stars Clear Rating
Add	The 39 Steps (1935)	UR	Classics	5 stars Clear Rating
Add	An American in Paris (1951)	UR	Classics	5 stars Clear Rating
Add	The Andromeda Strain (1971)	G	Sci-Fi & Fantasy	5 stars Clear Rating
Add	Apollo 13 (1995)	PG	Drama	5 stars Clear Rating
Add	The Battle of Algiers (1965) La Battaglia di Algeri	UR	Foreign	5 stars Clear Rating
Add	Being There (1979)	PG	Drama	5 stars Clear Rating
Add	Big Deal on Madonna Street (1958) I soliti ignoti	UR	Foreign	5 stars Clear Rating
Add	The Birds (1963)	PG-13	Thrillers	5 stars Clear Rating
Add	Blade Runner (1982)	R	Sci-Fi & Fantasy	5 stars Clear Rating

Value	Graphic representation	Textual representation
5	☆☆☆☆☆	Excellent
4	☆☆☆☆	Very good
3	☆☆☆	Good
2	☆☆	Fair
1	☆	Poor

Table 9.1: User-Item Matrix

	Lion King	Aladdin	Mulan	Anastasia
John	3	0	3	3
Joe	5	4	0	2
Jill	1	2	4	2
Jane	3	?	1	0
Jorge	2	2	0	1

Collaborative Filtering

■ Rating matrix

- **Explicit ratings:** entered by a user directly
 - i.e., “Please rate this on a scale of 1-5”



Rating: 5.2/10 (5 votes cast)



Rating: 5.2/10 (5 votes cast)



Rating: 8.8/10 (5 votes cast)

- **Implicit ratings:** inferred from other user behavior
 - Play lists or music listened to, for a music Rec system
 - The amount of time users spent on a webpage

Collaborative Filtering Algorithm

■ Steps

1. Weigh all users/items with respect to their similarity with the current user/item
2. Select a subset of the users/items (neighbors) as recommenders
3. Predict the rating of the user for specific items using neighbors' ratings for the same (or similar) items
4. Recommend items with the highest predicted rank

Collaborative Filtering Algorithm

- Measure Similarity between Users (or Items)

$$\text{sim}(U_i, U_j) = \cos(U_i, U_j) = \frac{U_i \cdot U_j}{\|U_i\| \|U_j\|} = \frac{\sum_k r_{ik} r_{jk}}{\sqrt{\sum_k r_{ik}^2} \sqrt{\sum_k r_{jk}^2}}$$

- Pearson Correlation Coefficient

$$\text{sim}(U_i, U_j) = \frac{\sum_k (r_{ik} - \bar{r}_i)(r_{jk} - \bar{r}_j)}{\sqrt{\sum_k (r_{ik} - \bar{r}_i)^2} \sqrt{\sum_k (r_{jk} - \bar{r}_j)^2}}$$

Collaborative Filtering Algorithm

Updating the ratings:

The diagram illustrates the formula for updating a user's rating for a specific item. The formula is:
$$r_{u,i} = \bar{r}_u + \frac{\sum_{v \in N(u)} \text{sim}(u, v)(r_{v,i} - \bar{r}_v)}{\sum_{v \in N(u)} \text{sim}(u, v)},$$
 Annotations with arrows point to various parts of the formula:

- An arrow points from "User u's mean rating" to \bar{r}_u .
- An arrow points from "User v's mean rating" to \bar{r}_v .
- An arrow points from "Observed rating of user v for item i" to $r_{v,i}$.
- An arrow points from "Predicted rating of user u for item i" to $r_{u,i}$.

Diagram illustrating the formula for updating ratings:

$$r_{u,i} = \bar{r}_u + \frac{\sum_{v \in N(u)} \text{sim}(u, v)(r_{v,i} - \bar{r}_v)}{\sum_{v \in N(u)} \text{sim}(u, v)},$$

Annotations:

- User u's mean rating (\bar{r}_u)
- User v's mean rating (\bar{r}_v)
- Observed rating of user v for item i ($r_{v,i}$)
- Predicted rating of user u for item i ($r_{u,i}$)

Example

	Lion King	Aladdin	Mulan	Anastasia
John	3	0	3	3
Joe	5	4	0	2
Jill	1	2	4	2
Jane	3	?	1	0
Jorge	2	2	0	1

Predict Jane's rating
for Aladdin

1- Calculate average ratings

$$\bar{r}_{John} = \frac{3 + 3 + 0 + 3}{4} = 2.25$$

$$\bar{r}_{Joe} = \frac{5 + 4 + 0 + 2}{4} = 2.75$$

$$\bar{r}_{Jill} = \frac{1 + 2 + 4 + 2}{4} = 2.25$$

$$\bar{r}_{Jane} = \frac{3 + 1 + 0}{3} = 1.33$$

$$\bar{r}_{Jorge} = \frac{2 + 2 + 0 + 1}{4} = 1.25$$

2- Calculate user-user similarity

$$sim(Jane, John) = \frac{3 \times 3 + 1 \times 3 + 0 \times 3}{\sqrt{10} \sqrt{27}} = 0.73$$

$$sim(Jane, Joe) = \frac{3 \times 5 + 1 \times 0 + 0 \times 2}{\sqrt{10} \sqrt{29}} = 0.88$$

$$sim(Jane, Jill) = \frac{3 \times 1 + 1 \times 4 + 0 \times 2}{\sqrt{10} \sqrt{21}} = 0.48$$

$$sim(Jane, Jorge) = \frac{3 \times 2 + 1 \times 0 + 0 \times 1}{\sqrt{10} \sqrt{5}} = 0.84$$

User_based CF, Example

3- Calculate Jane's rating for Aladdin,
Assume that neighborhood size = 2

$$\begin{aligned}r_{Jane, Aladdin} &= \bar{r}_{Jane} + \frac{sim(Jane, Joe)(r_{Joe, Aladdin} - \bar{r}_{Joe})}{sim(Jane, Joe) + sim(Jane, Jorge)} \\&\quad + \frac{sim(Jane, Jorge)(r_{Jorge, Aladdin} - \bar{r}_{Jorge})}{sim(Jane, Joe) + sim(Jane, Jorge)} \\&= 1.33 + \frac{0.88(4 - 2.75) + 0.84(2 - 1.25)}{0.88 + 0.84} = 2.33\end{aligned}$$

User_based CF, Example

3- Calculate Jane's rating for Aladdin,
Assume that neighborhood size = 2

$$\begin{aligned}r_{Jane, Aladdin} &= \bar{r}_{Jane} + \frac{sim(Jane, Joe)(r_{Joe, Aladdin} - \bar{r}_{Joe})}{sim(Jane, Joe) + sim(Jane, Jorge)} \\&\quad + \frac{sim(Jane, Jorge)(r_{Jorge, Aladdin} - \bar{r}_{Jorge})}{sim(Jane, Joe) + sim(Jane, Jorge)} \\&= 1.33 + \frac{0.88(4 - 2.75) + 0.84(2 - 1.25)}{0.88 + 0.84} = 2.33\end{aligned}$$

User_based CF, Example

3- Calculate Jane's rating for Aladdin,
Assume that neighborhood size = 2

$$\begin{aligned}r_{Jane, Aladdin} &= \bar{r}_{Jane} + \frac{sim(Jane, Joe)(r_{Joe, Aladdin} - \bar{r}_{Joe})}{sim(Jane, Joe) + sim(Jane, Jorge)} \\&\quad + \frac{sim(Jane, Jorge)(r_{Jorge, Aladdin} - \bar{r}_{Jorge})}{sim(Jane, Joe) + sim(Jane, Jorge)} \\&= 1.33 + \frac{0.88(4 - 2.75) + 0.84(2 - 1.25)}{0.88 + 0.84} = 2.33\end{aligned}$$

Outline

- What is Recommender System?
- Recommendation Algorithms
- Evaluation of Recommender Systems

Evaluation is Challenging

- Different algorithms may be better or worse on different datasets (applications)
 - Many algorithms are designed specifically for datasets
 - Differences exist for rating density, rating scale, and other properties of datasets
- The goals to perform evaluation may differ
 - Early evaluation work focused specifically on the "accuracy" in "predicting"
 - Other properties also have important effect on user satisfaction and performance

Evaluation is Challenging

- It is challenge in deciding what combination of measures should be used in comparative evaluation

Predictive Accuracy Metrics

- Mean Absolute Error (*MAE*)
measures the average absolute deviation between a predicted rating (\hat{r}) and the user's true rating (r)

$$MAE = \frac{\sum_{i,j} |\hat{r}_{ij} - r_{ij}|}{n}$$

- $NMAE = MAE / (r_{\max} - r_{\min})$

- Root Mean Square Error (*RMSE*) is similar to *MAE*, but places more emphasis on larger deviation

$$RMSE = \sqrt{\frac{1}{n} \sum_{i,j} (\hat{r}_{ij} - r_{ij})^2}$$

Example

Consider the following table with both the predicted ratings and true ratings of five items

<i>Item</i>	<i>Predicted Rating</i>	<i>True Rating</i>
1	1	3
2	2	5
3	3	3
4	4	2
5	4	1

$$MAE = \frac{|1 - 3| + |2 - 5| + |3 - 3| + |4 - 2| + |4 - 1|}{5} = 2$$

$$NMAE = \frac{MAE}{5 - 1} = 0.5$$

$$\begin{aligned} RMSE &= \sqrt{\frac{(1 - 3)^2 + (2 - 5)^2 + (3 - 3)^2 + (4 - 2)^2 + (4 - 1)^2}{5}} \\ &= 2.28 \end{aligned}$$

Relevance: Precision and Recall

- **Precision:** a measure of exactness, determines the fraction of relevant items retrieved out of all items retrieved

$$P = \frac{N_{rs}}{N_s}$$

- **Recall:** a measure of completeness, determines the fraction of relevant items retrieved out of all relevant items

$$R = \frac{N_{rs}}{N_r}$$

	Selected	Not Selected	Total
Relevant	N_{rs}	N_{rn}	N_r
Irrelevant	N_{is}	N_{in}	N_i
Total	N_s	N_n	N

Example

	<i>Selected</i>	<i>Not Selected</i>	<i>Total</i>
<i>Relevant</i>	9	15	24
<i>Irrelevant</i>	3	13	16
<i>Total</i>	12	28	40

$$P = \frac{9}{12} = 0.75$$

$$R = \frac{9}{24} = 0.375$$

$$F = \frac{2 \times 0.75 \times 0.375}{0.75 + 0.375} = 0.5$$

Evaluating Ranking

■ Spearman's Rank Correlation

$$\rho = 1 - \frac{6 \sum_{i=1}^n (x_i - y_i)^2}{n^3 - n}$$

■ Kendall's τ

- It checks the concordant the items of the recommended ranking list against the ground truth ranking list
- If the two orders are consistent, it is concordant
- For top 4 items in ranking list, there are $4 \cdot 3 / 2 = 6$ pairs

$$\tau = \frac{c - d}{\binom{n}{2}}$$

where c is the number of concordants and d of discordants

Example

Consider a set of four items $I = \{i_1, i_2, i_3, i_4\}$ for which the predicted and true rankings are as follows

	<i>Predicted Rank</i>	<i>True Rank</i>
i_1	1	1
i_2	2	4
i_3	3	2
i_4	4	3

Pair of items and their status
{concordant/discordant} are

(i_1, i_2) : concordant

(i_1, i_3) : concordant

(i_1, i_4) : concordant

(i_2, i_3) : discordant

(i_2, i_4) : discordant

(i_3, i_4) : concordant

$$\tau = \frac{4 - 2}{6} = 0.33$$