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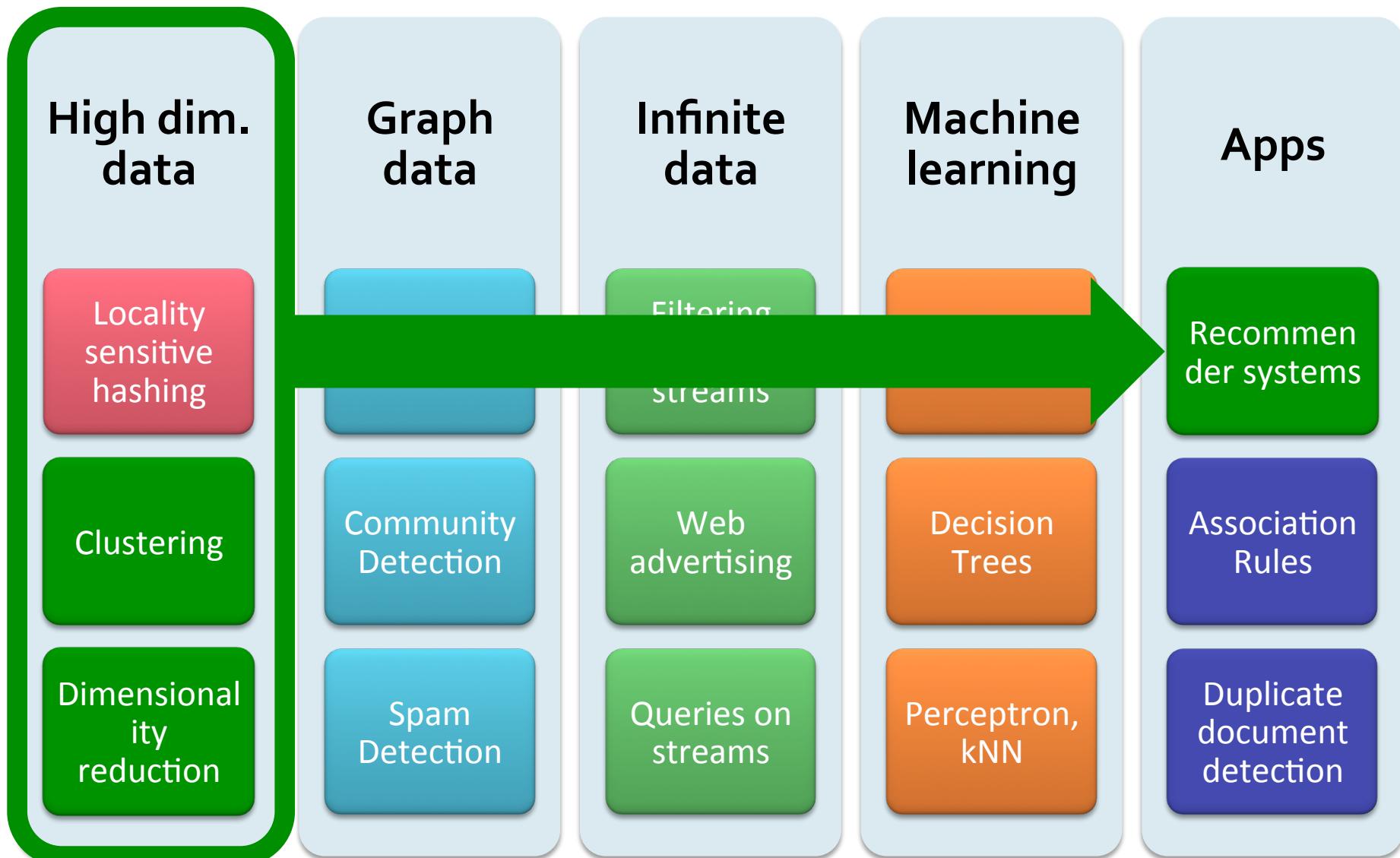
Recommender Systems: Content-based Systems & Collaborative Filtering

Mining of Massive Datasets
Jure Leskovec, Anand Rajaraman, Jeff Ullman
Stanford University

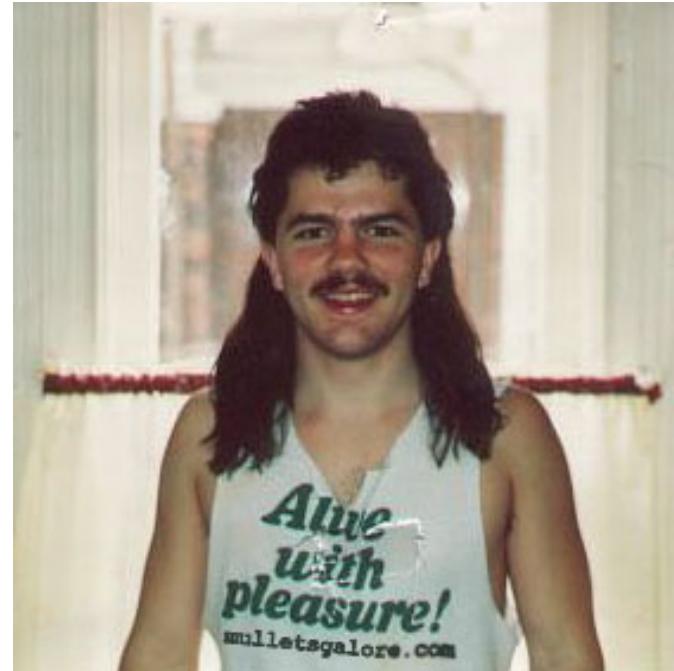
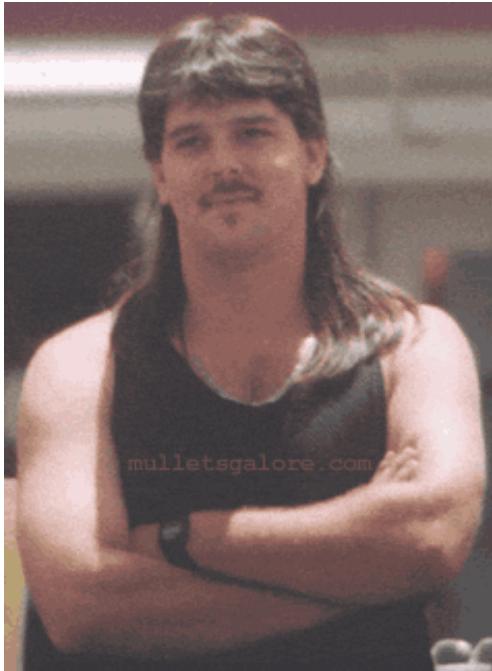
<http://www.mmmds.org>



High Dimensional Data



Example: Recommender Systems



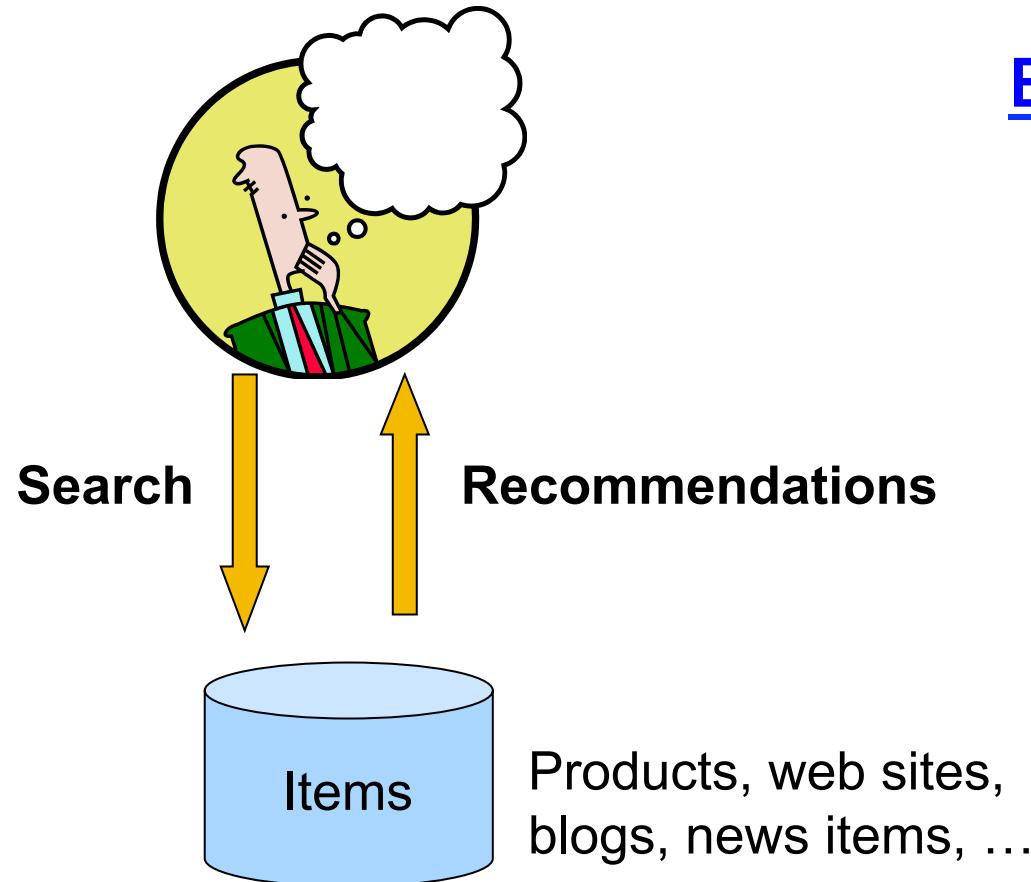
■ Customer X

- Buys Metallica CD
- Buys Megadeth CD

■ Customer Y

- Does search on Metallica
- Recommender system suggests Megadeth from data collected about customer X

Recommendations



Examples:

amazon.com.



StumbleUpon

del.icio.us



movieLens
helping you find the *right* movies

last.fm™
the social music revolution

Google™
News

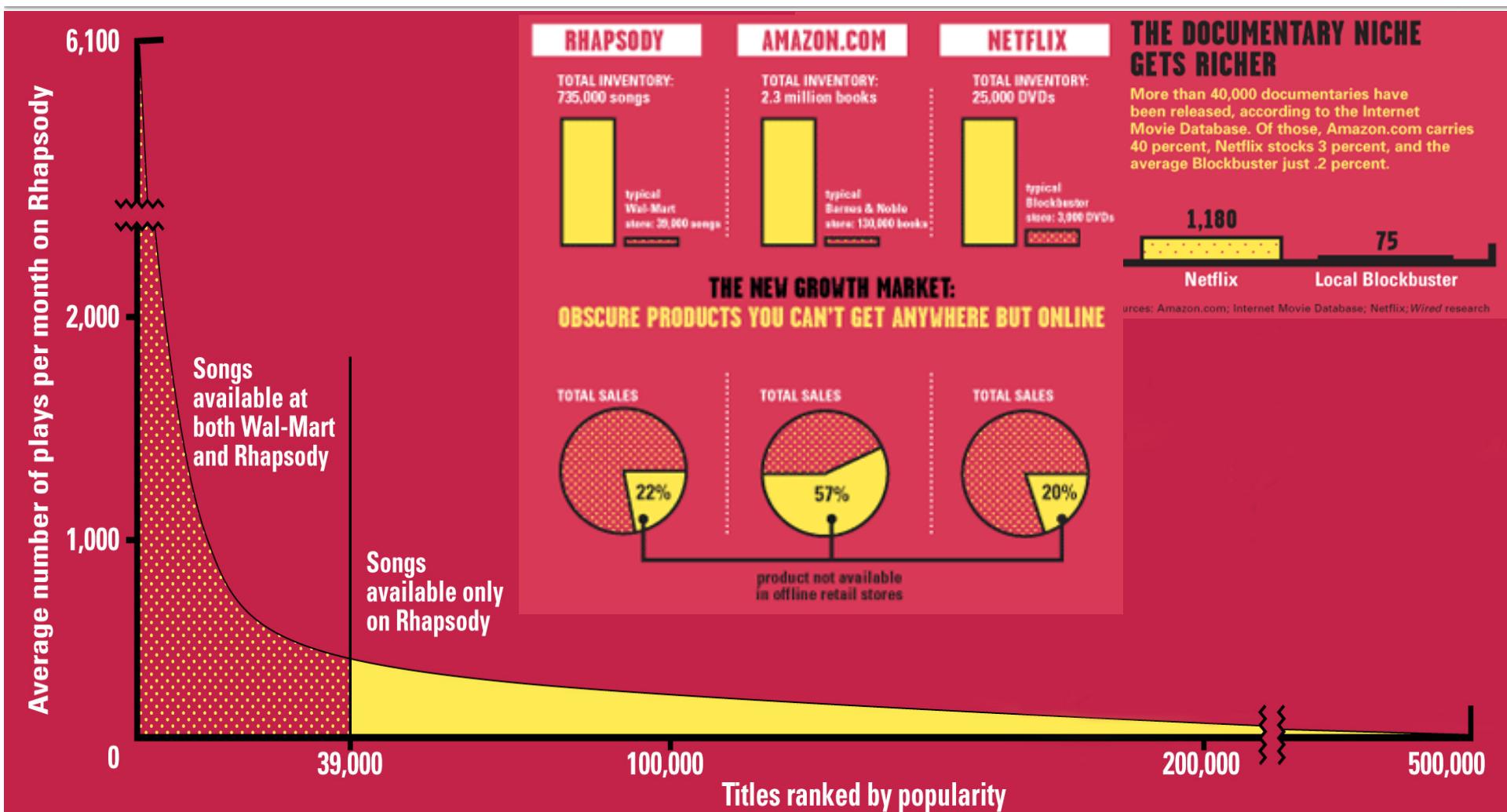
YouTube

XBOX
LIVE

From Scarcity to Abundance

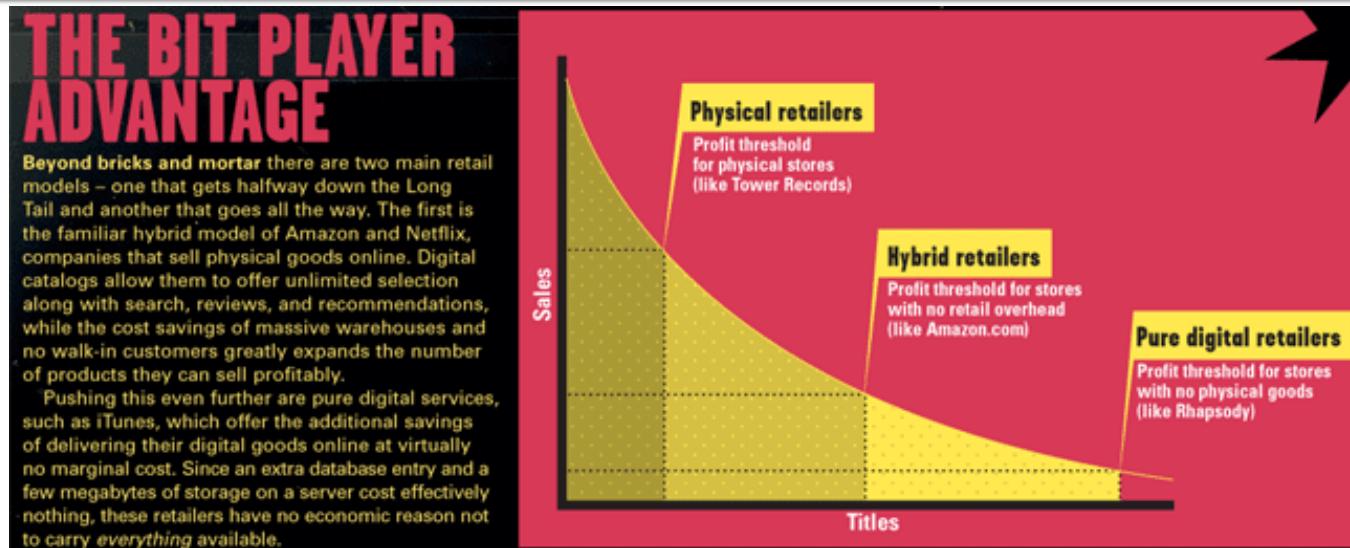
- **Shelf space is a scarce commodity for traditional retailers**
 - Also: TV networks, movie theaters,...
- **Web enables near-zero-cost dissemination of information about products**
 - From scarcity to abundance
- **More choice necessitates better filters**
 - Recommendation engines
 - How **Into Thin Air** made **Touching the Void** a bestseller: <http://www.wired.com/wired/archive/12.10/tail.html>

Sidenote: The Long Tail



Sources: Erik Brynjolfsson and Jeffrey Hu, MIT, and Michael Smith, Carnegie Mellon; Barnes & Noble; Netflix; RealNetworks
Source: Chris Anderson (2004)

Physical vs. Online



Read <http://www.wired.com/wired/archive/12.10/tail.html> to learn more!

Types of Recommendations

- **Editorial and hand curated**

- List of favorites
- Lists of “essential” items

- **Simple aggregates**

- Top 10, Most Popular, Recent Uploads

- **Tailored to individual users**

- Amazon, Netflix, ...

Formal Model

- X = set of **Customers**
- S = set of **Items**
- **Utility function** $u: X \times S \rightarrow R$
 - R = set of ratings
 - R is a totally ordered set
 - e.g., 0-5 stars, real number in $[0,1]$

Utility Matrix

	Avatar	LOTR	Matrix	Pirates
Alice	1		0.2	
Bob		0.5		0.3
Carol	0.2		1	
David				0.4

Key Problems

- **(1) Gathering “known” ratings for matrix**
 - How to collect the data in the utility matrix
- **(2) Extrapolate unknown ratings from the known ones**
 - Mainly interested in high unknown ratings
 - We are not interested in knowing what you don't like but what you like
- **(3) Evaluating extrapolation methods**
 - How to measure success/performance of recommendation methods

(1) Gathering Ratings

■ Explicit

- Ask people to rate items
- Doesn't work well in practice – people can't be bothered

■ Implicit

- Learn ratings from user actions
 - E.g., purchase implies high rating
- What about low ratings?

(2) Extrapolating Utilities

- **Key problem:** Utility matrix U is **sparse**
 - Most people have not rated most items
 - **Cold start:**
 - New items have no ratings
 - New users have no history
- **Three approaches to recommender systems:**
 - 1) Content-based
 - 2) Collaborative
 - 3) Latent factor basedToday!

Content-based Recommender Systems

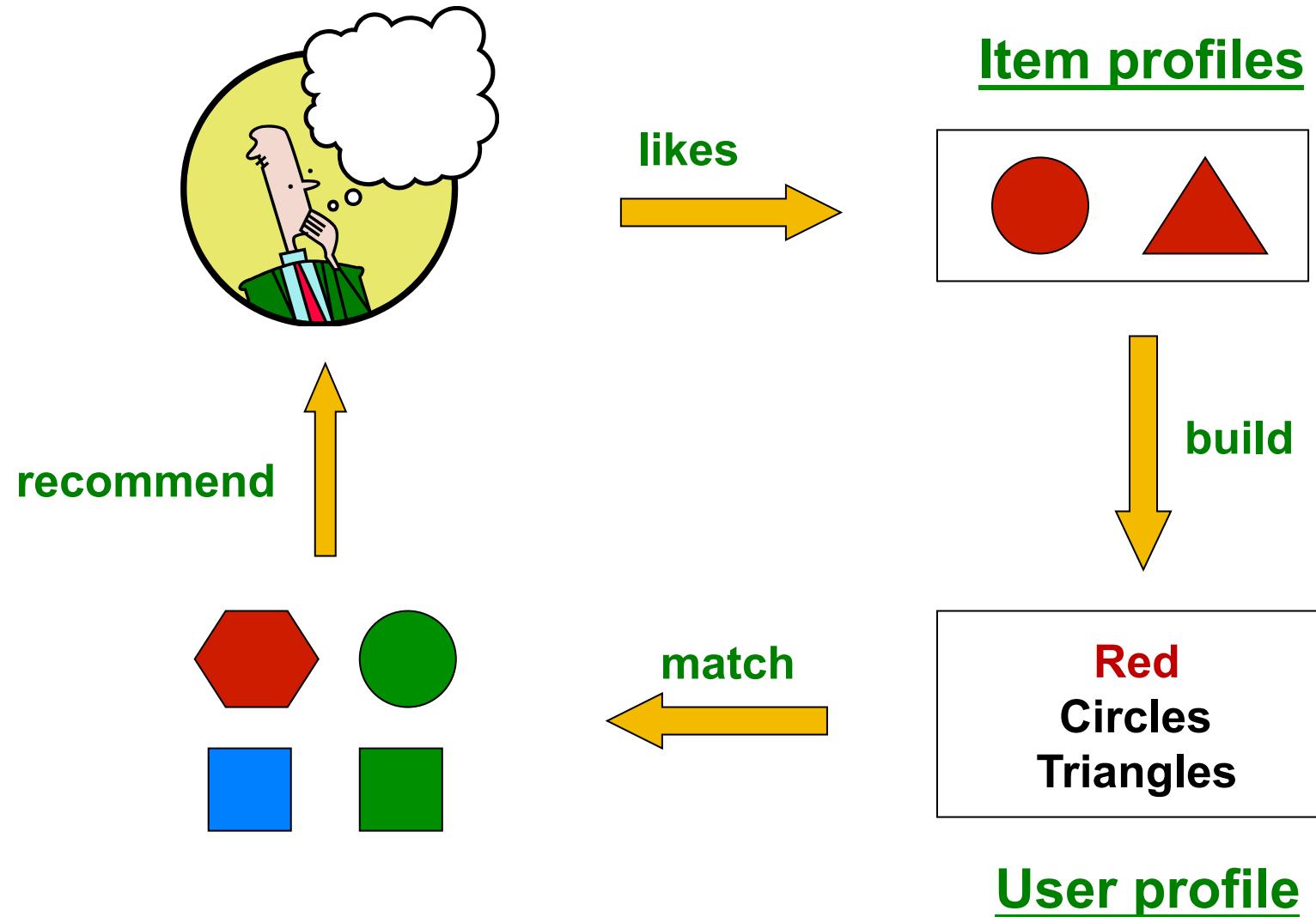
Content-based Recommendations

- **Main idea:** Recommend items to customer x similar to previous items rated highly by x

Example:

- **Movie recommendations**
 - Recommend movies with same actor(s), director, genre, ...
- **Websites, blogs, news**
 - Recommend other sites with “similar” content

Plan of Action



Item Profiles

- For each item, create an **item profile**
- **Profile is a set (vector) of features**
 - **Movies:** author, title, actor, director,...
 - **Text:** Set of “important” words in document
- **How to pick important features?**
 - Usual heuristic from text mining is **TF-IDF**
(Term frequency * Inverse Doc Frequency)
 - **Term ... Feature**
 - **Document ... Item**

Sidenote: TF-IDF

f_{ij} = frequency of term (feature) i in doc (item) j

$$TF_{ij} = \frac{f_{ij}}{\max_k f_{kj}}$$

Note: we normalize TF
to discount for “longer”
documents

n_i = number of docs that mention term i

N = total number of docs

$$IDF_i = \log \frac{N}{n_i}$$

TF-IDF score: $w_{ij} = TF_{ij} \times IDF_i$

Doc profile = set of words with highest TF-IDF scores, together with their scores

User Profiles and Prediction

■ User profile possibilities:

- Weighted average of rated item profiles
- **Variation:** weight by difference from average rating for item
- ...

■ Prediction heuristic:

- Given user profile \mathbf{x} and item profile \mathbf{i} , estimate
$$u(\mathbf{x}, \mathbf{i}) = \cos(\mathbf{x}, \mathbf{i}) = \mathbf{x} \cdot \mathbf{i} / \| \mathbf{x} \| \cdot \| \mathbf{i} \|$$

Pros: 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 & unpopular items**
 - No first-rater problem
- **+: Able to provide explanations**
 - Can provide explanations of recommended items by listing content-features that caused an item to be recommended

Cons: Content-based Approach

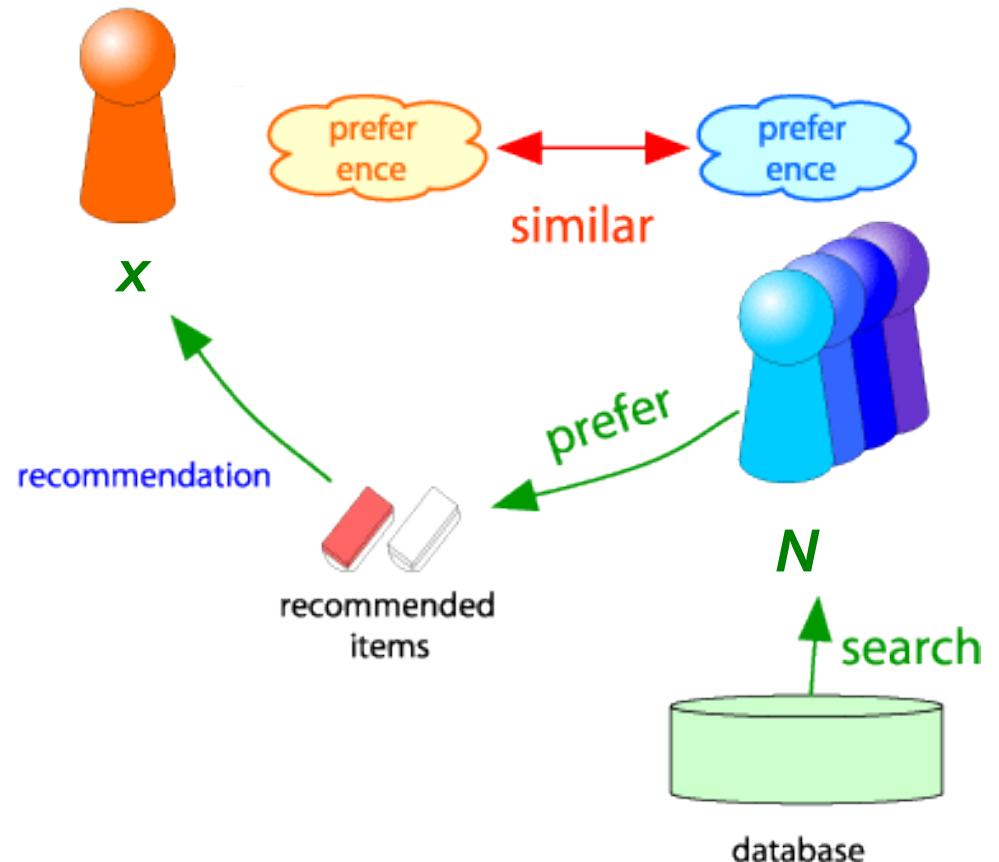
- -: **Finding the appropriate features is hard**
 - E.g., images, movies, music
- -: **Recommendations for new users**
 - **How to build a user profile?**
- -: **Overspecialization**
 - Never recommends items outside user's content profile
 - People might have multiple interests
 - **Unable to exploit quality judgments of other users**

Collaborative Filtering

Harnessing quality judgments of other users

Collaborative Filtering

- Consider user x
- Find set N of other users whose ratings are “similar” to x 's ratings
- Estimate x 's ratings based on ratings of users in N



Finding “Similar” Users

$$\begin{aligned}r_x &= [* , _, _, *, **] \\r_y &= [* , _, ** , ** , _]\end{aligned}$$

- Let r_x be the vector of user x 's ratings

- Jaccard similarity measure**

- Problem:** Ignores the value of the rating

$$\begin{aligned}r_x, r_y \text{ as sets:} \\r_x = \{1, 4, 5\} \\r_y = \{1, 3, 4\}\end{aligned}$$

- Cosine similarity measure**

- $\text{sim}(x, y) = \cos(r_x, r_y) = r_x \cdot r_y / \|r_x\| \cdot \|r_y\|$

$$\begin{aligned}r_x, r_y \text{ as points:} \\r_x = \{1, 0, 0, 1, 3\} \\r_y = \{1, 0, 2, 2, 0\}\end{aligned}$$

- Problem:** Treats missing ratings as “negative”

- Pearson correlation coefficient**

- S_{xy} = items rated by both users x and y

$$\text{sim}(x, y) = \frac{\sum s \in S_{xy} ((r_{xs} - \bar{r}_x)(r_{ys} - \bar{r}_y))}{\sqrt{\sum s \in S_{xy} ((r_{xs} - \bar{r}_x)^2 + (r_{ys} - \bar{r}_y)^2)}}$$

$\bar{r}_x, \bar{r}_y \dots$ avg.
rating of x, y

Cosine sim:

Similarity Metric

	HP1	HP2	HP3	TW	SW1	SW2	SW3
A	4			5	1		
B	5	5	4				
C				2	4	5	
D		3					3

- Intuitively we want: $\text{sim}(A, B) > \text{sim}(A, C)$

- Jaccard similarity: $1/5 < 2/4$

- Cosine similarity: $0.386 > 0.322$

- Considers missing ratings as “negative”

- Solution: subtract the (row) mean

	HP1	HP2	HP3	TW	SW1	SW2	SW3
A	2/3			5/3	-7/3		
B	1/3	1/3	-2/3				
C				-5/3	1/3	4/3	
D		0					0

sim A,B vs. A,C:
 $0.092 > -0.559$

Notice cosine sim. is correlation when data is centered at 0

Rating Predictions

From similarity metric to recommendations:

- Let r_x be the vector of user x 's ratings
- Let N be the set of k users most similar to x who have rated item i
- Prediction for item s of user x :
 - $r_{xi} = \frac{1}{k} \sum_{y \in N} r_{yi}$
 - $r_{xi} = \sum_{y \in N} s_{xy} \cdot r_{yi} / \sum_{y \in N} s_{xy}$ Shorthand:
 - Other options?
- Many other tricks possible...

Item-Item Collaborative Filtering

- So far: User-user collaborative filtering
- Another view: Item-item
 - For item i , find other similar items
 - Estimate rating for item i based on ratings for similar items
 - Can use same similarity metrics and prediction functions as in user-user model

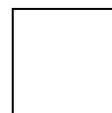
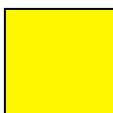
$$r_{xi} = \frac{\sum_{j \in N(i; x)} s_{ij} \cdot r_{xj}}{\sum_{j \in N(i; x)} s_{ij}}$$

s_{ij} ... similarity of items i and j
 r_{xj} ... rating of user u on item j

$N(i; x)$... set items rated by x similar to i

Item-Item CF ($|N|=2$)

	users											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1		3			5			5		4	
2			5	4			4			2	1	3
3	2	4		1	2		3		4	3	5	
4		2	4		5			4			2	
5			4	3	4	2					2	5
6	1		3		3			2			4	

 - unknown rating  - rating between 1 to 5

Item-Item CF ($|N|=2$)

	Users											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1		3		?	5			5		4	
2			5	4			4			2	1	3
3	2	4		1	2		3		4	3	5	
4		2	4		5			4			2	
5			4	3	4	2					2	5
6	1		3		3			2			4	

 - estimate rating of movie 1 by user 5

Item-Item CF ($|N|=2$)

	Users												
	1	2	3	4	5	6	7	8	9	10	11	12	
movies	1	1		3		?	5			5		4	
	2			5	4			4			2	1	3
	3	2	4		1	2		3		4	3	5	
	4		2	4		5			4			2	
	5			4	3	4	2					2	5
	6	1		3		3			2			4	

$\text{sim}(1,m)$
1.00
-0.18
0.41
-0.10
-0.31
0.59

Neighbor selection:

Identify movies similar to movie 1, rated by user 5

Here we use Pearson correlation as similarity:

- 1) Subtract mean rating m_i from each movie i
 $m_1 = (1+3+5+4)/5 = 3.6$
row 1: [-2.6, 0, -0.6, 0, 0, 1.4, 0, 0, 1.4, 0, 0.4, 0]
- 2) Compute cosine similarities between rows

Item-Item CF ($|N|=2$)

	Users												
	1	2	3	4	5	6	7	8	9	10	11	12	
movies	1	1		3		?	5			5		4	
	2			5	4			4			2	1	3
	3	2	4		1	2		3		4	3	5	
	4		2	4		5			4			2	
	5			4	3	4	2					2	5
	6	1		3		3			2			4	

$\text{sim}(1,m)$

1.00

-0.18

0.41

-0.10

-0.31

0.59

Compute similarity weights:

$$\mathbf{s_{1,3}=0.41, s_{1,6}=0.59}$$

Item-Item CF ($|N|=2$)

	users											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1		3		2.6	5			5		4	
2			5	4			4			2	1	3
3	2	4		1	2		3		4	3	5	
4		2	4		5			4			2	
5			4	3	4	2					2	5
6	1		3		3			2			4	

Predict by taking weighted average:

$$r_{i|x} = \sum_{j \in N(i|x)} s_{ij} \cdot 1$$

$$r_{1,5} = (0.41*2 + 0.59*3) / (0.41+0.59) = 2.6$$

CF: Common Practice

Before:

$$r_{xi} = \frac{\sum_{j \in N(i; x)} s_{ij} r_{xj}}{\sum_{j \in N(i; x)} s_{ij}}$$

- Define **similarity** s_{ij} of items i and j
- Select k nearest neighbors $N(i; x)$
 - Items most similar to i , that were rated by x
- Estimate rating r_{xi} as the weighted average:

$$r_{xi} = b_{xi} + \frac{\sum_{j \in N(i; x)} s_{ij} \cdot (r_{xj} - b_{xj})}{\sum_{j \in N(i; x)} s_{ij}}$$

baseline estimate for r_{xi}

$$b_{xi} = \mu + b_x + b_i$$

- μ = overall mean movie rating
- b_x = rating deviation of user x
= (avg. rating of user x) – μ
- b_i = rating deviation of movie i

Item-Item vs. User-User

	Avatar	LOTR	Matrix	Pirates
Alice	1		0.8	
Bob		0.5		0.3
Carol	0.9		1	0.8
David			1	0.4

- In practice, it has been observed that item-item often works better than user-user
- Why? Items are simpler, users have multiple tastes

Pros/Cons of Collaborative Filtering

- + **Works for any kind of item**
 - No feature selection needed
- - **Cold Start:**
 - Need enough users in the system to find a match
- - **Sparsity:**
 - The user/ratings matrix is sparse
 - 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 taste
 - Tends to recommend popular items

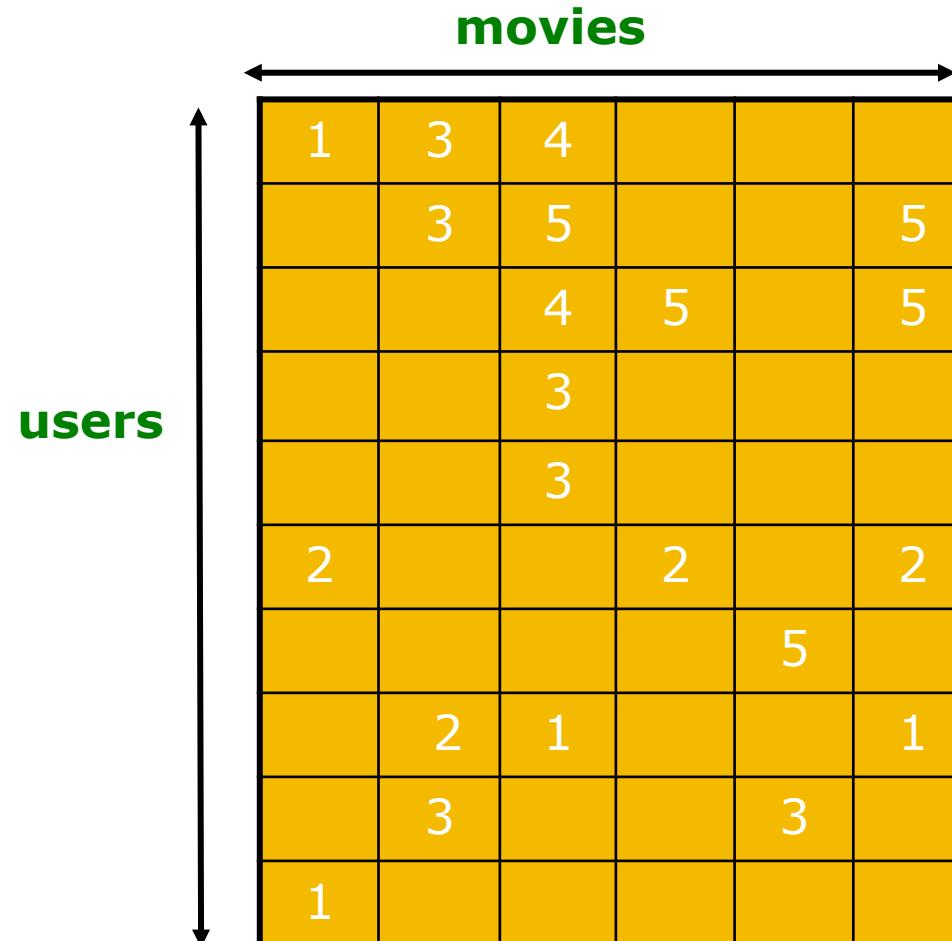
Hybrid Methods

- **Implement two or more different recommenders and combine predictions**
 - Perhaps using a linear model
- **Add content-based methods to collaborative filtering**
 - Item profiles for new item problem
 - Demographics to deal with new user problem

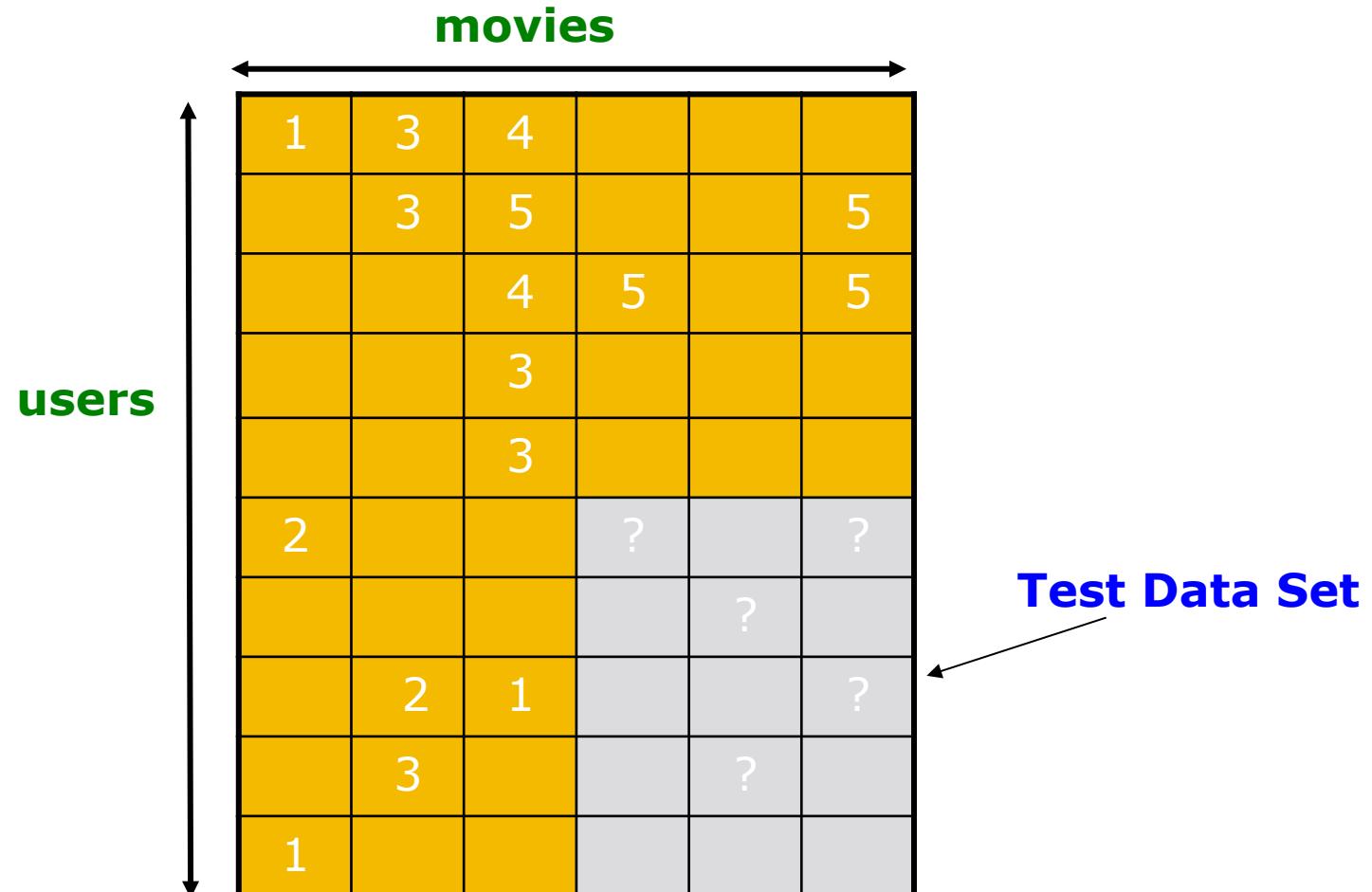
Remarks & Practical Tips

- Evaluation
- Error metrics
- Complexity / Speed

Evaluation



Evaluation



Evaluating Predictions

- **Compare predictions with known ratings**
 - **Root-mean-square error (RMSE)**
 - $\sqrt{\sum_{i=1}^n (r_{xi} - \hat{r}_{xi})^2 / n}$ where r_{xi} is predicted, \hat{r}_{xi} is the true rating of x on i
 - **Precision at top 10:**
 - % of those in top 10
 - **Rank Correlation:**
 - Spearman's *correlation* between system's and user's complete rankings
- **Another approach: 0/1 model**
 - **Coverage:**
 - Number of items/users for which system can make predictions
 - **Precision:**
 - Accuracy of predictions
 - **Receiver operating characteristic (ROC)**
 - Tradeoff curve between false positives and false negatives

Problems with Error Measures

- **Narrow focus on accuracy sometimes misses the point**
 - Prediction Diversity
 - Prediction Context
 - Order of predictions
- **In practice, we care only to predict high ratings:**
 - RMSE might penalize a method that does well for high ratings and badly for others

Collaborative Filtering: Complexity

- Expensive step is finding k most similar customers: $O(|X|)$
- **Too expensive to do at runtime**
 - Could pre-compute
- Naïve pre-computation takes time $O(k \cdot |X|)$
 - X ... set of customers
- **We already know how to do this!**
 - Near-neighbor search in high dimensions (**LSH**)
 - Clustering
 - Dimensionality reduction

Tip: Add Data

- **Leverage all the data**
 - Don't try to reduce data size in an effort to make fancy algorithms work
 - Simple methods on large data do best
- **Add more data**
 - e.g., add IMDB data on genres
- **More data beats better algorithms**

<http://anand.typepad.com/datawocky/2008/03/more-data-usual.html>