

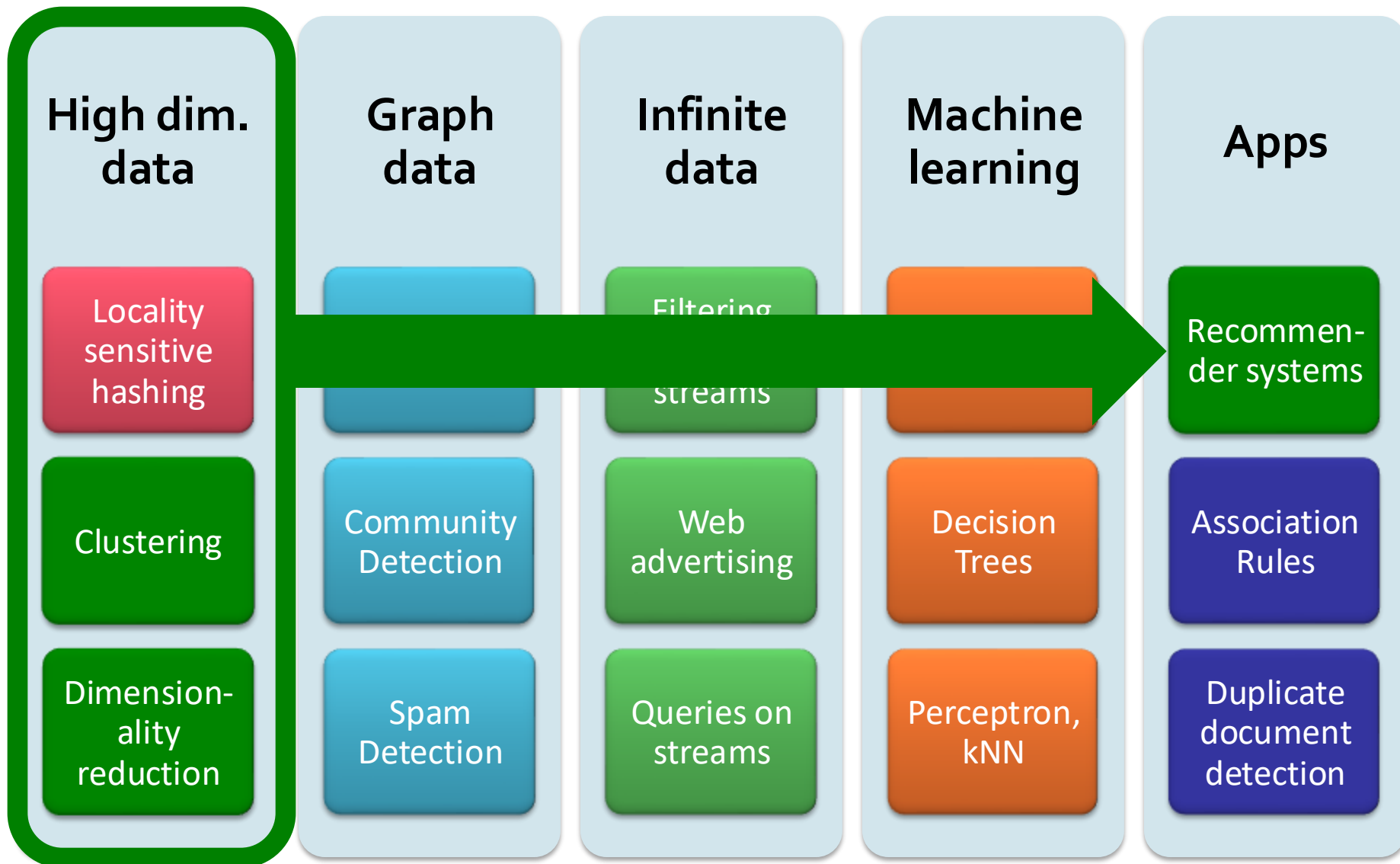
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Recommender Systems: Content-based Systems & Collaborative Filtering

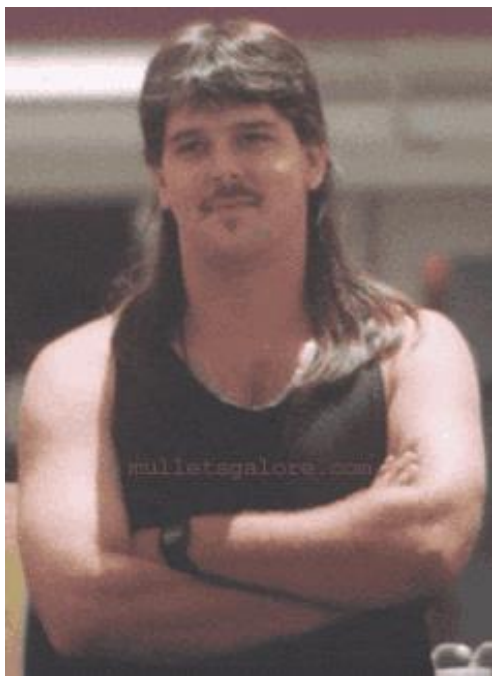
CS246: Mining Massive Datasets
Jure Leskovec, Stanford University
<http://cs246.stanford.edu>



High Dimensional Data



Example: Recommender Systems



■ Customer X

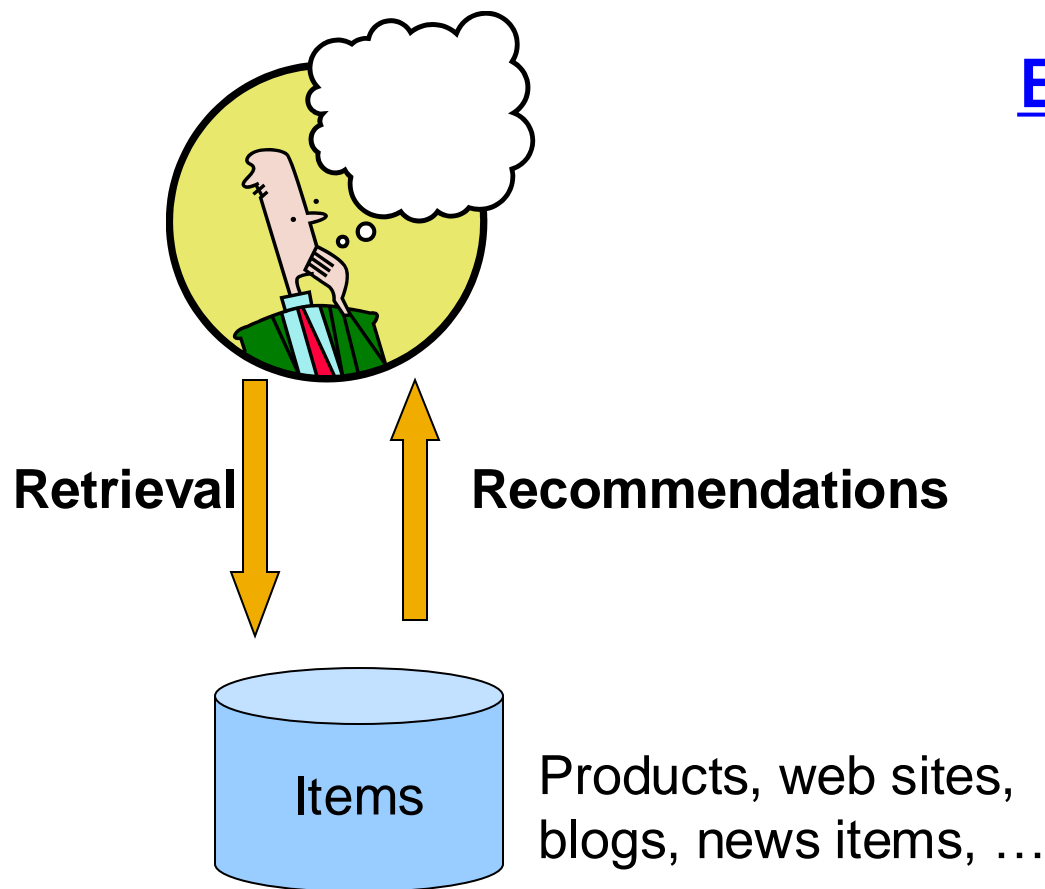
- Buys Metallica CD
- Buys Megadeth CD



■ Customer Y

- Clicks on Metallica album
- Recommender system suggests Megadeth from data collected about customer X

Recommendations



Examples:

amazon.com



StumbleUpon



Google News



TikTok

XBOX LIVE

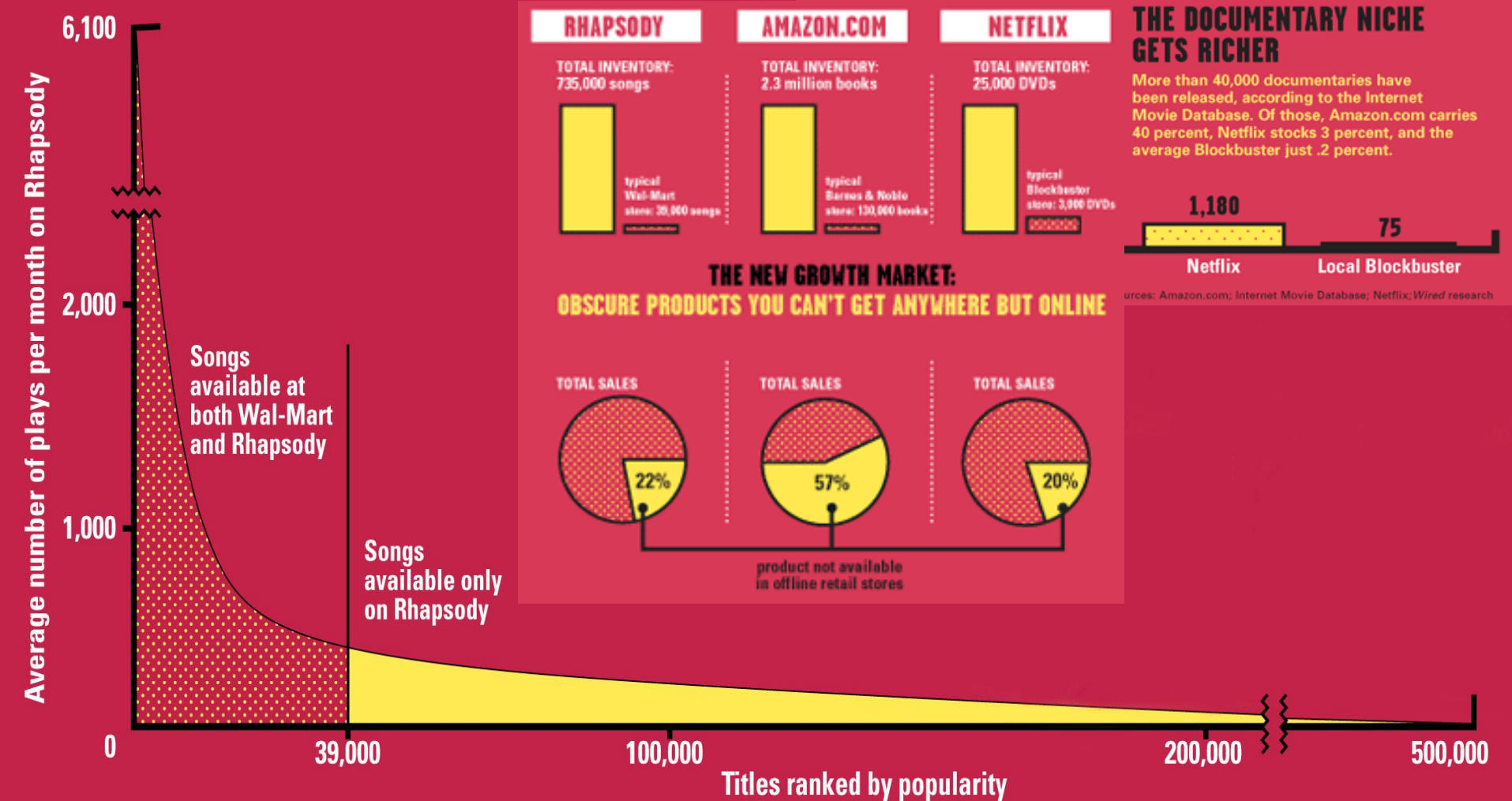
YouTube



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
 - Association rules: 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)

Types of Recommendations

- **Non-personalized recommendations:**

- Editorial and hand curated
 - List of favorites
 - List of “essential” items
- Simple aggregates
 - Top 10, Most Popular, Recent Uploads

- **Personalized recommendations:**

- Tailored to individual users
- Examples: Amazon, Netflix, Youtube,...



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., **1-5** 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) Extrapolating 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 don't like being bothered
- Crowdsourcing: Pay people to label items

■ 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 filtering
 - 3) Latent factor based

} **Today!**

Content-based Recommender Systems

Content-based Recommendations

- **Main idea:**

- Items have profiles:
 - Video -> [genre, director, actors, plot, release year]
 - News -> [set of keywords]
- Recommend items to customer x similar to previous items rated highly by x

Example:

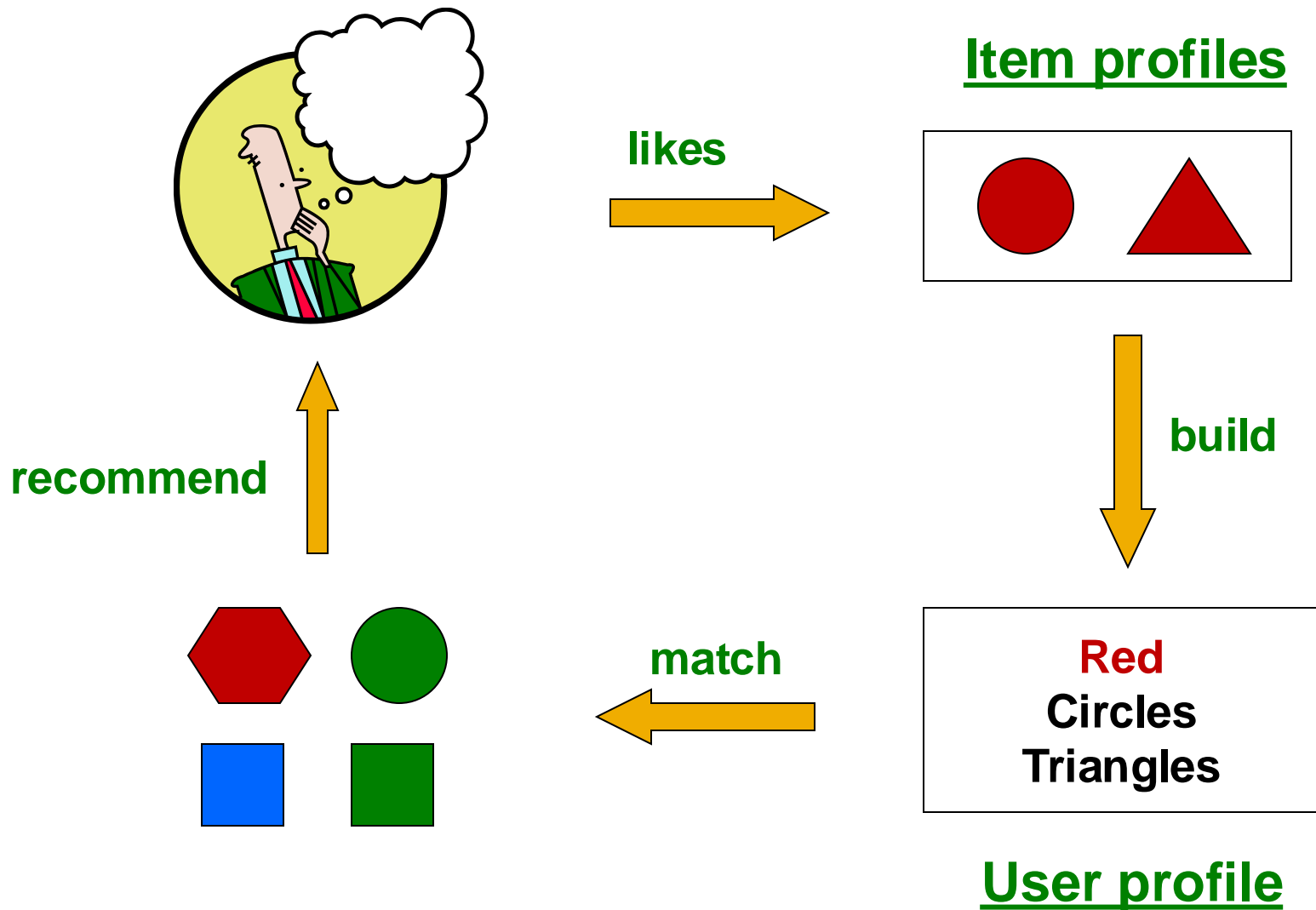
- **Movie recommendations**

- 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: Cosine similarity of user and item profiles**
 - Given user profile \mathbf{x} and item profile \mathbf{i} , estimate
$$u(\mathbf{x}, \mathbf{i}) = \cos(\mathbf{x}, \mathbf{i}) = \frac{\mathbf{x} \cdot \mathbf{i}}{||\mathbf{x}|| \cdot ||\mathbf{i}||}$$
- **How do you quickly find items closest to \mathbf{x} ?**
 - Job for LSH!

Pros: Content-based Approach

- **+: No need for data on other users**
 - No item cold-start problem, no sparsity problem
- **+: 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

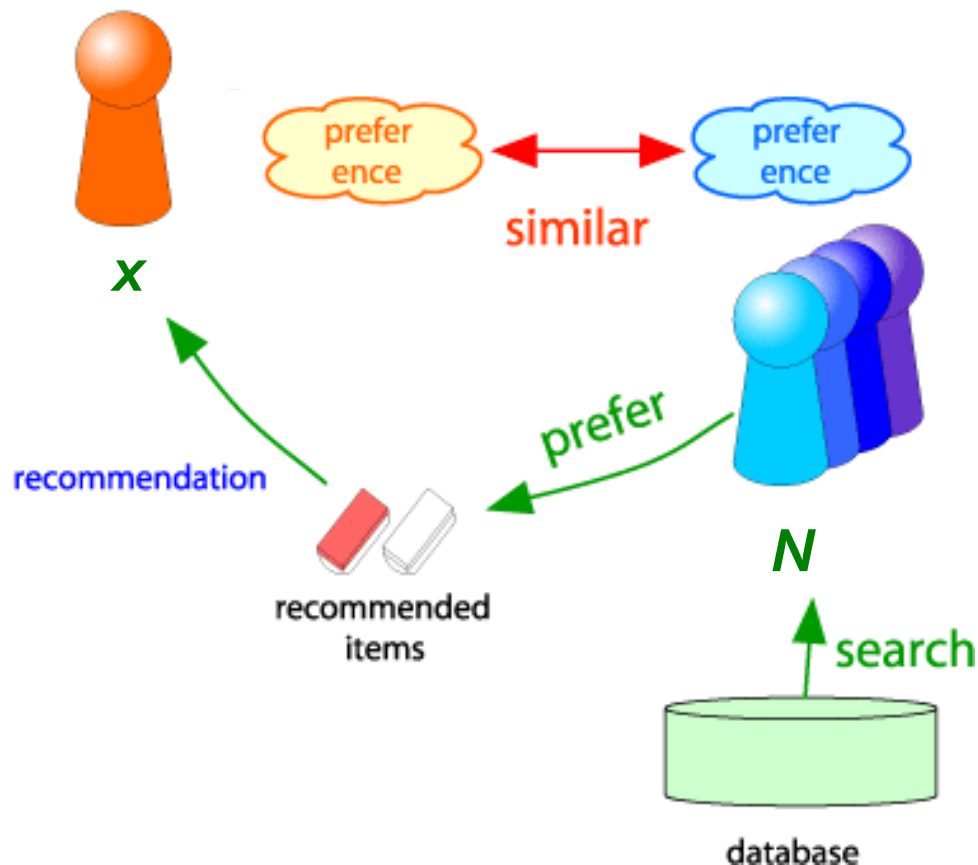
Harnessing quality judgments of other users

Collaborative Filtering

- Does not build item profile or user profile
- In place of item-profile (user-profile) we use its row (column) in the utility matrix.
- Comes in two flavors:
 - User-user collaborative filtering
 - Item-Item collaborative filtering

User-User 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

$$\begin{aligned}r_x &= [1, _, _, 1, 3] \\ r_y &= [1, _, 2, 2, _]\end{aligned}$$

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

- **Jaccard similarity measure**

- **Problem:** Ignores the value of the rating

r_x, r_y as sets:
 $r_x = \{1, 4, 5\}$
 $r_y = \{1, 3, 4\}$

- **Cosine similarity measure**

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

r_x, r_y as points:
 $r_x = \{1, 0, 0, 1, 3\}$
 $r_y = \{1, 0, 2, 2, 0\}$

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

- **Pearson correlation coefficient**

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

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

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

Similarity Metric

$$\text{Cosine sim: } \text{sim}(x, y) = \frac{\sum_i r_{xi} \cdot r_{yi}}{\sqrt{\sum_i r_{xi}^2} \cdot \sqrt{\sum_i r_{yi}^2}}$$

	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:** $0.380 > 0.322$
 - 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 \mathbf{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 i of user x :**
 - $r_{xi} = \frac{1}{k} \sum_{y \in N} r_{yi}$
 - Or even better: $r_{xi} = \frac{\sum_{y \in N} s_{xy} \cdot r_{yi}}{\sum_{y \in N} s_{xy}}$
- **Many other tricks possible...**

Shorthand:

$$s_{xy} = \text{sim}(x, y)$$

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

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

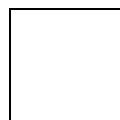
s_{ij} ... similarity of items i and j

r_{xj} ... rating of user x on item j

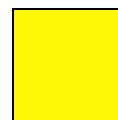
$N(i;x)$... set of items which were rated by x and similar to i

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	



- 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
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	



- estimate rating of movie 1 by user 5

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

		users												$S_{1,m}$
		1	2	3	4	5	6	7	8	9	10	11	12	
movies	1	1		3		?	5			5		4		1.00
	2			5	4			4			2	1	3	-0.18
	<u>3</u>	2	4		1	2		3		4	3	5		<u>0.41</u>
	4		2	4		5			4			2		-0.10
	5			4	3	4	2					2	5	-0.31
	<u>6</u>	1		3		3			2			4		<u>0.59</u>

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

$$m_1 = (1+3+5+5+4)/5 = 3.6$$

row 1: $[-2.6, 0, -0.6, 0, 0, 1.4, 0, 0, 1.4, 0, 0.4, 0]$

2) Compute dot products 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		$S_{1,m}$ 1.00
	2			5	4			4			2	1	3	-0.18
	<u>3</u>	2	4		1	2		3		4	3	5		<u>0.41</u>
	4		2	4		5			4			2		-0.10
	5			4	3	4	2					2	5	-0.31
	<u>6</u>	1		3		3			2			4		<u>0.59</u>

Compute similarity weights:

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

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

		users											
		1	2	3	4	5	6	7	8	9	10	11	12
movies	1	1		3		2.6	5			5		4	
	2			5	4			4			2	1	3
	<u>3</u>	2	4		1	2		3		4	3	5	
	4		2	4		5			4			2	
	5			4	3	4	2					2	5
	<u>6</u>	1		3		3			2			4	

Predict by taking weighted average:

$$r_{1.5} = (0.41 \cdot 2 + 0.59 \cdot 3) / (0.41 + 0.59) = 2.6$$

$$r_{ix} = \frac{\sum_{j \in N(i;x)} s_{ij} \cdot r_{jx}}{\sum s_{ij}}$$

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

movies

users

1	3	4			
	3	5			5
		4	5		5
		3			
		3			
2			2		2
				5	
	2	1			1
	3			3	
1					

Evaluation

movies

users

1	3	4			
	3	5			5
		4	5		5
		3			
		3			
2			?		?
				?	
	2	1			?
	3			?	
1					

Test Data Set

Evaluating Predictions

- **Compare predictions with known ratings**

- **Root-mean-square error (RMSE)**

- $\sqrt{\frac{1}{N} \sum_{xi} (r_{xi} - r_{xi}^*)^2}$ where r_{xi} is predicted, r_{xi}^* is the true rating of x on i
 - *N is the number of points we are making comparisons on*

- **Precision at top 10:**

- % of relevant items in top 10

- **Another approach: 0/1 model**

- **Coverage:**

- Number of items/users for which the 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>

On Thursday:

The Netflix prize and the
Latent Factor Models

On Thursday: The Netflix Prize

■ Training data

- 100 million ratings, 480,000 users, 17,770 movies
- 6 years of data: 2000-2005

■ Test data

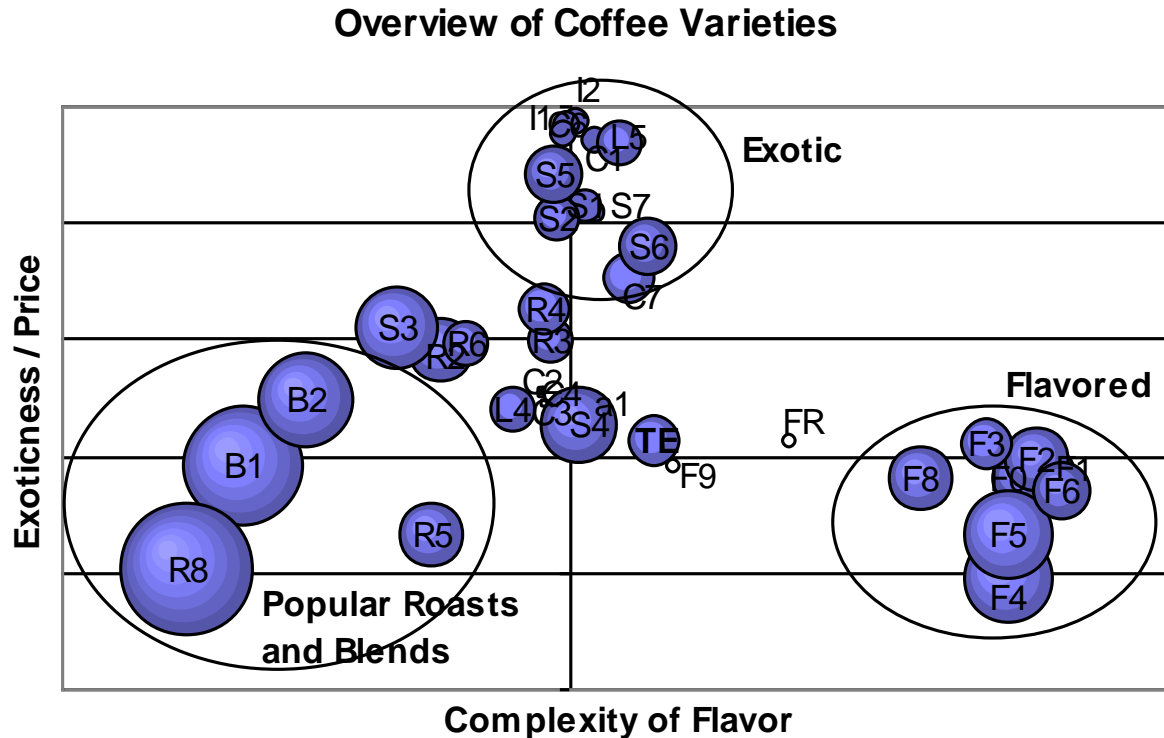
- Last few ratings of each user (2.8 million)
- Evaluation criterion: root mean squared error (RMSE)
- Netflix Cinematch RMSE: 0.9514

■ Competition

- 2,700+ teams
- \$1 million prize for 10% improvement on Cinematch

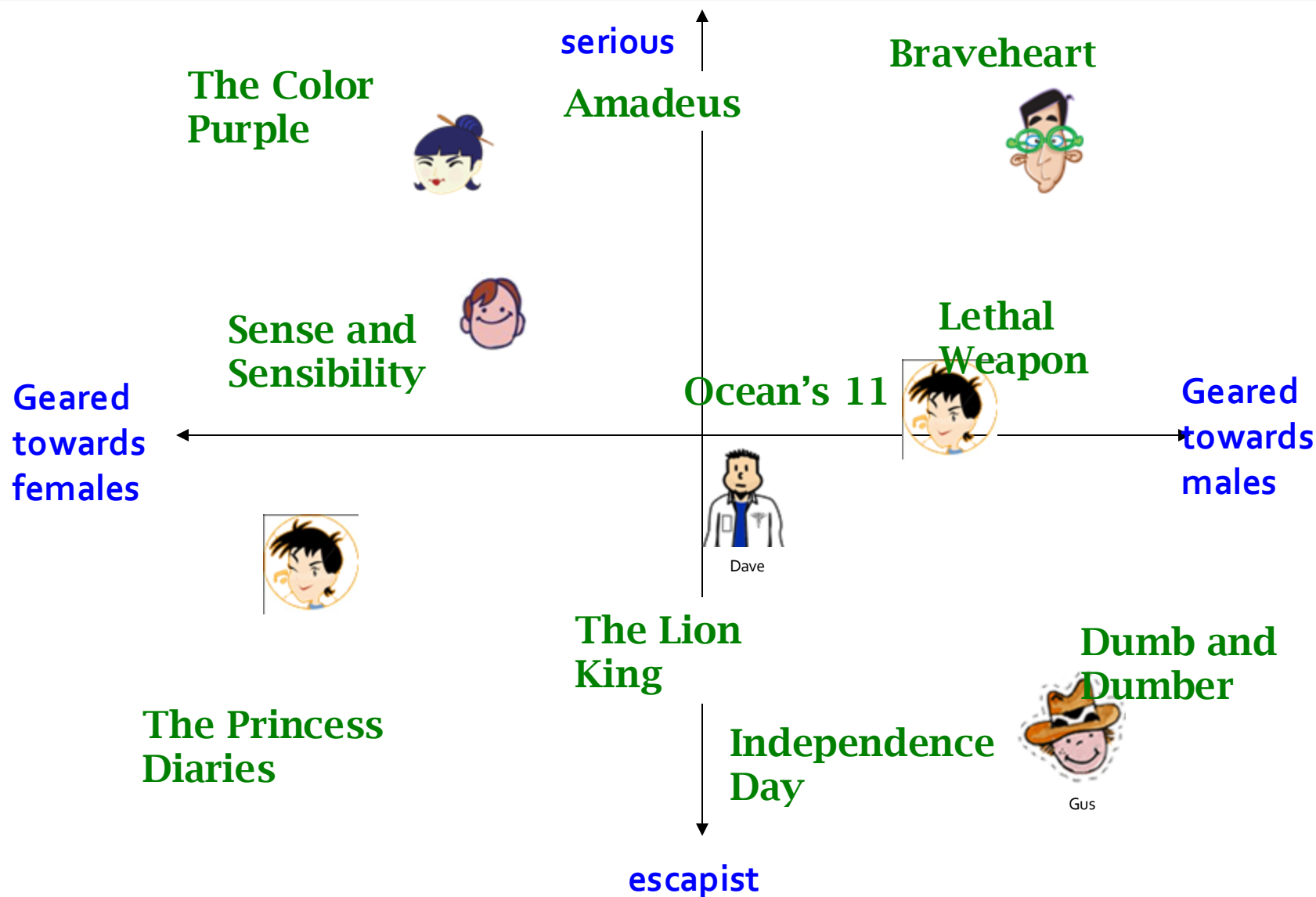
On Thursday: Latent Factor Models

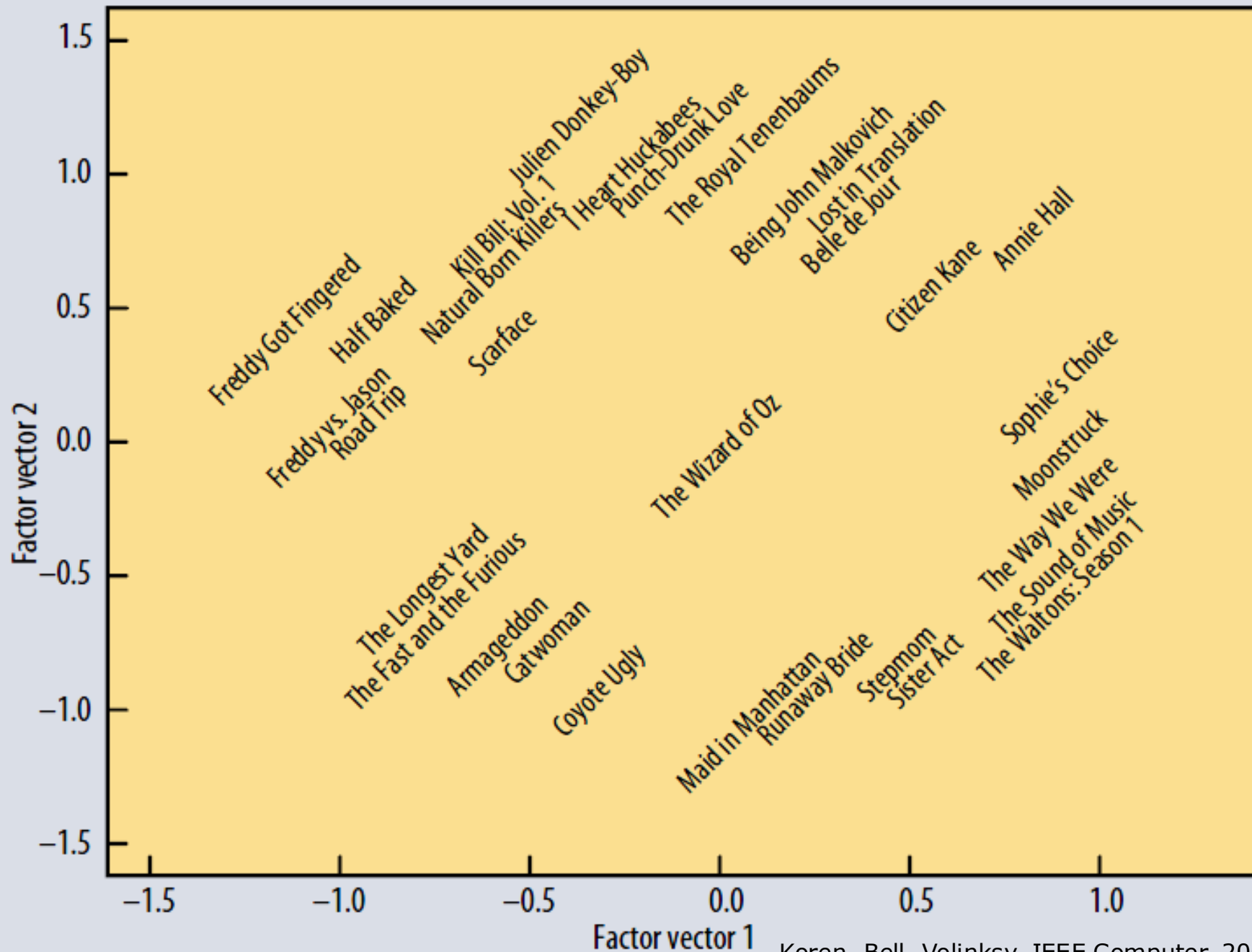
- **Next topic: Recommendations via Latent Factor models**



The bubbles above represent products sized by sales volume. Products close to each other are recommended to each other.

Latent Factor Models (i.e., SVD++)





Koren, Bell, Volinsky, IEEE Computer, 2009