

# Recommender Systems

<b>Class</b>	Data Mining
<b>Program</b>	Master in Computer Engineering
<b>University</b>	Sapienza University of Rome
<b>Semester</b>	Fall 2024
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<b>Slides</b>	Carlos Castillo <a href="http://chato.cl/">http://chato.cl/</a>

## Sources:

- Ricci, Rokach and Shapira: Introduction to Recommender Systems Handbook [[link](#)]
- Bobadilla et al. Survey 2013 [[link](#)]
- Xavier Amatriain 2014 tutorial on rec systems [[link](#)]
- Ido Guy 2011 tutorial on social rec systems [[link](#)]
- Alex Smola's tutorial on recommender systems [[link](#)]

# Why recommender systems?

# Definition

Recommender systems are software tools and techniques providing suggestions for items to be of use to a user.

# User-based recommendations

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

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

1.



## **Short and Sweet**

by Dan Lepard (29 Sep 2011)

Average Customer Review: ★★★★★ (92)

In stock

RRP: ~~£26.00~~

**Price: £14.00**

39 used & new from £7.91

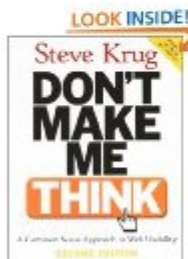
Add to Basket

Add to Wish List

I own it  Not interested  ★★★★★ Rate this item

Recommended because you purchased **Mary Berry's Baking Bible** and more (Fix this)

2.



## **Don't Make Me Think!: A Common Sense Approach to Web Usability**

by Steve Krug (18 Aug 2005)

Average Customer Review: ★★★★★ (99)

In stock

RRP: ~~£24.99~~

**Price: £17.49**

73 used & new from £8.50

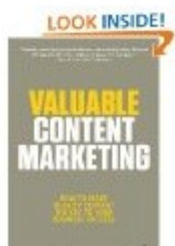
Add to Basket

Add to Wish List

I own it  Not interested  ★★★★★ Rate this item

Recommended because you purchased **Content Strategy for the Web (Voices That Matter)** (Fix this)

3.



## **Valuable Content Marketing: How to Make Quality Content the Key to Your Business Success**

by Sonja Jefferson (3 Jan 2013)

Average Customer Review: ★★★★★ (24)

In stock

RRP: ~~£49.99~~

**Price: £17.59**

55 used & new from £12.49

Add to Basket

Add to Wish List

es



THE GODFATHER MEETS NIXON  
A FILM BY PAOLO SOZZANI

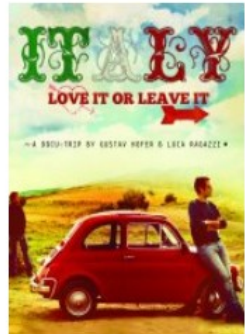
# IL DIVO

THE STUNNING LIFE OF GIUSEPPE ANGERISI



★★★★

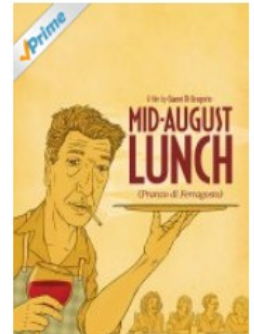
NUMBER ONE ON THE BEST OF MARTIN SCORSESE AND TRACY M. FORD COMPILATION



# ITALY

LOVE IT OR LEAVE IT

A BROTHERHOOD BY GUSTAV HOFER & LEA RAGAZZI



Prime

# MID-AUGUST LUNCH

(FRANCESCO FERRAGROSSI)



# CARO DIARIO



# L'ECLISSE



# To Rome With Love



ACADEMY AWARD NOMINEE - BEST FOREIGN LANGUAGE FILM

(L'Espresso) (L'Espresso) (L'Espresso) (L'Espresso)

# AFTER THE WEDDING

DESIGNED BY JACQUES-ANTOINE LAFAY

# Assumptions

- Users rely on recommendations
- Users lack sufficient personal expertise
- Number of items is very large
  - e.g. around  $10^{10}$  books in Amazon
- Recommendations need to be personalized

Amazon as of  
December 2015

Paperback (30,020,393)

Hardcover (11,107,514)

Kindle Edition (2,861,600)

Audible Audio Edition (87,578)

Printed Access Code (30,338)

Digital Access Code (4)

Loose Leaf (94,891)

Audio CD (433,467)

Board Book (168,736)

# Who uses recommender systems?

- Retailers and e-commerce in general
  - Amazon, Netflix, etc.
- Service sites, e.g. travel sites
- Media organizations
- Dating apps
- ...

# Why?

- Increase number of items sold
  - 2/3 of Netflix watched are recommendations
  - 1/3 of Amazon sales are from recommendations
  - ...



# Why? (cont.)

- Sell more diverse items
- Increase user satisfaction
  - Users enjoy the recommendations
- Increase user fidelity
  - Users feel recognized (but not creeped out)
- Understand users (see next slides)

# By-products

- Recommendations generate by-products
- Recommending requires understanding users and items, which is valuable by itself
- Some recommender systems are very good at this (e.g. factorization methods)
- Automatically identify marketing profiles
- Describe users to better understand them

# The recommender system problem


**Estimate the utility for a user of an item for which the user has not expressed utility**

*What information can be used?*

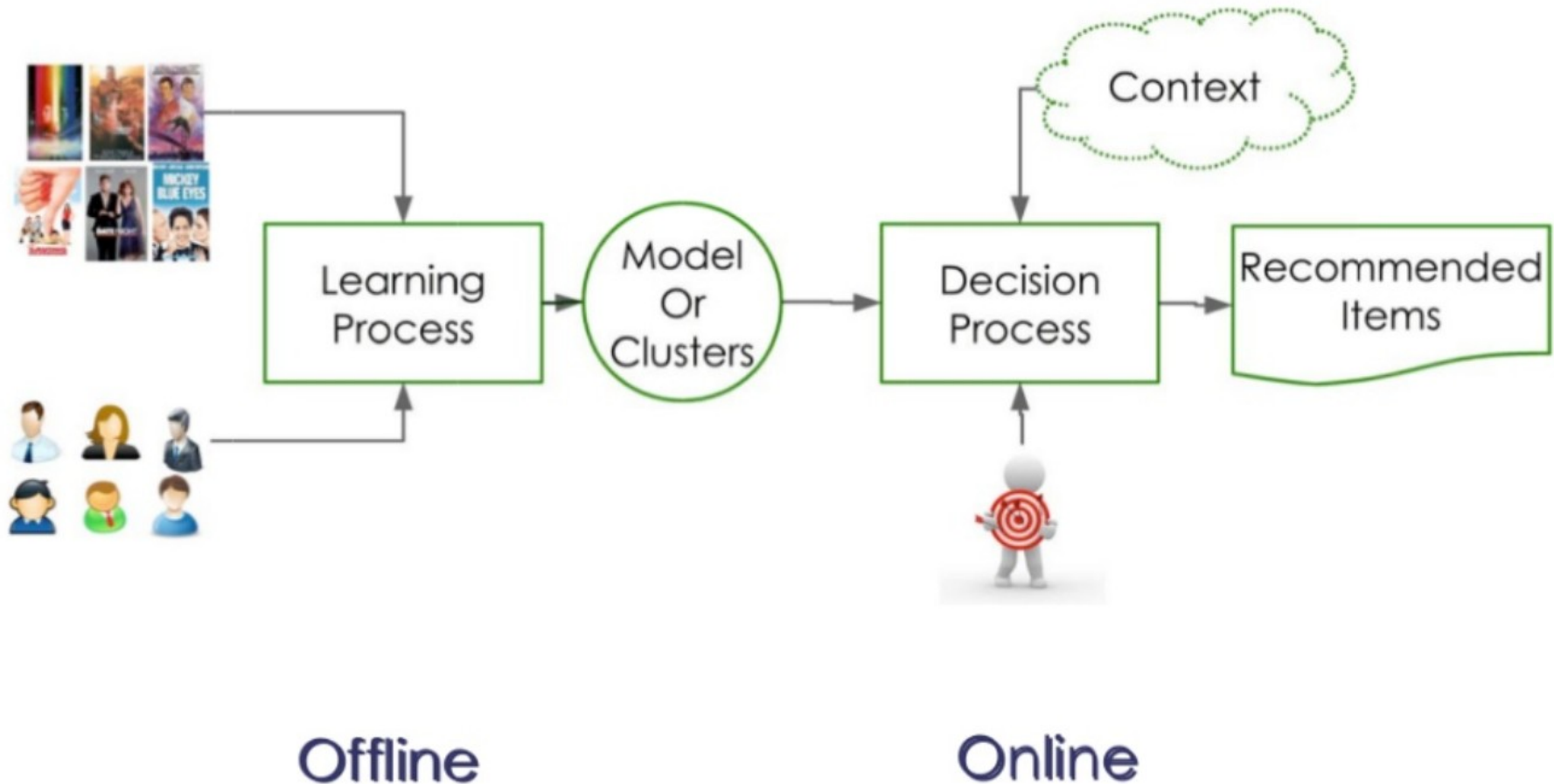
# Types of problem

- Find some good items (most common)
- Find all good items
- Annotate in context (why I would like this)
- Recommend a sequence (e.g. tour of a city)
- Recommend a bundle (camera+lens+bag)
- Support browsing (seek longer session)
- ...

# Data sources

- Items, Users
  - Structured attributes, semi-structured or unstructured descriptions
- Transactions
  - Appraisals
    - Numerical ratings (e.g. 1-5) 
    - Binary ratings (like/dislike)
    - Unary ratings (like/don't know)
  - Sales
  - Tags/descriptions/reviews

# Recommender system process



*Why is part of the processing done offline?*

# Aspects of this process

- Data preparation
  - Normalization, removal of outliers, feature selection, dimensionality reduction, ...
- Data mining
  - Clustering, classification, rule generation, ...
- Post-processing
  - Visualization, interpretation, meta-mining, ...

# Desiderata for recommender system

- Must inspire trust
- Must convince users to try the items
- Must offer a good combination of novelty, coverage, and precision
- Must have a somewhat transparent logic
- Must be user-tunable

We're recommending **Foreign Films in Video** because ✕



3 Idiots  
Aamir Khan

Don't use for recommendations



Kaminey  
Shahid Kapur

Don't use for recommendations



My Name Is Khan  
Shah Rukh Khan

Don't use for recommendations



# Human factors

- Advanced systems are **conversational**
- Transparency and scrutability
  - Explain users how the system works
  - Allow users to tell the system it is wrong
- Help users make a good decision
- Convince users in a persuasive manner
- Increase enjoyment to users
- Provide serendipity

# Serendipity

- “An aptitude for making desirable discoveries by accident”
- Don't recommend items the user already knows
- Delight users by expanding their taste
  - But still recommend them something somewhat familiar
- It can be controlled by specific parameters

# High-level approaches

- Memory-based
  - Use data from the past in a somewhat “raw” form
- Model-based
  - Use models built from data from the past

# Approaches

- Collaborative filtering
- Content-based (item features)
- Knowledge-based (expert system)
- Personalized learning to rank
  - Estimate ranking function
- Demographic
- Social/community based
  - Based on connections
- Hybrid (combination of some of the above)

# Collaborative filtering

# Collaborative Filtering approach

- User has seen/liked certain items
- Community has seen/liked certain items
- Recommend to users items similar to the ones they have seen/liked
  - Based on finding similar users
  - Based on finding similar items

# Algorithmic elements

- M users and N items
- Transaction matrix  $R_{M \times N}$
- Active user
- Method to compute similarity of users
- Method to sample high-similarity users
- Method to aggregate their ratings on an item

# k nearest users algorithm


- Compute common elements with other users
- Compute distance between rating vectors
- Pick top 3 most similar users
- For every unrated item
  - Average rating of 3 most similar users
- Recommend highest score unrated items



# Ratings data



ITEMS 

USERS 


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

# Try it! Generate recommendations

ITEMS

USERS

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



$$\text{dist}(i, j) = \frac{\sum_{\alpha \in U_i \cap U_j} |r_i(\alpha) - r_j(\alpha)|}{|U_i \cap U_j|}$$

Given the **red** user  
Determine 3 nearest users  
Average their ratings on unrated items  
Pick top 3 unrated elements

# Compute user intersection size

		ITEMS														
		1	2	3	4	5	6	7	8	9	1	1	1	$ U_i \cap U_j $	$\text{sim}(i, j)$	
											0	1	2			
USERS	1	1			5					2		3		0		
	2	5		1		5		4			5	3	2	3		
	3		5	5			1		3				2	4	3	
	4		3			5	4				5			1		
	5				2	5	4			4	5				3	
	6	4		3			1			4		2			1	
	7		4	1		4		5				4	1		3	

# Compute user similarity

ITEMS

USERS

	1	2	3	4	5	6	7	8	9	10	11	12	$ U_i \cap U_j $	$\text{sim}(i, j)$
1	1			5					2		3		0	
2	5		1		5		4			5	3	2	3	0.33
3		5	5			1		3			2	4	3	2.67
4		3			5	4				5		1		
5				2	5	4			4	5			3	0.00
6	4		3			1			4		2		1	3.00
7		4	1		4		5				4	1	3	0.67

# Pick top-3 most similar

		ITEMS														
		1	2	3	4	5	6	7	8	9	1	1	1	$ U_i \cap U_j $	$\text{sim}(i, j)$	
											0	1	2			
USERS	2	5		1		5		4			5	3	2	3	0.33	
	4		3			5	4				5		1			
	5				2	5	4			4	5			3	0.00	
	7		4	1		4		5				4	1	3	0.67	

# Estimate unrated items

ITEMS

USERS

	1	2	3	4	5	6	7	8	9	1	1	1
										0	1	2
2	5		1		5		4			5	3	2
4	5.0	3	1.0	2.0	5	4	4.5	-	4.0	5	3.5	1
5				2	5	4			4	5		
7		4	1		4		5				4	1

$|U_i \cap U_j| \text{ sim}(i, j)$

3	0.33
3	0.00
3	0.67

# Recommend top-3 estimated

ITEMS

USERS

	1	2	3	4	5	6	7	8	9	1	1	1
										0	1	2
2	5		1		5		4			5	3	2
4	5.0	3	1.0	2.0	5	4	4.5	-	4.0	5	3.5	1
5				2	5	4			4	5		
7		4	1		4		5				4	1

$|U_i \cap U_j| \text{ sim}(i, j)$

3	0.33
3	0.00
3	0.67


# Improvements?

- *How would you improve the algorithm?*
- *How would you provide explanations?*




# Item-based collaborative filtering

ITEMS



USERS

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



- Would user 4 like item 11?

# Item-based collaborative filtering

ITEMS



USERS


	1	2	3	4	5	6	7	8	9	10	11	12
1	1			5					2		3	
2	5		1		5		4			5	3	2
3		5	5			1		3			2	4
4		3			5	4				5		1
5				2	5	4			4	5		
6	4		3			1			4		2	
7		4	1		4		5				4	1
	2.0	1.5	2.3	2.0	1.0	1.0	1.0	1.0	1.5	2.0	-	2.0



- Compute pair-wise similarities to target item

# Item-based collaborative filtering

ITEMS



USERS

	1	2	3	4	5	6	7	8	9	10	11	12
1	1			5					2		3	
2	5		1		5		4			5	3	2
3		5	5			1		3			2	4
4		3			5	4				5		1
5				2	5	4			4	5		
6	4		3			1			4		2	
7		4	1		4		5				4	1
					1.0	1.0	1.0	1.0			-	



- Pick k most similar items

# Item-based collaborative filtering

ITEMS



USERS

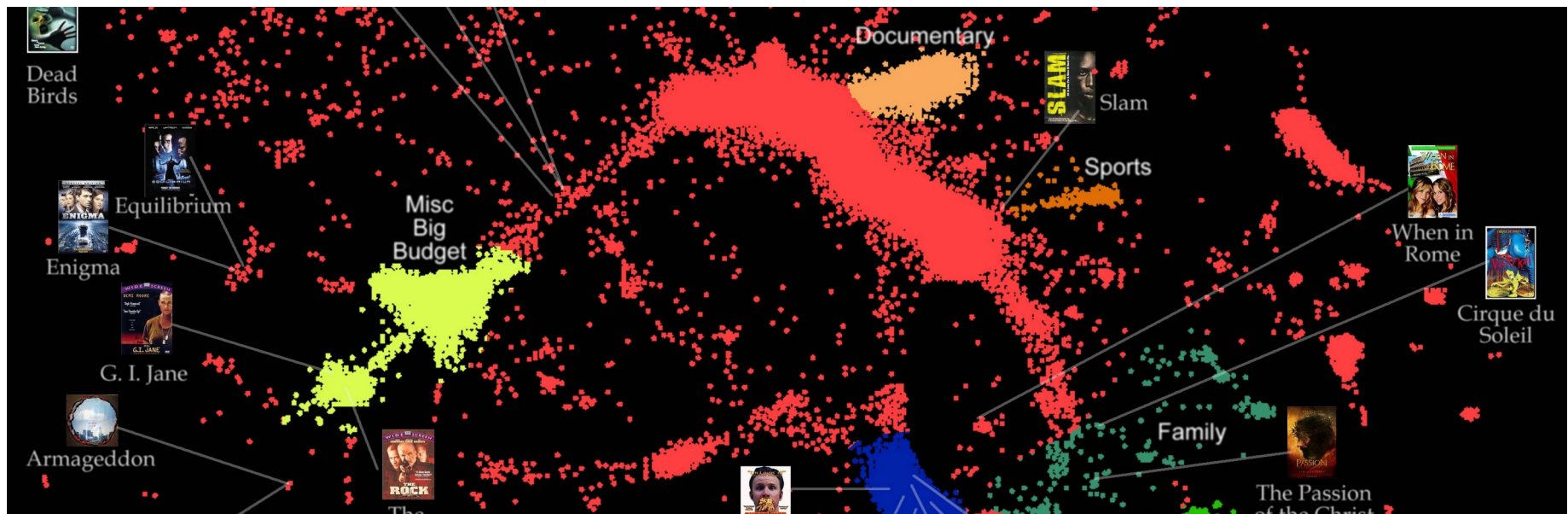
	1	2	3	4	5	6	7	8	9	10	11	12
1	1			5					2		3	
2	5		1		5		4			5	3	2
3		5	5			1		3			2	4
4		3			5	4				5	4.5	1
5				2	5	4			4	5		
6	4		3			1			4		2	
7		4	1		4		5				4	1
					1.0	1.0	1.0	1.0			-	



- Average ratings of target user on item

# Performance implications

- Similarity between users is uncovered slowly
- Similarity between items is supposedly static
  - Can be precomputed!
- Item-based clusters can also be precomputed



# Weaknesses

- Assumes standardized products
  - E.g. a touristic destination at any time of the year and under any circumstance is the same item
- Does not take into account context
- Requires a relatively large number of transactions to yield reasonable results

# Cold-start problem

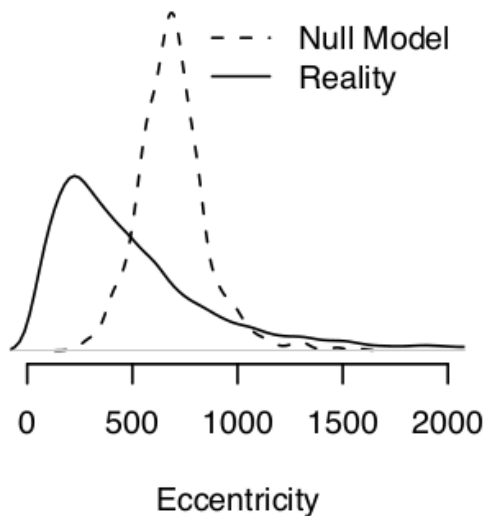
- What to do with a new item?
- What to do with a new user?

# Assumptions

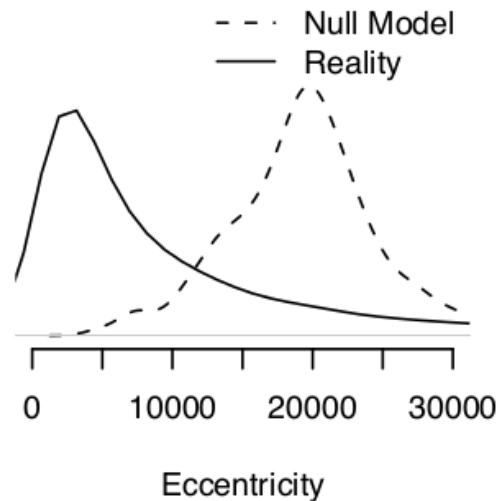
- Collaborative filtering assumes the following:
  - We take recommendations from friends
  - Friends have similar tastes
  - A person who have similar tastes to you, could be your friend
  - Discover people with similar tastes, use them as friends
- BUT, people's tastes are complex!



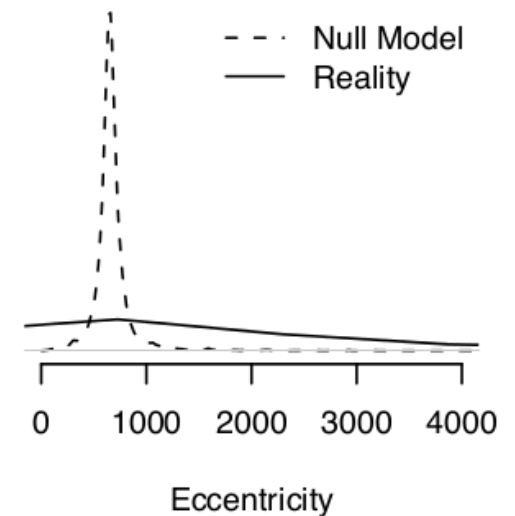
# Ordinary people and extraordinary tastes



(a) Netflix



(b) Yahoo! Music



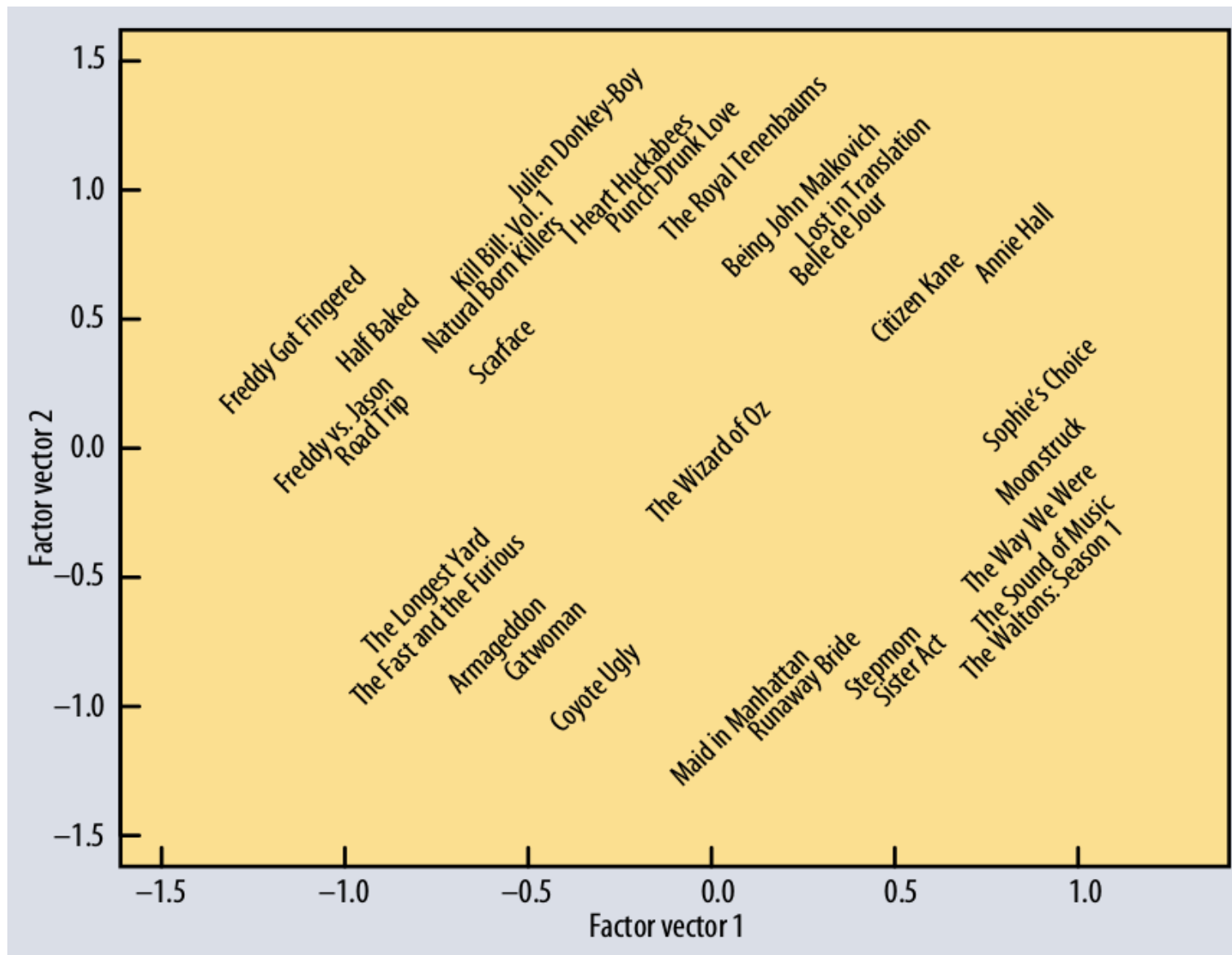
(c) Web Browsing (Nielsen)

Distribution of user eccentricity: the median rank of consumed items.

In the null model, users select items proportional to item popularity

# Matrix factorization approaches

# 2D projection of interests



# SVD approach

$$R_{n \times m} = U_{n \times f} S_{f \times f} V_{f \times m}$$

- R is the matrix of ratings
  - n users, m items
- U is a user-factor matrix
- S is a diagonal matrix, strength of each factor
- V is a factor-item matrix
- Matrices USV can be computed used an approximate SVD method

# General factorization approach

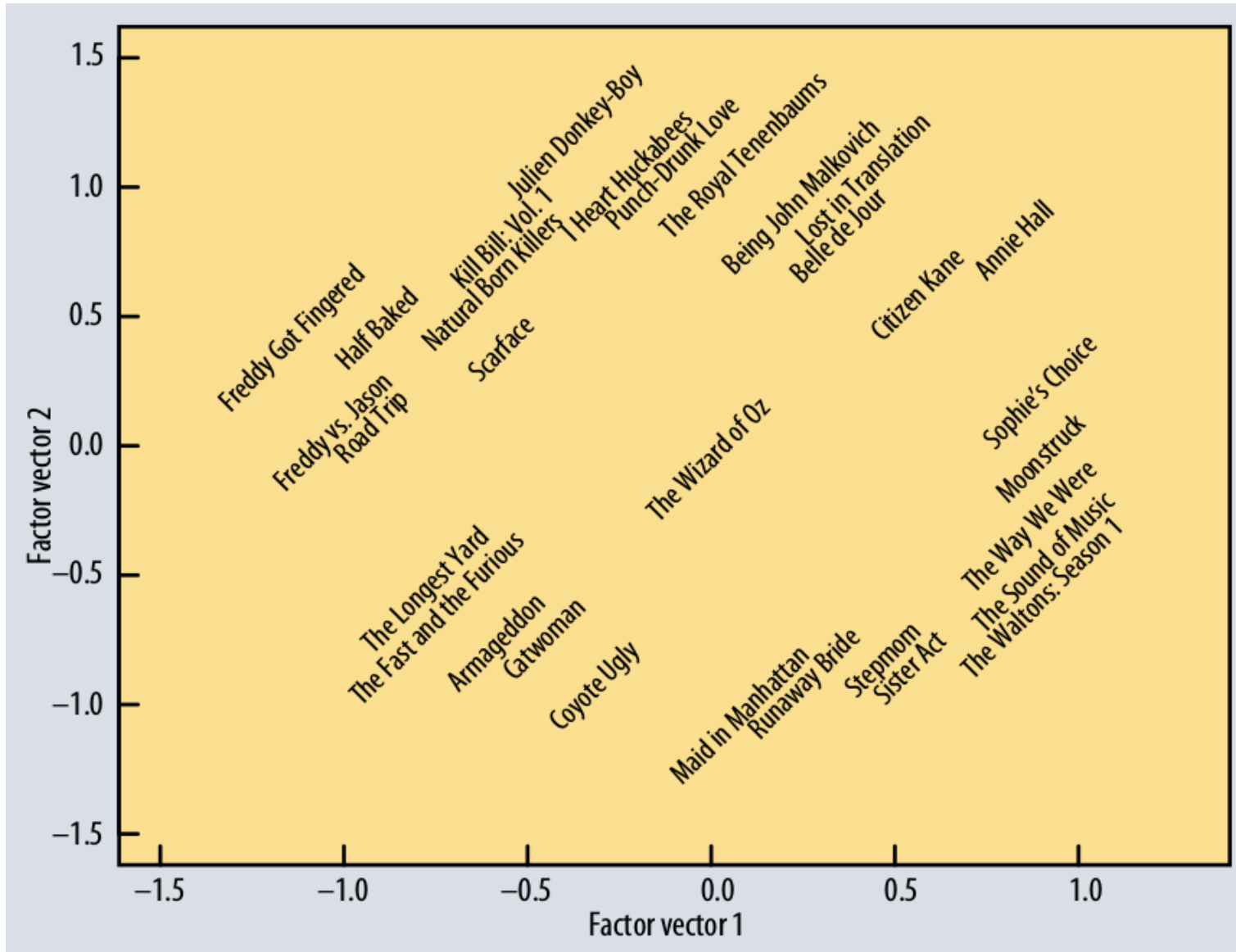
$$R_{n \times m} = P_{n \times f} Q_{f \times m}$$

- R is the matrix of ratings
  - n users, m items
- P is a user-factor matrix
- Q is a factor-item matrix

(Sometimes we force P, Q to be non-negative: factors are easier to interpret!)

$$R_{n \times m} = P_{n \times f} Q_{f \times m}$$

# What is this plot?

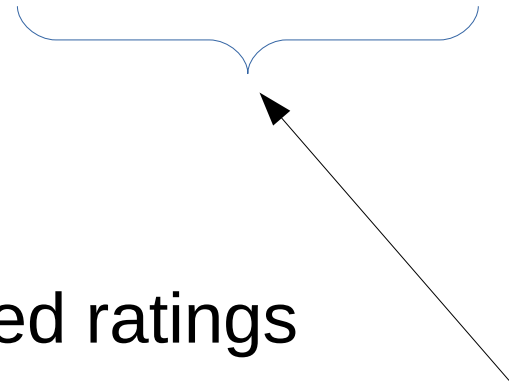


[Koren et al. 2009]

# Computing expected ratings

- Given:
  - user vector  $p_u \in \mathbb{R}^f$
  - item vector  $q_i \in \mathbb{R}^f$
- Expected rating is  $\hat{r}_{ui} = \langle p_u, q_i \rangle$

# Model directly observed ratings

$$\min_{q, p} \sum_{(u, i) \in R_o} (r_{ui} - \langle p_u, q_i \rangle)^2 + \lambda(\|q_i\|^2 + \|p_u\|^2)$$


- $R_o$  are the observed ratings
- We want to minimize a reconstruction error
- Second term avoids over-fitting
  - Parameter  $\lambda$  found by cross-validation
- Two basic optimization methods



# 1. Stochastic gradient descend

$$\min_{q, p} \sum_{(u, i) \in R_o} (r_{ui} - \langle p_u, q_i \rangle)^2 + \lambda(\|q_i\|^2 + \|p_u\|^2)$$

- Compute reconstruction error

$$e_{ui} = r_{ui} - \langle p_u, q_i \rangle$$

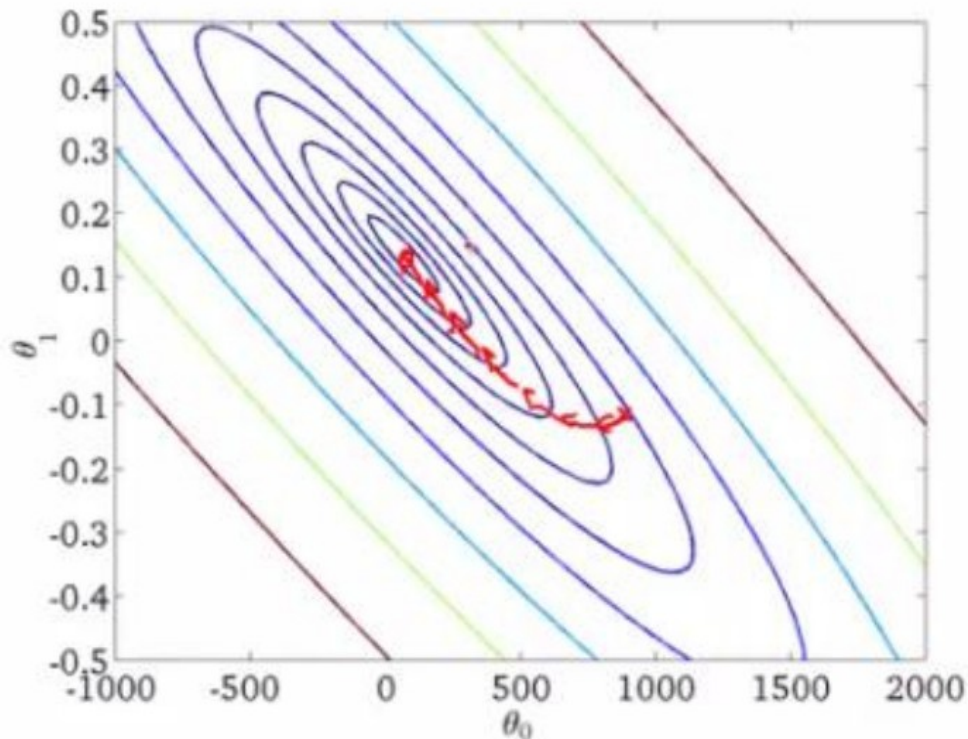
- Update in opposite direction to gradient

$$p_u \leftarrow p_u - \eta_t q_i e_{ui} - \eta_t \lambda p_u$$

$$q_i \leftarrow q_i - \eta_t p_u e_{ui} - \eta_t \lambda q_i$$

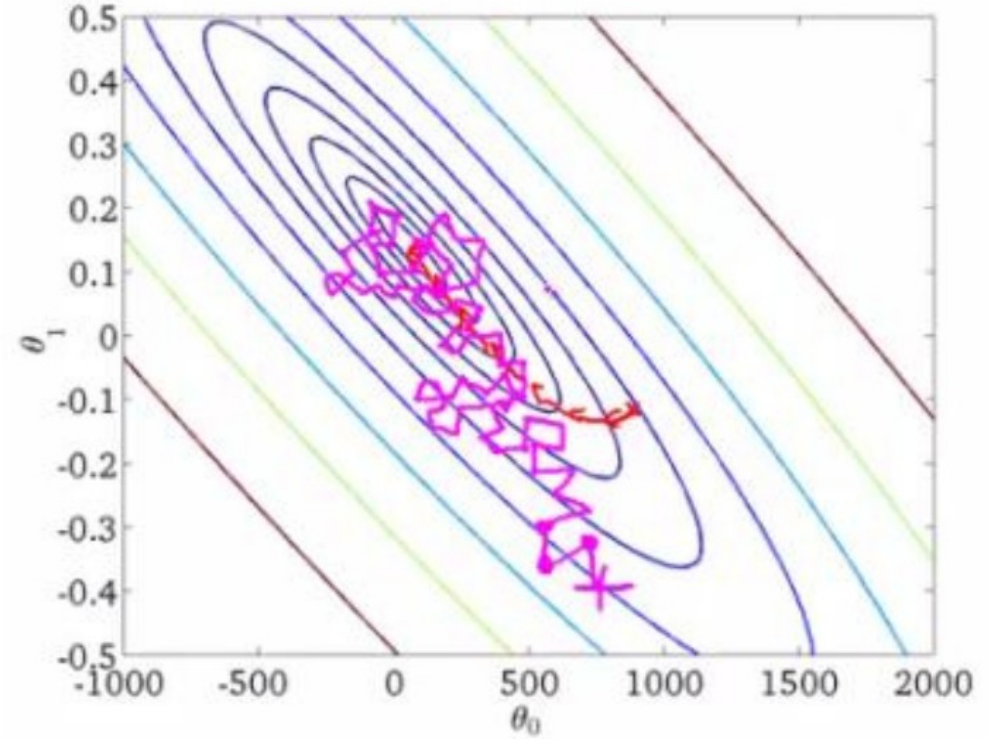
learning speed

# Illustration: batch gradient descent vs stochastic gradient descent



Batch: gradient

$$x \leftarrow x - \eta \nabla F(x)$$



Stochastic: single-example gradient

$$x \leftarrow x - \eta \nabla F_i(x)$$

# A simpler example of gradient descent

Fit a set of  $n$  two-dimensional data points  $(x_i, y_i)$  with a line  $L(x) = w_1 + w_2x$ , means minimizing:

$$F(w) = \sum_{i=1}^n (L(x_i) - y_i)^2 = \sum_{i=1}^n (w_1 + w_2x_i - y_i)^2$$

The update rule is to take a random point and do:

$$\begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \leftarrow \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} - \eta \begin{bmatrix} 2(w_1 + w_2x_i - y_i) \\ 2x_i(w_1 + w_2x_i - y_i) \end{bmatrix}$$

## 2. Alternating least squares

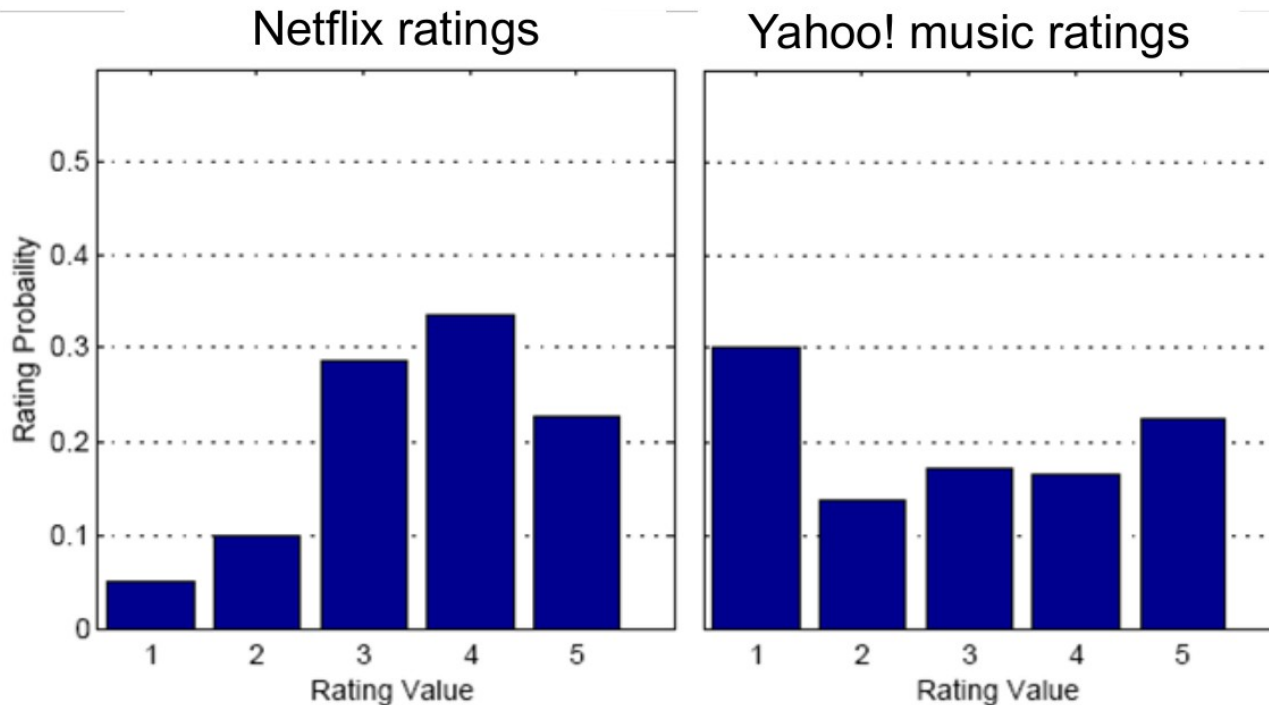
$$\min_{q, p} \sum_{(u, i) \in R_o} (r_{ui} - \langle p_u, q_i \rangle)^2 + \lambda(\|q_i\|^2 + \|p_u\|^2)$$

- With vectors  $p$  fixed:
  - Find vectors  $q$  that minimize above function
- With vectors  $q$  fixed
  - Find vectors  $p$  that minimize above function
- Iterate until convergence
- Slower in general, but parallelizes better

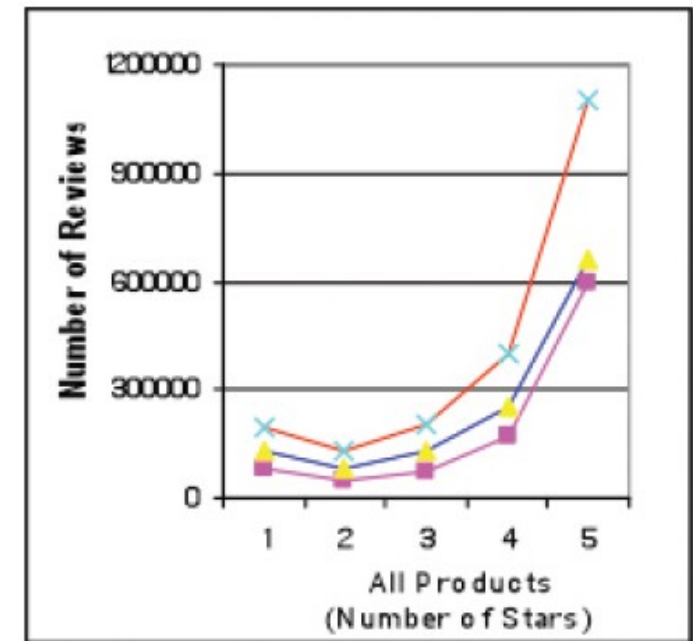
# UNDERSTANDING ONLINE STAR RATINGS:



# Ratings are not normally-distributed

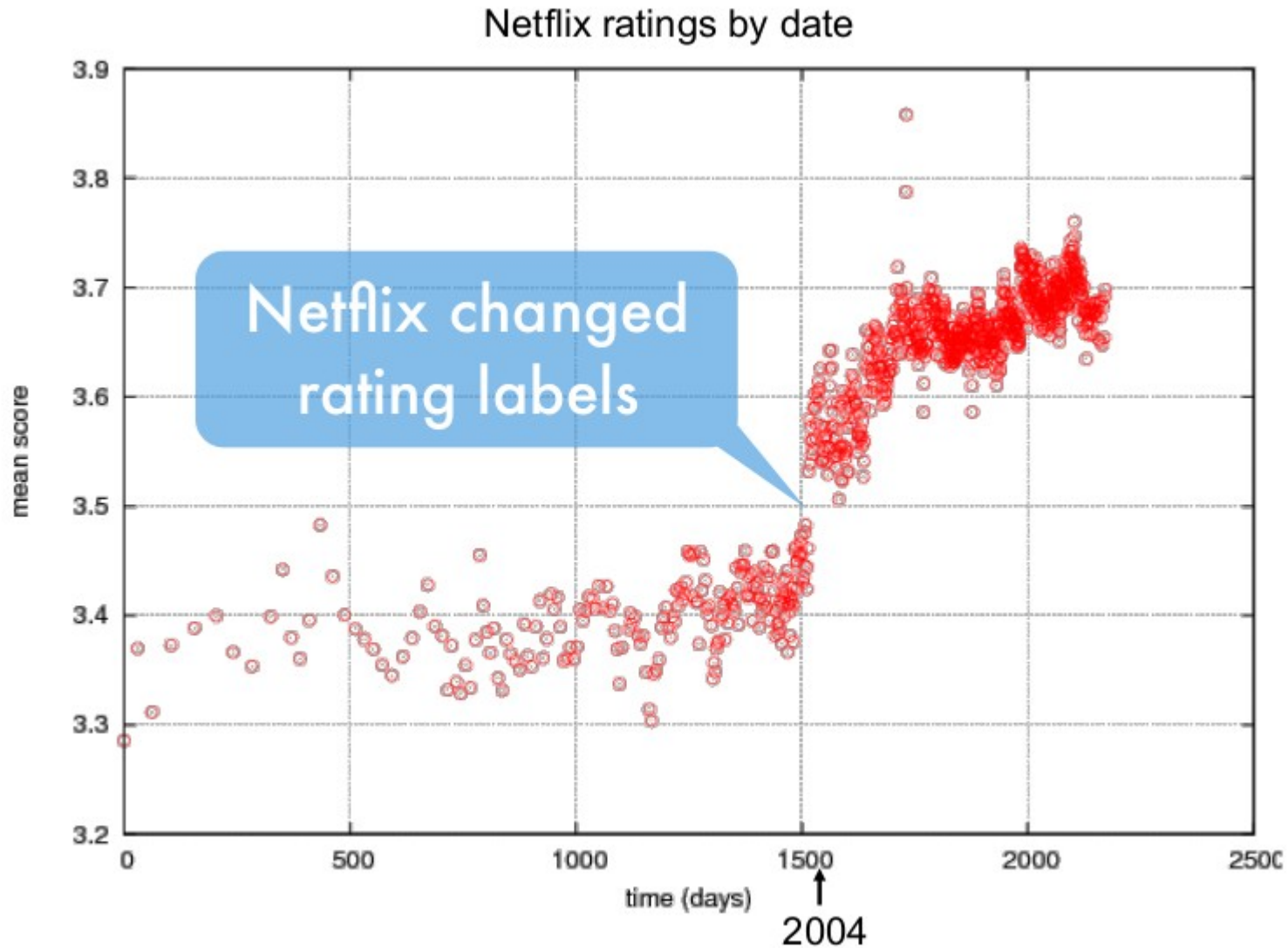


Amazon  
(DVDs, Videos, Books)



Sometimes referred to as the “J” distribution of ratings

# How you label ratings matters



# In general, there are many biases

- Some movies always get better (or worse) ratings than others
- Some people always give better (or worse) ratings than others
- Some systems make people give better (or worse) ratings than others, e.g. labels

$$\hat{r}_{ui} = \mu + b_u + b_i + \langle p_u, q_i \rangle$$

- Time-sensitive user preferences

$$\hat{r}_{ui}(t) = \mu + b_u(t) + b_i + \langle p_u(t), q_i \rangle$$



# Other approaches

# Other approaches

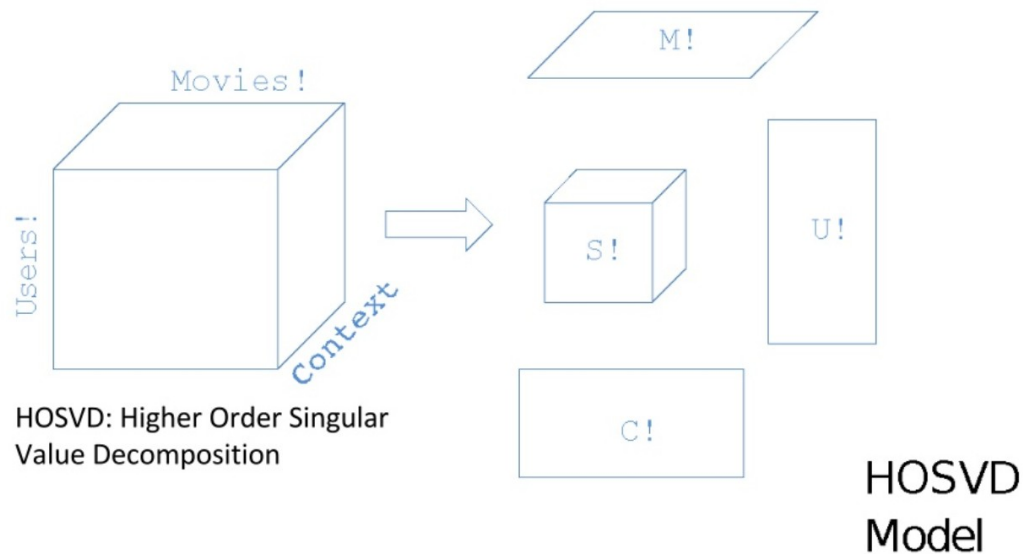
- Association rules (sequence-mining based)
- Regression (e.g. using a neural network)
  - e.g. based on user characteristics, number of ratings in different tags/categories
- Clustering
- Learning-to-rank

# Hybrid methods (some types)

- Weighted
  - E.g. average recommended scores of two methods
- Switching
  - E.g. use one method when little info is available, a different method when more info is available
- Cascade
  - E.g. use a clustering-based approach, then refine using a collaborative filtering approach

# Context-sensitive methods

- Context: where, when, how, ...
- Pre-filter
- Post-filter
- Context-aware methods
  - E.g. tensor factorization



# Evaluation

# Evaluation methodologies

- User experiments
- Precision @ Cut-off
- Ranking-based metrics
  - E.g. Kendall's Tau
- Score-based metrics
  - E.g. RMSE

# Example user testing

- [Liu et al. IUI 2010] News recommender

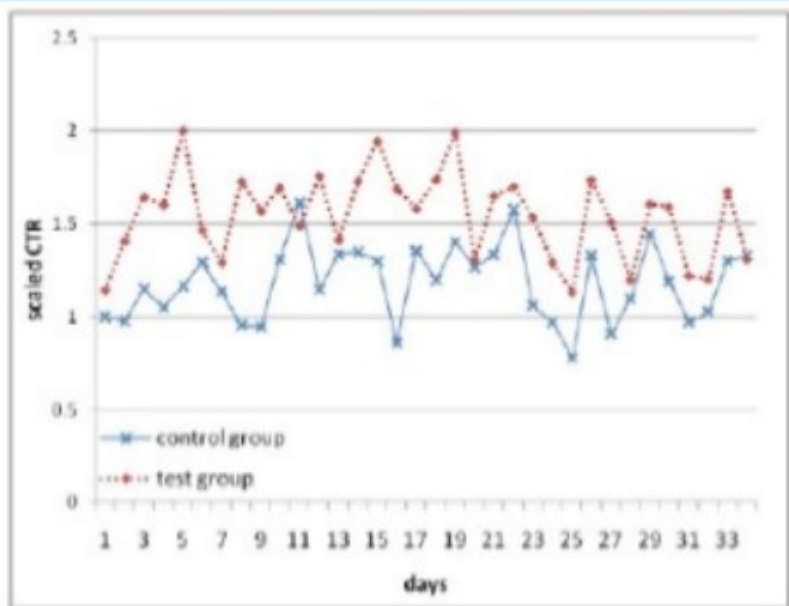


Figure 4. CTR of the recommended news section

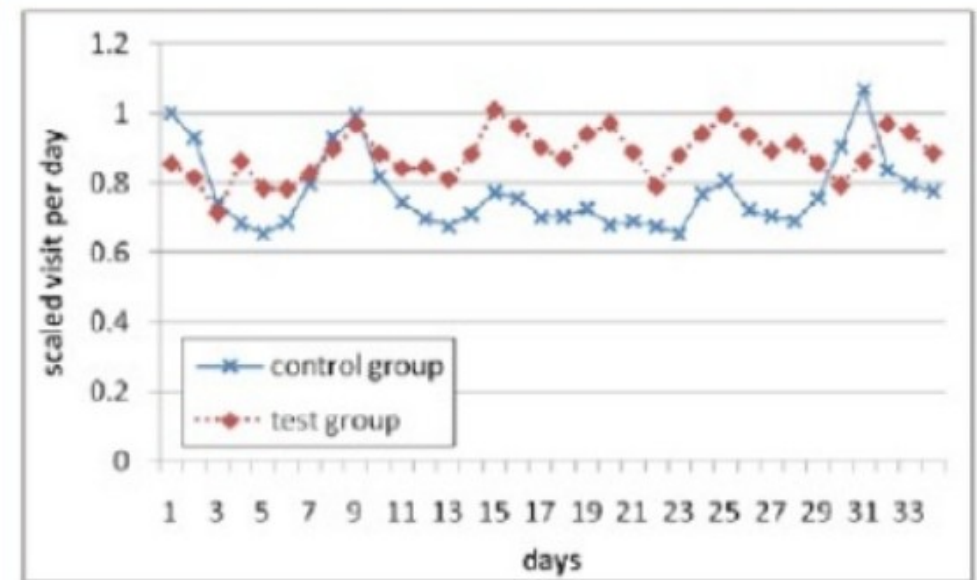


Figure 6. Frequency of website visit per day

# Score-based metric: RMSE

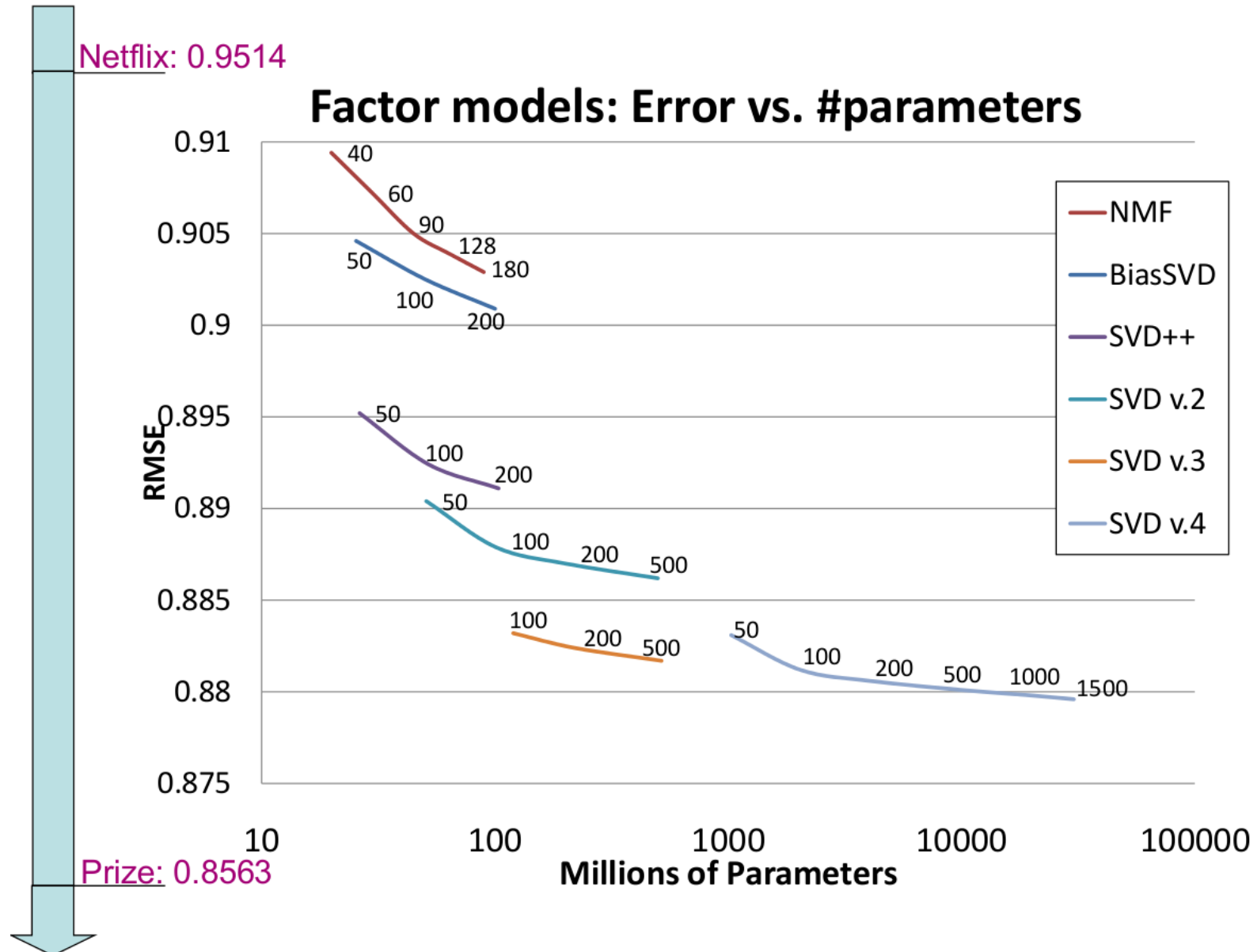
- “Root of mean square error”

$$\text{RMSE} = \sqrt{\frac{1}{|R_o|} \sum_{(u,i) \in R_o} (r_{ui} - \hat{r}_{ui})^2}$$

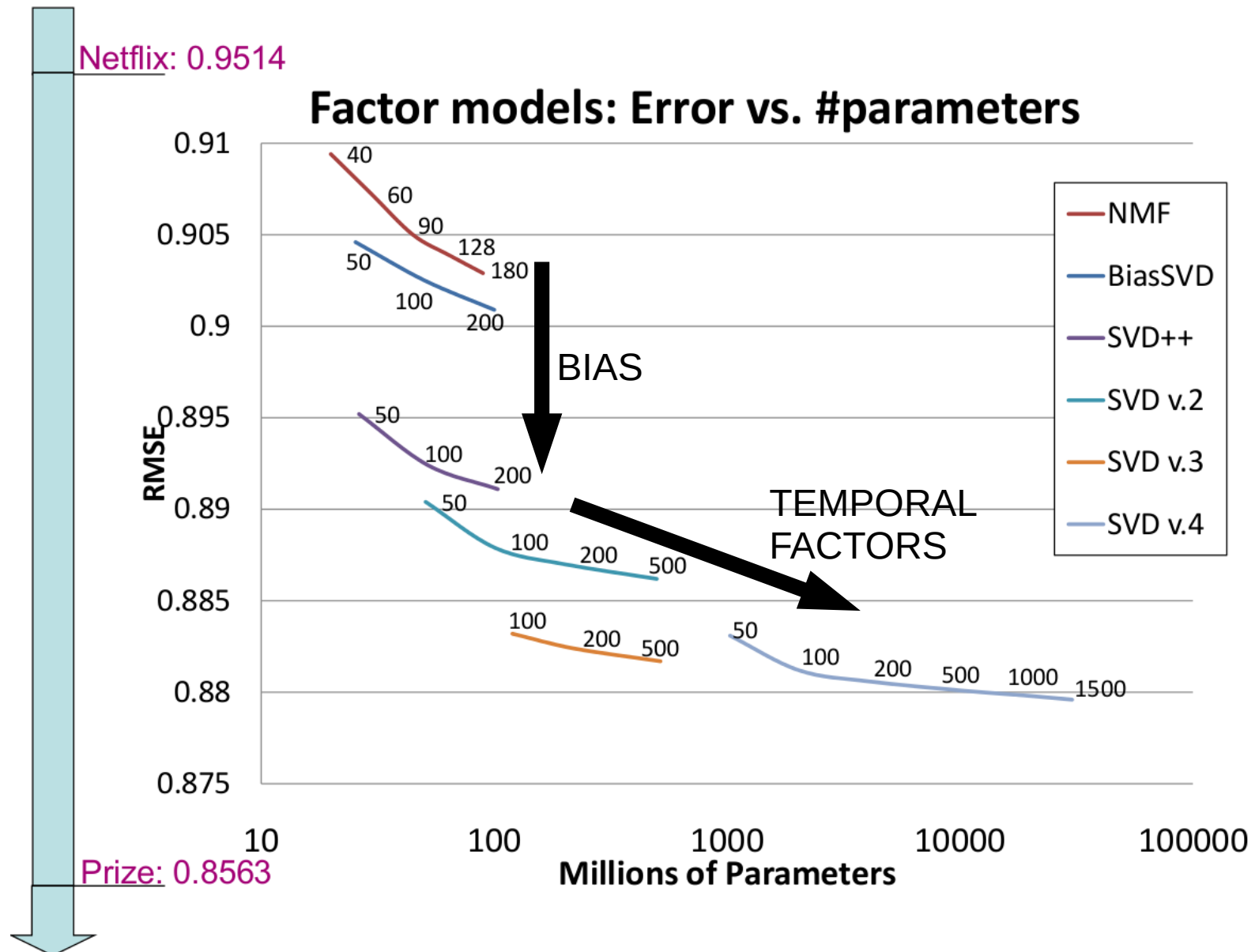
- Problem with all score-based metrics: niche items with good ratings (by those who consumed them)



# Evaluation by RMSE



# Evaluation by RMSE



# Netflix challenge results

- It is easy to provide reasonable results
- It is hard to improve them

