

Introduction to Data Science

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RECOMMENDATIONS EVERYWHERE

RECOMMENDATIONS ARE EVERYWHERE

If you use the internet, you likely suffer from this little problem - *too much information and too little time.*

Most companies try to solve this problem for you using data science

The collage illustrates various recommendation systems:

- News Inbox:** Shows a list of recommended news items, such as "Missouri: Panel Will Study Race and Poverty" and "Florida: A.C.L.U. Sues Over Housing Law".
- Music Player:** Displays a track from "Neon Bible by Arcade Fire" with a play button.
- Job Search:** Shows job recommendations like "Senior Biostatistician" at "CAMBIA" and "Product Manager - Netop".
- Search Engine Results:** A Google search for "ebola" showing news articles about Ebola cases and a "Popular on Netflix" section featuring "The Hunger Games: Catching Fire" and "The Walking Dead".

RECOMMENDATIONS DRIVE

Who gets to be your friend...

People You May Know

	5 mutual friends	Add Friend
	2 mutual friends	Add Friend
	2 mutual friends	Add Friend
	28 mutual friends	Add Friend
	15 mutual friends	Add Friend
	28 mutual friends	Add Friend

RECOMMENDATIONS DRIVE

Where you might work ...

Jobs you may be interested in

Preferences:

Your job activity is private.

Sponsored



Senior Biostatistician

Home-based Anywhere in the US



Senior Biostatistician

Naperville, IL



Senior Biostatistician

Raleigh, NC



Senior Director - Consumer Decision Science
Portland, Oregon Area



Enterprise Big Data Architect
Portland, OR



Product Manager - Netop Education Group
Portland, Oregon Area



Director, Global Health Science (Medical...
Portland, OR



Vice President of Product Management,...
Portland, OR

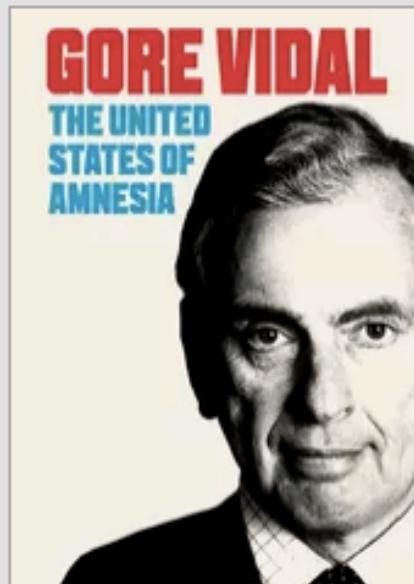


Hardware Engineering,
Director - Microsoft...
Portland, OR, US

RECOMMENDATIONS DRIVE

What you'll watch tonight...

Documentaries



RECOMMENDATIONS DRIVE

The information I am exposed to...

Google Search

Web News Images Videos Books More ▾ Search tools

About 330,000,000 results (0.22 seconds)

In the news

 Hospital staffers reportedly take sick day rather than treat New York's first **Ebola** patient
Fox News - 3 hours ago
New York City's first **Ebola** patient is prompting frightened staffers tasked with his treatment ...

Nina Pham beat **Ebola**; now it's back to normal.
CNN.com - 9 hours ago

As **Ebola** spreads, states enact stricter quarantines
USA TODAY - 1 hour ago

[More news for ebola](#)

WHO | Ebola virus disease
www.who.int/mediacentre/factsheets/.../en/ ▾ World Health Organization ▾
WHO fact sheet on **Ebola** haemorrhagic fever: includes key facts, definition, transmission, symptoms, diagnosis, treatment, prevention, WHO response.

RECOMMENDATIONS ARE VERY INTERESTING

- There is no single technique, and each problem is unique, though there are some core fundamentals
- Evaluation is not obvious, requires creativity and ingenuity
- Very few data mining products are this exposed to the public.
 - What are the design implications of a recommender system?
 - What are the ethical implications of a recommender system?

HOW TO RECOMMEND

TWO PHILOSOPHICAL APPROACHES

Recommend what is popular

MOST EMAILED MOST VIEWED RECOMMENDED FOR YOU

- 1. [Parachutist's Record Fall: Over 25 Miles in 15 Minutes](#) 
- 2. Why the Strong Reaction to Renée Zellweger's Face? 
- 3. First Patient Quarantined Under Strict New Policy Tests Negative for Ebola 
- 4. WELL The Advanced 7-Minute Workout 
- 5. 2 Die, Including Gunman, in Shooting at Washington State High School 
- 6. Kissing Your Socks Goodbye 

Try to understand your tastes

MOST EMAILED MOST VIEWED RECOMMENDED FOR YOU

- 1. Missouri: Panel Will Study Race and Poverty
- 2. Florida: A.C.L.U. Sues Over Housing Law
- 3. Amnesty International Report Faults the Police in Ferguson, Mo.
- 4. Debate for Florida Governor Takes On a Hostile Edge 
- 5. Searching for the Fountain of Youth 
- 6. MORTGAGES Cheaper to Buy Than to Rent 
- 7. New York City Police to Be Equipped With Smartphones and Tablets 

COLLABORATIVE FILTERING

2 TYPES

User based

Find like users and make recommendations based on ratings/scores of like users

Item Based

Find similar items and recommend items similar to an item a user has shown interest in.

USER BASED

INTUITION

1. Find a group of people who like the same things similarly
2. Not everyone will like the exact same set of things

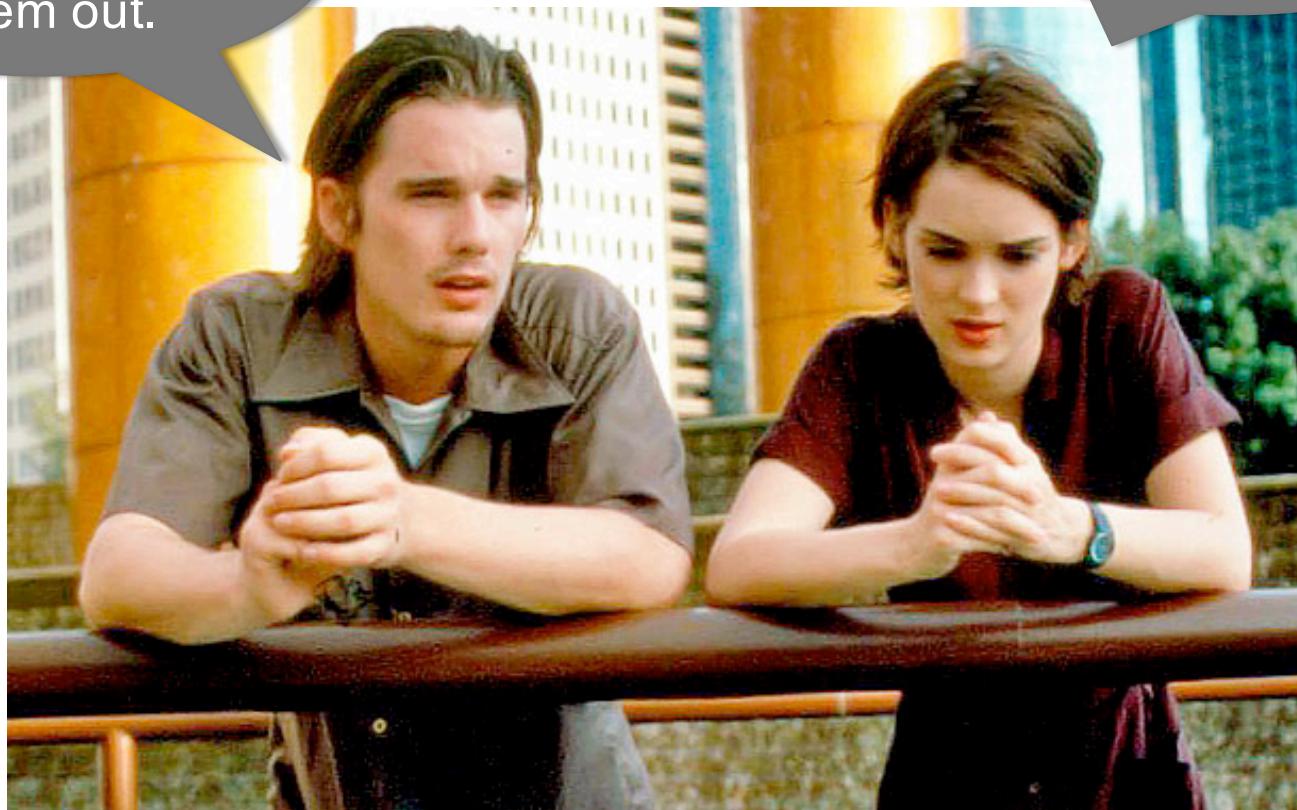


INTUITION

1. Find a group of people who like the same things similarly
2. Not everyone will like the exact same set of things
3. Recommend the non-overlapping items.

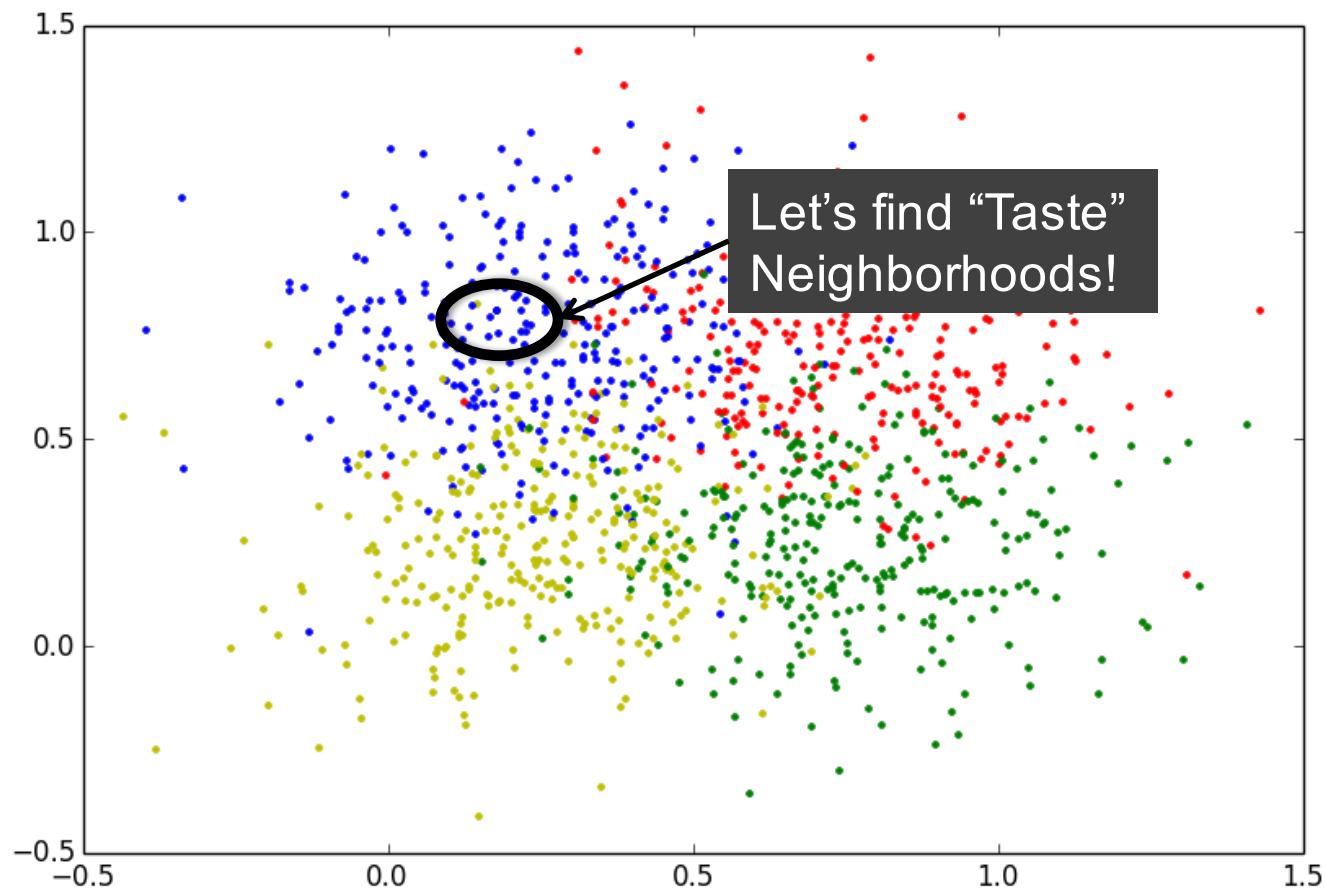
We have similar tastes, I'll check them out.

I think you'd like Pearl Jam



DEFINING A MECHANISM FOR “WE HAVE SIMILAR TASTES”

How do we translate “Find a group of people who like the same things” into a data science algorithm?



TOWARDS A “TASTE” NEIGHBORHOOD

First let's define the data structure.

Let A be the user-item matrix. Each entry a_{ij} can either be a rating or some binary indicator for user i on item j .

$$A = \begin{bmatrix} & \text{Item 1} & \text{Item 2} & \text{Item 3} & \text{Item 4} & \dots & \text{Item K} \\ \text{User 1} & 2 & 1 & & & & \dots \\ \text{User 2} & & 2 & 4 & & & \dots & 2 \\ \text{User 3} & 3 & & & & & \dots & \\ \text{User 4} & 1 & 2 & 5 & 3 & & \dots & \\ \text{User 5} & 3 & 2 & & & & \dots & \\ \text{User 6} & & & & & & \dots & 1 \\ \text{User 7} & & 4 & 1 & & & \dots & 4 \\ \text{User 8} & & 4 & 2 & & & \dots & 5 \\ \text{User 9} & 1 & & & & & \dots & \\ \text{User 10} & & & 3 & 4 & & \dots & 1 \\ \dots & \\ \text{User N} & & & & 1 & & \dots & 4 \end{bmatrix}$$

TOWARDS A “TASTE” NEIGHBORHOOD

Second let's create a neighborhood for user i.

$$A = \begin{bmatrix} & \text{Item 1} & \text{Item 2} & \text{Item 3} & \text{Item 4} & \dots & \text{Item K} \\ \text{User 1} & 2 & 1 & & & \dots & \\ \text{User 2} & & 2 & 4 & & \dots & 2 \\ \text{User 3} & 3 & & & & \dots & \\ \text{User 4} & 1 & 2 & 5 & 3 & \dots & \\ \text{User 5} & 3 & 2 & & & \dots & \\ \text{User 6} & & & & & \dots & 1 \\ \text{User 7} & & 4 & 1 & & \dots & 4 \\ \text{User 8} & & 4 & 2 & & \dots & 5 \\ \text{User 9} & 1 & & & & \dots & \\ \text{User 10} & & & 3 & 4 & \dots & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots & \\ \text{User N} & & & & 1 & \dots & 4 \end{bmatrix}$$

TOWARDS A “TASTE” NEIGHBORHOOD

To do this, we need to define user-user similarity or distance.

$A =$

	Item 1	Item 2	Item 3	Item 4	...	Item K
User 1	2	1			...	
User 2		2	4		...	2
User 3	3				...	
User 4	1	2	5	3	...	
User 5	3	2			...	
User 6					...	1
User 7		4	1		...	4
User 8		4	2		...	5
User 9	1				...	
User 10			3	4	...	1
...	
User N				1	...	4

TOWARDS A “TASTE” NEIGHBORHOOD

Each user i corresponds to a row in our user-item matrix A . There are two popular ways to define similarity between similar rows of A .

Let A_i and A_k be two row vectors corresponding to the items i and k have rated.
Let S be the set of items both users have rated/selected. Then,

Cosine Similarity

$$sim(A_i, A_k) = cos(A_i, A_k) = \frac{A_i \cdot A_k}{\|A_i\|_2 \|A_k\|_2}$$

Pearson Correlation

$$sim(A_i, A_k) = \frac{\sum_{j \in S} (A_{ij} - \mu_i)(A_{kj} - \mu_k)}{\sqrt{\sum_{j \in S} (A_{ij} - \mu_i)^2 \sum_{j \in S} (A_{kj} - \mu_k)^2}}$$

A PRACTICAL ASIDE

Things to consider when choosing a similarity measure:

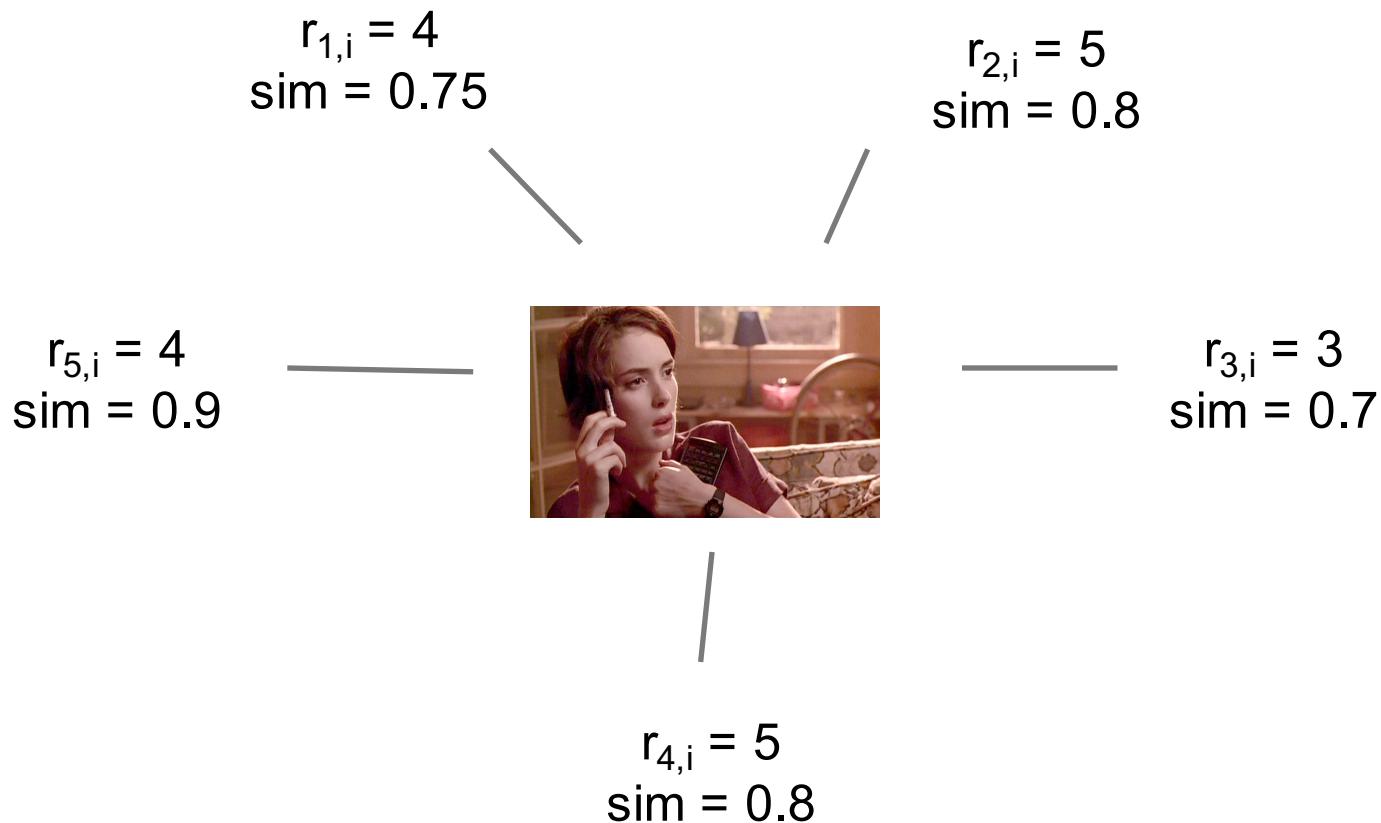
- Which metric is better for ratings vs. binary indicators?
- Should you mean normalize? I.e., subtract user and/or item average rating from each rating.
- Should take Similarity over all items for each user, or just those in common. I.e, should S be the intersection or union of A_i and A_k .

The right answer will likely depend on your problem.
Testing and experimentation is important in each case.

MAKING THE RECOMMENDATION

The predicted score/rating for user u on product i is then a function of scores/ratings that all users in u 's neighborhood gave to the same product.

$$r_{u,i} = \text{Agg}_{u' \in U} (r_{u',i})$$



DIFFERENT WAYS TO AGGREGATE

Take a simple average.

$$r_{u,i} = \frac{1}{N} \sum_{u' \in U} r_{u',i}$$

Take a weighted avg, weighted by similarity...

$$r_{u,i} = \frac{1}{k} \sum_{u' \in U} sim(u, u') * r_{u',i}$$

$$k = \sum_{u' \in U} sim(u, u')$$

There are many other ways to define the aggregation function. Other variants use averages but normalize out the means of the individual users to account for user-specific biases.

EG.

Once you have defined the neighborhood, aggregation is pretty straightforward.



$r_{1,i} = 4$
 $\text{sim} = 0.75$

$r_{2,i} = 5$
 $\text{sim} = 0.8$

$r_{3,i} = 3$
 $\text{sim} = 0.7$

$r_{4,i} = 5$
 $\text{sim} = 0.8$

$r_{5,i} = 4$
 $\text{sim} = 0.9$

User	$r_{i,j}$	sim	$r_{i,j} * \text{sim}$
1	4	0.75	3.0
2	5	0.8	4.0
3	3	0.6	1.8
4	4	0.8	3.2
5	5	0.9	4.5
Average		4.20	
Weighted Average			4.29

ITEM BASED

DEVELOPED BY AMAZON

User based methods can be unscalable as user-item matrix grows.

Frequently Bought Together



Price for all three: \$225.84

Add all three to Cart

Add all three to Wish List

Show availability and shipping details

- This item: An Introduction to Statistical Learning: with Applications in R (Springer Texts in Statistics)
- The Elements of Statistical Learning: Data Mining, Inference, and Prediction, Second Edition (Springer Series in Statistics)
- Applied Predictive Modeling by Max Kuhn Hardcover \$65.81

Customers Who Bought This Item Also Bought



Applied Predictive Modeling
by Max Kuhn
 27
Hardcover
\$65.81



The Elements of Statistical Learning:...
by Trevor Hastie
 40
Hardcover
\$84.04



Machine Learning with R
by Brett Lantz
 26
Paperback
\$49.49

START WITH USER-ITEM MATRIX

But this time we care about similarity between columns, not rows. We can use the same type of similarity functions that we used in the user based system.

$$A = \begin{bmatrix} & \text{Item 1} & \text{Item 2} & \text{Item 3} & \text{Item 4} & \dots & \text{Item K} \\ \text{User 1} & 2 & 1 & & & & \\ \text{User 2} & & 2 & 4 & & & 2 \\ \text{User 3} & 3 & & & & & \\ \text{User 4} & 1 & 2 & 5 & 3 & & \\ \text{User 5} & 3 & 2 & & & & \\ \text{User 6} & & & & & & 1 \\ \text{User 7} & & 4 & 1 & & & 4 \\ \text{User 8} & & 4 & 2 & & & 5 \\ \text{User 9} & 1 & & & & & \\ \text{User 10} & & & 3 & 4 & & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ \text{User N} & & & & 1 & & 4 \end{bmatrix}$$

DERIVE THE ITEM-ITEM MATRIX

2 approaches to recommendation:

1. If a user has selected/purchased an item, find the k most similar items
2. For each item the user hasn't selected/purchased, predict user's rating(score for that product as a function of the user's rating(score on similar items (similar to the user based kNN approach)

$$M = \begin{bmatrix} & \text{Item 1} & \text{Item 2} & \text{Item 3} & \text{Item 4} & \dots & \text{Item K} \\ \text{Item 1} & & .8 & 0.2 & 0 & \dots & 0.1 \\ \text{Item 2} & & & 0.5 & 0.11 & \dots & 0.6 \\ \text{Item 3} & & & & 0.3 & \dots & 0.4 \\ \text{Item 4} & & & & & \dots & 0.8 \\ \dots & & \dots & \dots & \dots & \dots & \dots \\ \text{Item K} & & & & & & 0.3 \end{bmatrix}$$

MATRIX FACTORIZATION BASED RECOMMENDATIONS

THE NETFLIX PRIZE

The \$1MM Netflix prize issued a renaissance of recommendation system techniques. Most notably, Matrix Factorizations become popular.

The screenshot shows the official Netflix Prize website. At the top, a large yellow banner displays the text "Netflix Prize" and "COMPLETED". Below the banner, a navigation bar includes links for "Home", "Rules", "Leaderboard", and "Update". The main content area features a dark background with a silhouette of two people watching a movie screen. On the screen, there's a "NETFLIX" logo and a "Movies For You" section. The "Movies For You" section lists movies like "Bowling for Columbine", "Six Feet Under", and "The Big One". To the right of this section is a promotional banner for "You really liked it..." with a "Buy DVDs" button. A large blue "Congratulations!" heading is prominently displayed on the right side of the page. Below it, a text block explains the purpose of the prize and details the award ceremony. Another text block at the bottom expresses appreciation for the contributors.

COMPLETED

Netflix Prize

Home Rules Leaderboard Update

Movies For You

Randy, the following movies were chosen based on your interest in:
Bowling for Columbine
Six Feet Under - Season 1
Fatigued

All Discs Guaranteed

You really liked it...

Now own it for just \$5.99

Shop for more titles as low as \$1.99

The Big One

★★★

Shop for more titles as low as \$1.99

Original art

Congratulations!

Congratulations!

The Netflix Prize sought to substantially improve the accuracy of predictions about how much someone is going to enjoy a movie based on their movie preferences.

On September 21, 2009 we awarded the \$1M Grand Prize to team "BellKor's Pragmatic Chaos". Read about [their algorithm](#), checkout team scores on the [Leaderboard](#), and join the discussions on the [Forum](#).

We applaud all the contributors to this quest, which improves our ability to connect people to the movies they love.

MULTI-YEAR DEVELOPMENT

It took several years to beat house algorithm by >10%

Leaderboard

Showing Test Score. [Click here to show quiz score](#)

Display top leaders.

Rank	Team Name	Best Test Score	% Improvement	Best Submit Time
Grand Prize - RMSE = 0.8567 - Winning Team: BellKor's Pragmatic Chaos				
1	BellKor's Pragmatic Chaos	0.8567	10.06	2009-07-26 18:18:28
2	The Ensemble	0.8567	10.06	2009-07-26 18:38:22
3	Grand Prize Team	0.8582	9.90	2009-07-10 21:24:40
4	Opera Solutions and Vandelay United	0.8588	9.84	2009-07-10 01:12:31
5	Vandelay Industries !	0.8591	9.81	2009-07-10 00:32:20
6	PragmaticTheory	0.8594	9.77	2009-06-24 12:06:56
7	BellKor in BigChaos	0.8601	9.70	2009-05-13 08:14:09
8	Dace	0.8612	9.59	2009-07-24 17:18:43
9	Feeds2	0.8622	9.48	2009-07-12 13:11:51
10	BigChaos	0.8623	9.47	2009-04-07 12:33:59
11	Opera Solutions	0.8623	9.47	2009-07-24 00:34:07
12	BellKor	0.8624	9.46	2009-07-26 17:19:11

AFTERMATH

The winning algorithm was never used...

“We evaluated some of the new methods offline but the additional accuracy gains that we measured did not seem to justify the engineering effort needed to bring them into a production environment.”

The leader after 1 year of development:

- Reported more than 2000 hrs of work
- Solution was a combination of 107 different algorithms

Do you think this was worth \$1MM? Why?

A VERY IMPORTANT DEVELOPMENT

Despite not being adopted exactly, the collective research was very important for the development of recommender systems.

Given a ratings matrix, remember:

$$A = U \Sigma V^T$$

Instead of creating user taste, or item similarity neighborhoods, we can predict a user's rating on an item by uncovering the latent dimensions of the ratings matrix.

FACTORIZING THE RATINGS MATRIX

We simplify the factorization to:

$$A = UV^T$$

V

Each column of V represents a latent movie dimension. The value V_{ij} tells us how much movie i can be described by the latent movie dimension j.

U

Each element U_{ij} of U represents how much user i has an affinity for the latent movie dimension V_j .

LATENT FACTORS (REVISTED)

We observe *things like*:



***Crime
Thrillers***

***Artistic
Dramas***

***Handsome
Leading Men***

LATENT FACTORS (REVISTED)

*What drives these observations? In other words,
why do we do watch what we watch?*

- Genre (comedy vs. romance)
- Audience (children vs. adults)
- Style (quirky vs. serious)
- Depth of Character
- Presence of certain actors



We want a computerized way to be able to extract these properties and not rely on human curation.

LATENT FACTORS (REVISTED)

When uncovering latent factors, we usually only want a subset k , where $k \ll \min(M, N)$

U_k

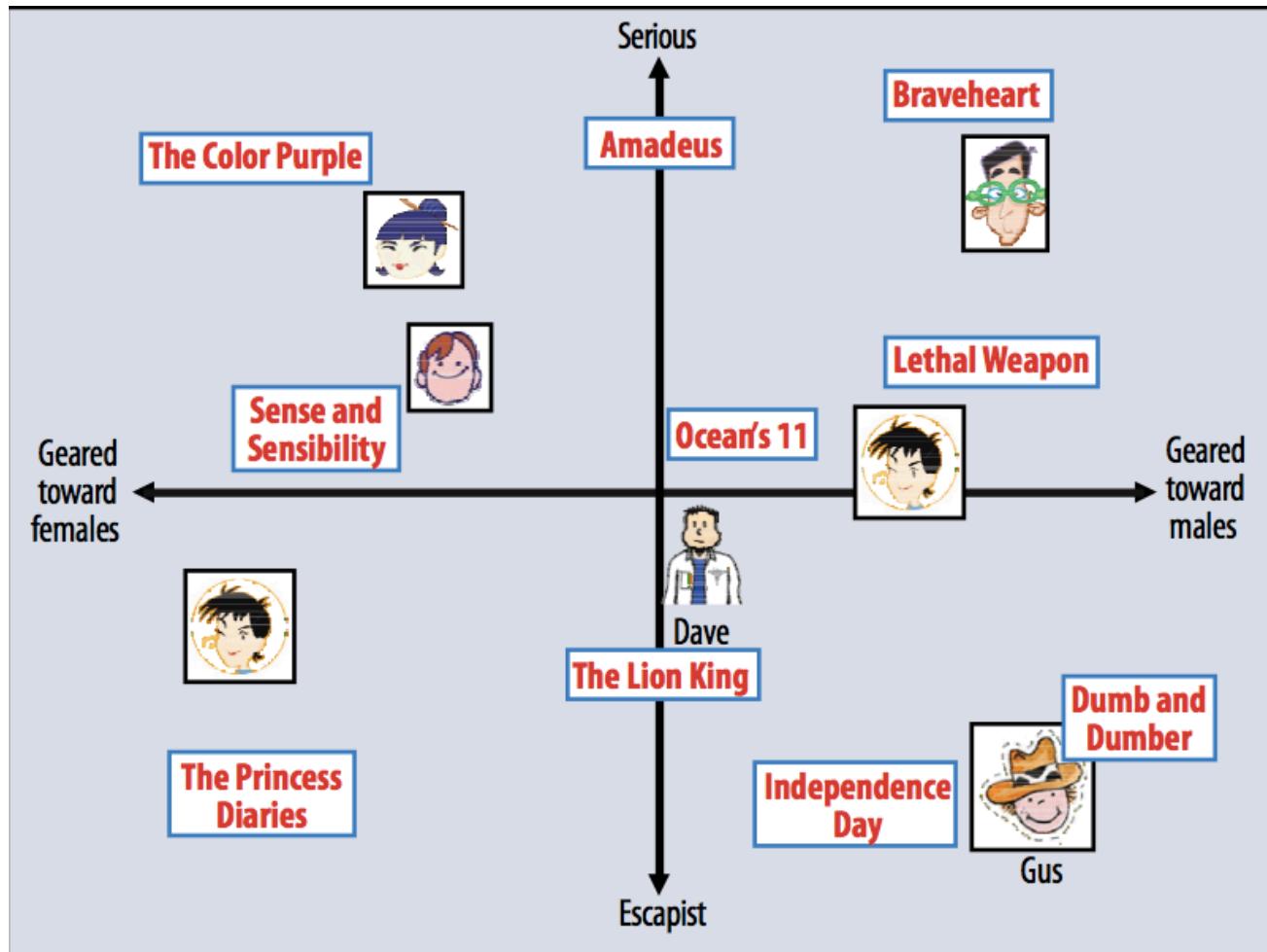
	LF 1	LF 1	LF 3
User 1	-0.7	-0.8	-0.4
User 2	0.2	-0.6	1.0
User 3	-0.8	-0.1	-0.8
User 4	0.4	0.3	-0.1
...			
User N	-0.3	1.0	0.4

V_k^T

	Item 1	Item 2	Item 3	...	Item M
LF 1	-0.4	0.6	0.8	...	-0.8
LF 2	-0.8	-0.5	-0.7	...	-0.4
LF 3	0.1	0.9	0.7	...	-0.7

LATENT FACTORS (REVISTED)

An example set of movies and how they load on two latent variables.



THE RATING PREDICTION

The rating prediction for user i on item j is then an inner product between the user's preferences for each latent factor and the item's strength on that factor.

v_{jt} indicates how much factor t describes item j

$$r_{ij} = u_{i1} * v_{j1} + u_{i2} * v_{j2} + \dots + u_{ik} * v_{jk} = \sum_{t=1,k} u_{it} * v_{jt}$$

```
graph TD; A["vjt indicates how much factor t describes item j"]; B["rij = ui1 * vj1 + ui2 * vj2 + ... + uik * vjk = Σt=1,k uit * vjt"]; B --> C["uit indicates how user i prefers factor t"];
```

LEARNING THE FACTORIZATION

We can set this recommendation problem up as a supervised learning problem.

Minimize the sum of squares predictions of observed ratings.



$$\hat{U}, \hat{V} = \operatorname{argmin}_{U,V} \sum_{r_{ij} \in A} \left(r_{ij} - \sum_t u_{it} * v_{jt} \right)^2 + \lambda (\|U\|^2 + \|V\|^2)$$



We regularize the components of U and V to avoid over-fitting