Embeddings:
Vector & Semantic Search

Applications | Concepts | Examples

January 22 2025 | Lecture at University of Washington, Seattle by Dr. Karthik Mohan

Today's Talk

1. Introduction and Motivation

2. Semantic Search

Netflix Recommendations

MULTIPLE CAROUSELS

Netflix Recommendations

POPULAR yet PERSONALIZED

PERSONALIZED TRENDS

PERSONALIZED GENRE

Netflix Recommendations

POPULAR yet PERSONALIZED

PERSONALIZED TRENDS

PERSONALIZED GENRE

Netflix Recommendations

POPULAR yet PERSONALIZED

PERSONALIZED TRENDS

PERSONALIZED GENRE

Netflix Million Dollar Prize!

Netflix Million Dollar Prize!

NETFLIX

Netflix Prize

Home | Rules | Leaderboard | Register | Update | Submit | Download

Leaderboard

Display top 40 leaders.

Rank	Team Name	Best Score	% Improvement	Last Submit Time
--	No Grand Prize candidates yet	--	--	--
Grand Prize - RMSE <= 0.8563				
1	PragmaticTheory	0.8584	9.78	2009-06-16 01:04:47
2	BellKor in BigChaos	0.8590	9.71	2009-05-13 08:14:09
3	Grand Prize Team	0.8593	9.68	2009-06-12 08:20:24
4	Dace	0.8604	9.56	2009-04-22 05:57:03
5	BigChaos	0.8613	9.47	2009-06-15 18:03:55
Progress Prize 2008 - RMSE = 0.8616 - Winning Team: BellKor in BigChaos				
6	BellKor	0.8620	9.40	2009-06-17 13:41:48
7	Gravity	0.8634	9.25	2009-04-22 18:31:32
8	Opera Solutions	0.8640	9.19	2009-06-09 22:24:53
9	xlvector	0.8640	9.19	2009-06-17 12:47:27
10	BruceDengDaoCiYiYou	0.8641	9.18	2009-06-02 17:08:31
11	Ces	0.8642	9.17	2009-06-12 23:04:25
12	majia2	0.8642	9.17	2009-06-15 03:35:00
13	xiangliang	0.8642	9.17	2009-06-13 16:35:35
14	Feeds2	0.8647	9.11	2009-06-16 22:21:19
15	Just a guy in a garage	0.8650	9.08	2009-05-24 10:02:54
16	Team ESP	0.8653	9.05	2009-06-16 05:25:11
17	pengpengzhou	0.8654	9.04	2009-05-05 18:18:03
18	NewNetflixTeam	0.8657	9.01	2009-05-31 07:30:22
19	J Dennis Su	0.8658	9.00	2009-03-11 09:41:54

Collaborative Filtering

Rishi

Michael

Karthik

Roshin

Amy

Collaborative Filtering

Avatar

Arrival

When Harry

Before Sunrise

Minions

Rishi

Michael

Karthik

Roshin

Amy

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎		👍	👍	👍
Karthik	👍		👎		👍
Roshin		👎	👍	👍	
Amy		👍		👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	❓	👍	👍	👍
Karthik	👍	❓	👎	❓	👍
Roshin	❓	👎	👍	👍	❓
Amy	❓	👍	❓	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	❓	👍	👍	👍
Karthik	👍	❓	👎	❓	👍
Roshin	❓	👎	👍	👍	❓
Amy	❓	👍	❓	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	❓	👍	👍	👍
Karthik	👍	❓	👎	❓	👍
Roshin	❓	👎	👍	👍	❓
Amy	❓	👍	❓	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	❓	👍	👍	👍
Karthik	👍	👍	👎	❓	👍
Roshin	❓	👎	👍	👍	❓
Amy	❓	👍	❓	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	❓	👍	👍	👍
Karthik	👍	👍	👎	❓	👍
Roshin	❓	👎	👍	👍	❓
Amy	❓	👍	❓	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	❓	👍	👍	👍
Karthik	👍	👍	👎	❓	👍
Roshin	❓	👎	👍	👍	❓
Amy	❓	👍	❓	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
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Karthik	👍	👍	👎	👎	👍
Roshin	❓	👎	👍	👍	❓
Amy	❓	👍	❓	👍	👎

Collaborative Filtering

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Karthik	👍	👍	👎	👎	👍
Roshin	❓	👎	👍	👍	❓
Amy	❓	👍	❓	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	?	👍	👍	👍
Karthik	👍	👍	👎	👎	👍
Roshin	?	👎	👍	👍	?
Amy	?	👍	👍	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
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Karthik	👍	👍	👎	👎	👍
Roshin	❓	👎	👍	👍	❓
Amy	❓	👍	👍	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
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Karthik	👍	👍	👎	👎	👍
Roshin	❓	👎	👍	👍	👍
Amy	❓	👍	👍	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
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Karthik	👍	👍	👎	👎	👍
Roshin	❓	👎	👍	👍	👍
Amy	❓	👍	👍	👍	👎

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Roshin	👎	👎	👍	👍	👍
Amy	❓	👍	👍	👍	👎

Collaborative Filtering

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Karthik	👍	👍	👎	👎	👍
Roshin	👎	👎	👍	👍	👍
Amy	❓	👍	👍	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	🚫	👍	👍	👍
Karthik	👍	👍	👎	🚫	👍
Roshin	🚫	👎	👍	👍	👍
Amy	?	👍	👍	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	🚫	👍	👍	👍
Karthik	👍	👍	👎	🚫	👍
Roshin	🚫	👎	👍	👍	👍
Amy	?	👍	👍	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
Rishi	👍	👍	👎	👎	👍
Michael	👎	🚫	👍	👍	👍
Karthik	👍	🟢	👎	🚫	👍
Roshin	🚫	👎	👍	👍	🟢
Amy	🟢	👍	🟢	👍	👎

Collaborative Filtering

Through Matrix Completion!

Collaborative Filtering

Through Matrix Completion!

Collaborative Filtering

Through Matrix Completion!

Collaborative Filtering

Through Matrix Completion!

Collaborative Filtering

Through Matrix Completion!

Collaborative Filtering

Through Matrix Completion!

Collaborative Filtering

Through Matrix Completion!

Linear Algebra in Action
Q: What is the closest Linear Algebra method that looks similar to the above factorization?

Collaborative Filtering

Through Matrix Completion!

Linear Algebra in Action

Q: What is the closest Linear Algebra method that looks similar to the above factorization?

A: SVD = Singular Value Decomposition

SVD of a matrix

SVD of a matrix

SVD of a matrix

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

SVD of a matrix

Every matrix has an SVD!

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

SVD of a matrix

Hence: Data Matrix also has an SVD!

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

Collaborative Filtering

Through Matrix Completion!

Collaborative Filtering: Advanced SVD method or Iterative SVD method

Collaborative Filtering

Avatar

Arrival

When Harry

Before Sunrise

Minions

Men in Black

	Avatar	Arrival	When Harry	Before Sunrise	Minions
U1	👍	👍	👎	👎	👍
U2	👎	👎	👍	👍	👍
U3	👍	👍	👎	👎	👍
U4	👎	👎	👍	👍	👍
U5	👍	👍	👍	👍	👎

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions	Men in Black
U1	👍	👍	👎	👎	👍	?
U2	👎	👎	👍	👍	👍	?
U3	👍	👍	👎	👎	👍	?
U4	👎	👎	👍	👍	👍	?
U5	👍	👍	👍	👍	👎	?

Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions	Men in Black
U1	👍	👍	👎	👎	👍	?
U2	👎	🚫	👍	👍	👍	?
U3	👍	🟢	👎	🚫	👍	?
U4	🚫	👎	👍	👍	🟢	?
U5	🟢	👍	🟢	👍	👎	?

Cold Start Problem

Content Based Filtering

vs Collaborative Filtering

Avatar

Arrival

When Harry

Before Sunrise

Minions

Men in Black

Karthik

	Avatar	Arrival	When Harry	Before Sunrise	Minions
U1	👍	👍	👎	👎	👍
U2	👎	🚫	👍	👍	👍
U3	👍	✅	👎	🚫	👍
U4	🚫	👎	👍	👍	✅
U5	✅	👍	✅	👍	👎

Content Based Filtering

vs Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
U1	👍	👍	👎	👎	👍
U2	👎	👎	👍	👍	👍
U3	👍	👍	👎	👎	👍
U4	👎	👎	👍	👍	👍
U5	👍	👍	👍	👍	👎

Karthik

Content Based Filtering

vs Collaborative Filtering

Avatar

Arrival

When Harry

Before Sunrise

Minions

	Avatar	Arrival	When Harry	Before Sunrise	Minions
U1	👍	👍	👎	👎	👍
U2	👎	👎	👍	👍	👍
U3	👍	👍	👎	👎	👍
U4	👎	👎	👍	👍	👍
U5	👍	👍	👍	👍	👎

Karthik

Watched →

Arrival

Content Based Filtering

vs Collaborative Filtering

Avatar

Arrival

When Harry

Before Sunrise

Minions

	Avatar	Arrival	When Harry	Before Sunrise	Minions
U1	👍	👍	👎	👎	👍
U2	👎	👎	👍	👍	👍
U3	👍	👍	👎	👎	👍
U4	👎	👎	👍	👍	👍
U5	👍	👍	👍	👍	👎

Karthik

Watched

Arrival

Men in Black

Content Based Filtering

vs Collaborative Filtering

	Avatar	Arrival	When Harry	Before Sunrise	Minions
U1	👍	👍	👎	👎	👍
U2	👎	👎	👍	👍	👍
U3	👍	👍	👎	👎	👍
U4	👎	👎	👍	👍	👍
U5	👍	👍	👍	👍	👎

Content Based Filtering

Minions

Men in Black

Arrival

When Harry met

Embeddings

Men in Black

Arrival

When Harry met

Content Based Filtering

Embeddings

Men in Black

Arrival

When Harry met

Typically 128 or 256 latent dimensions

Content Based Filtering

Embeddings

Men in Black

Arrival

When Harry met

How do we
Obtain these embeddings?

Content Based Filtering

Embeddings

Men in Black

Arrival

When Harry met

How do we
Obtain these embeddings?

A: Through a DL model!
Maybe last but one hidden layer activations

Embeddings Interpretation

Men in Black

Arrival

When Harry met

Embeddings

Latent Dimensions → **Interpretation**

?
?
?
?
⋮

Comedy + Romance
Thriller + Adventure
Comedy + Thriller
Adventure
⋮

Embeddings | Vector Representations

Men in Black

Arrival

When Harry met

Embeddings

Latent Dimensions → **Interpretation**

?
?
?
?
⋮

Comedy + Romance
Thriller + Adventure
Comedy + Thriller
Adventure
⋮

Embeddings in Action

Minions

Men in Black

Arrival

When Harry met

Embeddings

Men in Black

Arrival

When Harry met

Embeddings in Action

Minions

Men in Black

Arrival

When Harry met

Embeddings

High Cosine Similarity

Men in Black

Arrival

When Harry met

Embeddings in Action

Minions

Men in Black

Arrival

Men in Black

Arrival

When Harry met

Embeddings in Action

Minions

Men in Black

Men in Black

Arrival

When Harry met

Smaller Angle = Higher Cosine Similarity
Larger Angle = Lower Cosine Similarity

Arrival

High Cosine Similarity

Low Cosine Similarity

When Harry met

Embeddings in Action

Minions

Men in Black

Men in Black

Arrival

When Harry met

$$? \leq \quad CosineSimilarity(x, y) = \frac{x^T y}{||x|| \, ||y||} \quad \leq ?$$

Embeddings in Action

Minions

Men in Black

Men in Black

Arrival

When Harry met

Embeddings

Smaller Angle = Higher Cosine Similarity
Larger Angle = Lower Cosine Similarity

High Cosine Similarity

Low Cosine Similarity

$$-1 \leq CosineSimilarity(x, y) = \frac{x^T y}{||x|| \, ||y||} \leq 1$$

Cauchy-Schwarz Inequality!

$$-1 \leq \; CosineSimilarity(x, y) = \frac{x^T y}{||x||||y||} \leq 1$$

Cauchy-Schwarz Inequality!

$$-1 \leq \ CosineSimilarity(x, y) = \frac{x^T y}{||x||||y||} \leq 1$$

$$|x^T y| <= ||x||||y||$$

Cauchy-Schwarz Inequality!

$$-1 \leq \; CosineSimilarity(x, y) = \frac{x^T y}{||x||||y||} \leq 1$$

$$|x^T y| <= ||x||||y||$$

$$||x||_2$$

Euclidean Norm of x

Embeddings in Action

What if I like both sci-fi and romance?

Content Based Filtering

Minions

Men in Black

Arrival

When Harry met

Embeddings

Karthik

Men in Black

Arrival

When Harry met

Content Based Filtering

Minions

Men in Black

Men in Black

Arrival

Arrival

When Harry met

When Harry met

Embeddings

Karthik

Can Embed both Movies and Users in Same space!

Content Based Filtering

Minions

Men in Black

Arrival

When Harry met

Men in Black

Arrival

When Harry met

Content Based Filtering

Minions

Men in Black

Arrival

When Harry met

Men in Black

Arrival

When Harry met

Like both Sci-fi and Romance

Karthik

Watched

Arrival

Likely To Watch

Men in Black

Likely To Watch

When Harry met

Word Embeddings

Word Embeddings

Word and Sentence Embeddings

Word and Sentence Embeddings

How do we
Obtain these embeddings?

A: Through a DL model!
Maybe last but one hidden layer activations

Word and Sentence Embeddings

How do we
Obtain these embeddings?

A: Through a DL model!
Maybe last but one hidden layer activations

Glove Embeddings

Sentence BERT

We will cover Sentence BERT when we Get to Transformers!

Semantic Search | Vector Search

Semantic Search:
Enables us to find
the closest category for
A given sentence

Semantic Search | Vector Search

Typical Search:
Based on look-up. May Not handle semantics. Uses Trie Datastructure

Semantic Search | Vector Search

Typical Search:
Based on look-up.

Down-sides?

Semantic Search | Vector Search

Semantic Search | Vector Search

What's the closest category
for the following sentence? "I love to drive cars. And paint flowers too!"

Semantic Search | Vector Search

What's the closest category
for the following sentence? "I love to drive cars. And paint flowers too!"

Highest cosine similarity based on vector search: Flowers and Cars

Vector Arithmetic!

What is King - Man + Woman?

Demo on Semantic Search