Embeddings:
Vector & Semantic Search

Applications | Concepts | Examples

January 23 2025 | Lecture at University of Washington, Seattle by Dr. Karthik Mohan

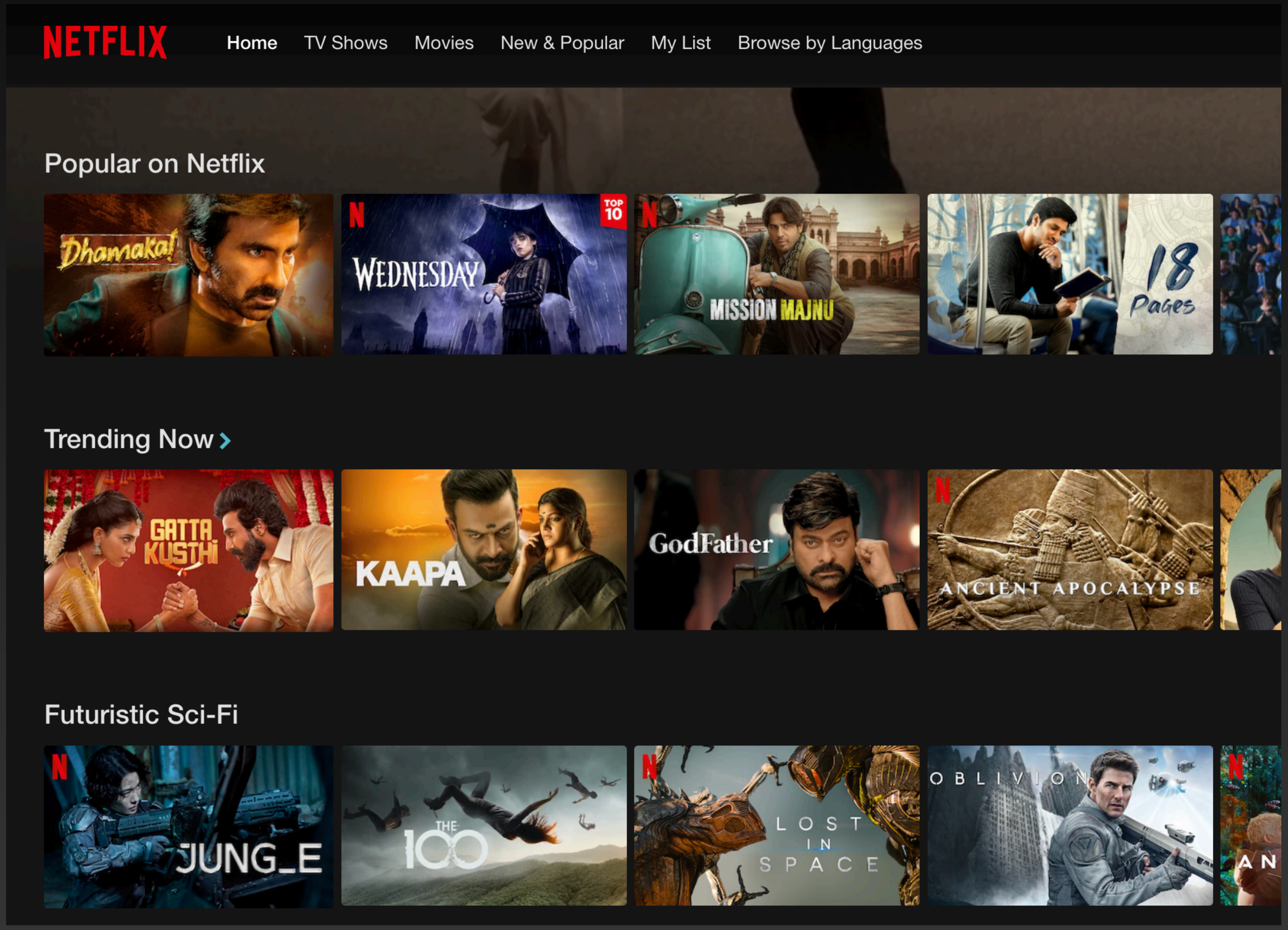
Today's Talk

1. Introduction and Motivation

2. Semantic Search

Netflix Recommendations

MULTIPLE CAROUSELS

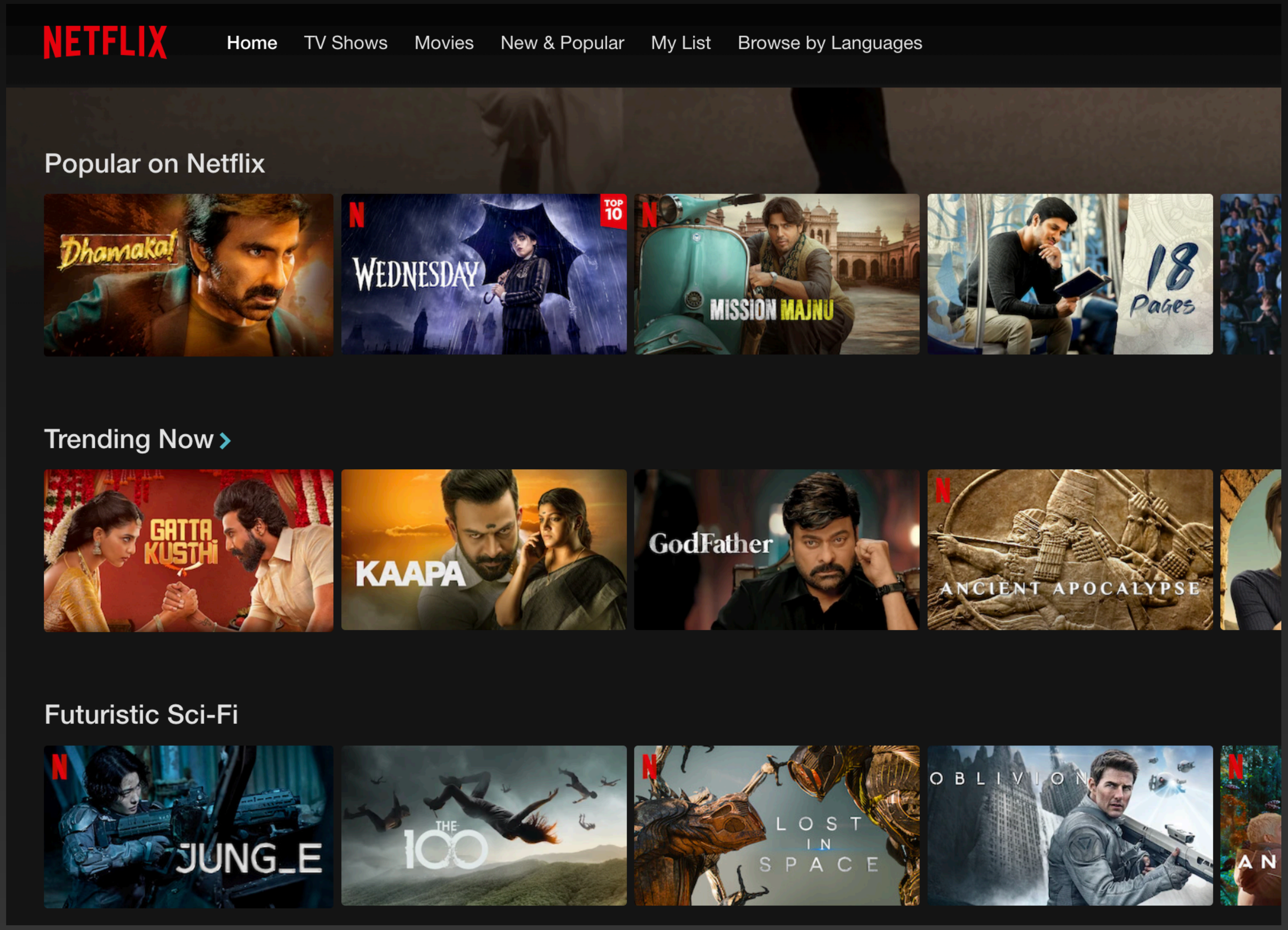


Netflix Recommendations

POPULAR yet PERSONALIZED

PERSONALIZED TRENDS

PERSONALIZED GENRE



Netflix Recommendations

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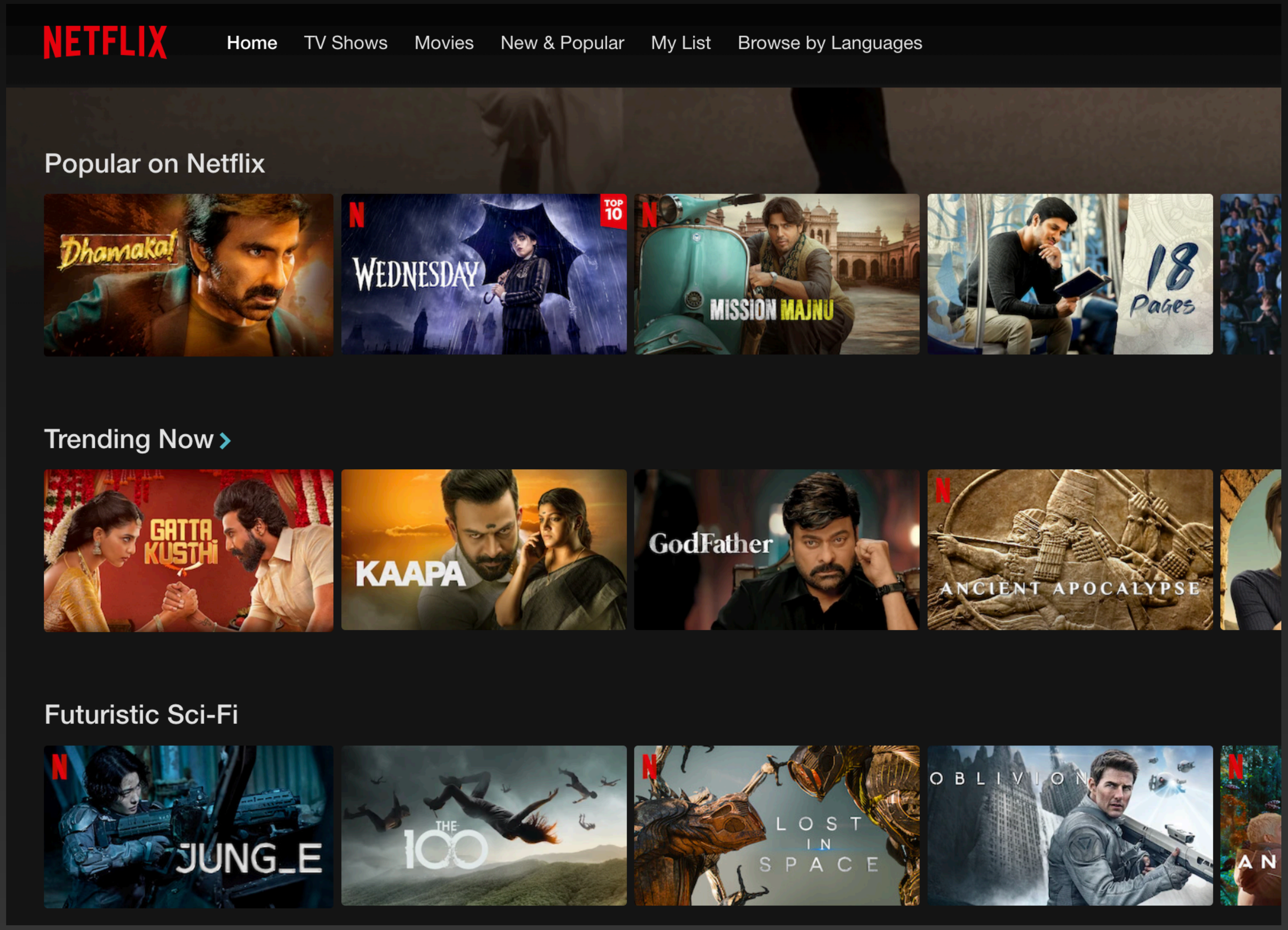
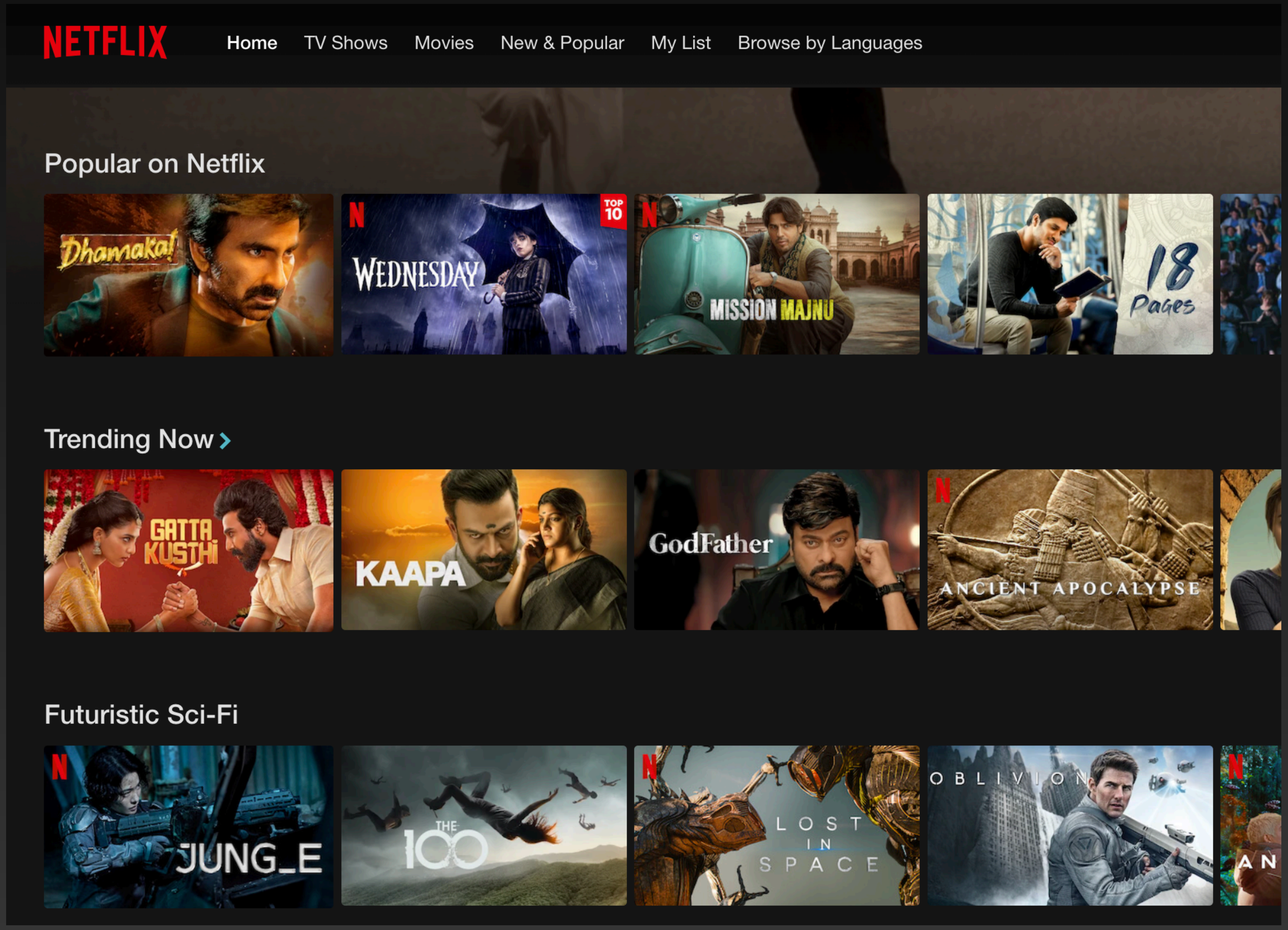


Netflix Recommendations



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
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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
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Michael	👎	?	👍	👍	👍
Karthik	👍	👍	👎	👎	👍
Roshin	?	👎	👍	👍	?
Amy	?	👍	?	👍	👎

Collaborative Filtering

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Roshin	?	👎	👍	👍	?
Amy	?	👍	👍	👍	👎

Collaborative Filtering

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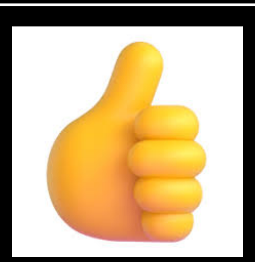
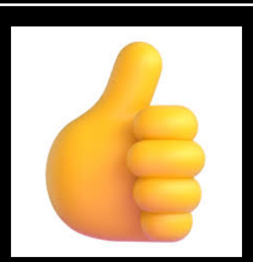
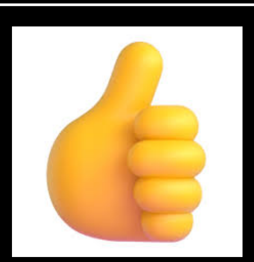
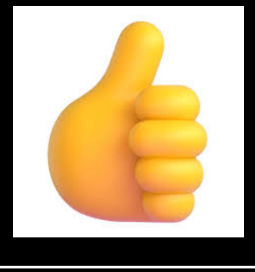
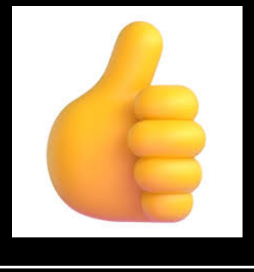
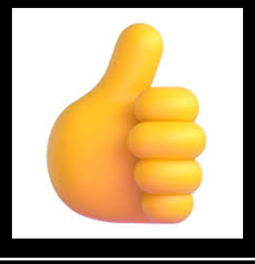
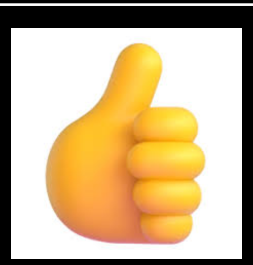
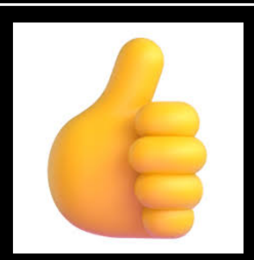
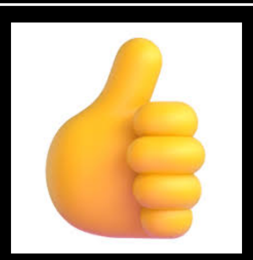
Karthik	👍	👍	👎	👎	👍
Roshin	?	👎	👍	👍	?
Amy	?	👍	👍	👍	👎

Collaborative Filtering

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

Collaborative Filtering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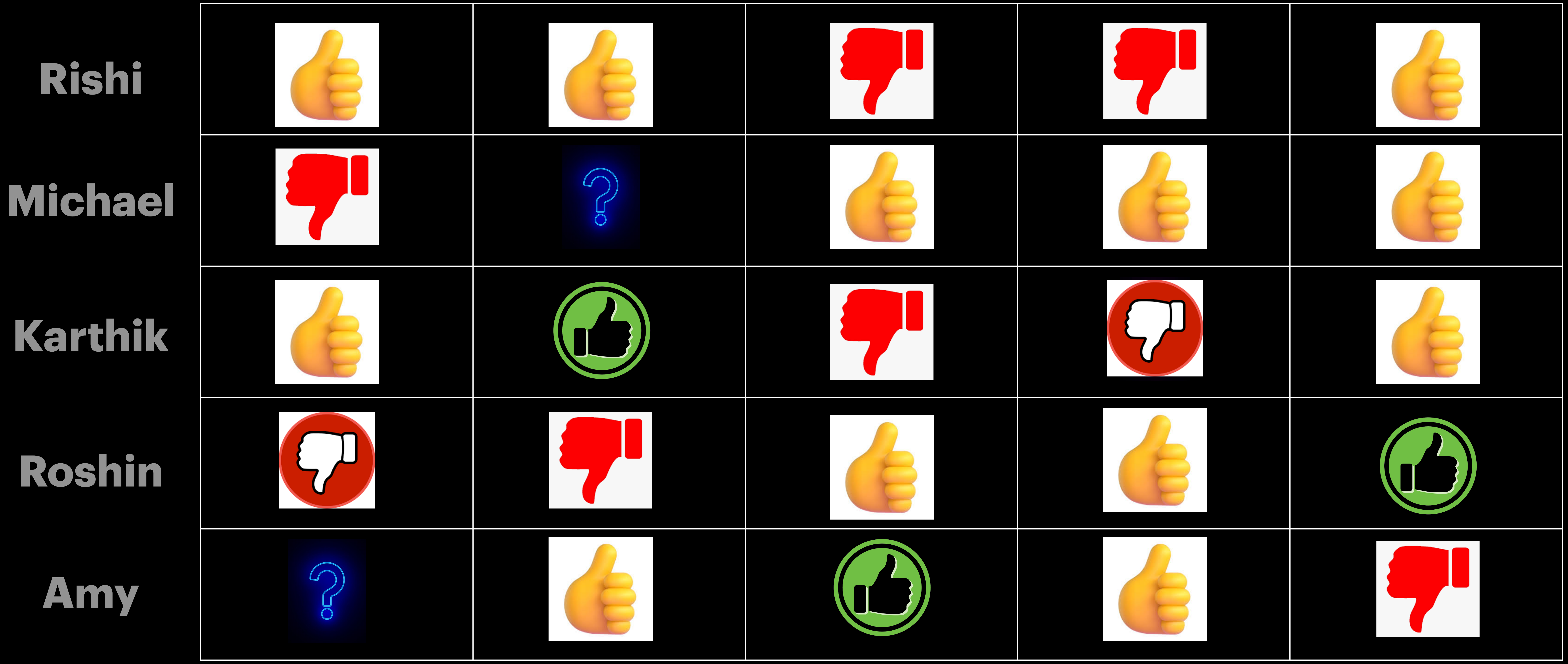
Karthik	👍	👍	👎	👎	👍
Roshin	?	👎	👍	👍	👍
Amy	?	👍	👍	👍	👎

Collaborative Filtering

Avatar | Arrival | When Harry | Before Sunrise | Minions



Collaborative Filtering

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Karthik	👍	👍	👎	👎	👍
Roshin	👎	👎	👍	👍	👍
Amy	?	👍	👍	👍	👎

Collaborative Filtering

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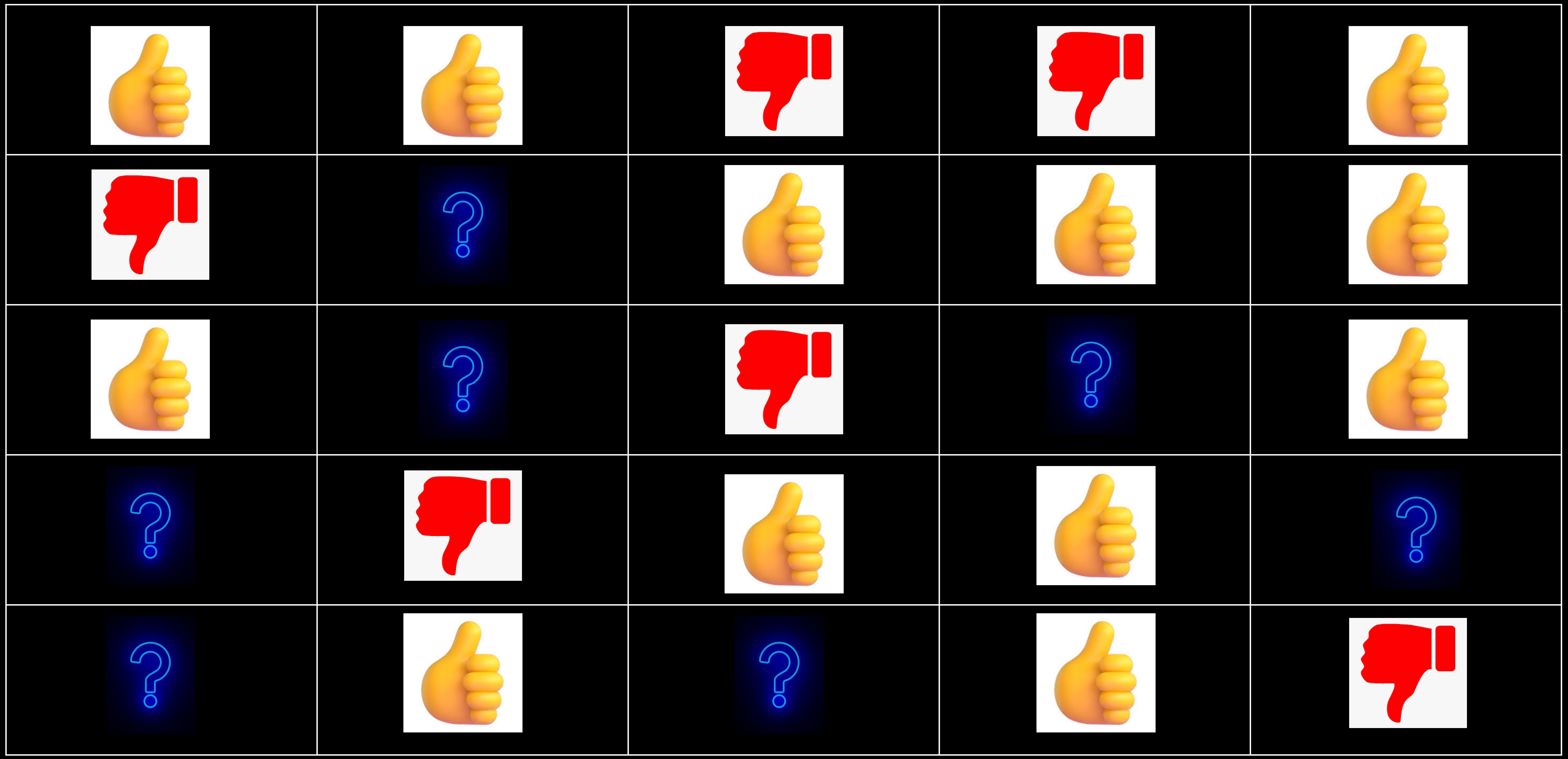
Roshin	👎	👎	👍	👍	👍
Amy	?	👍	👍	👍	👎

Collaborative Filtering

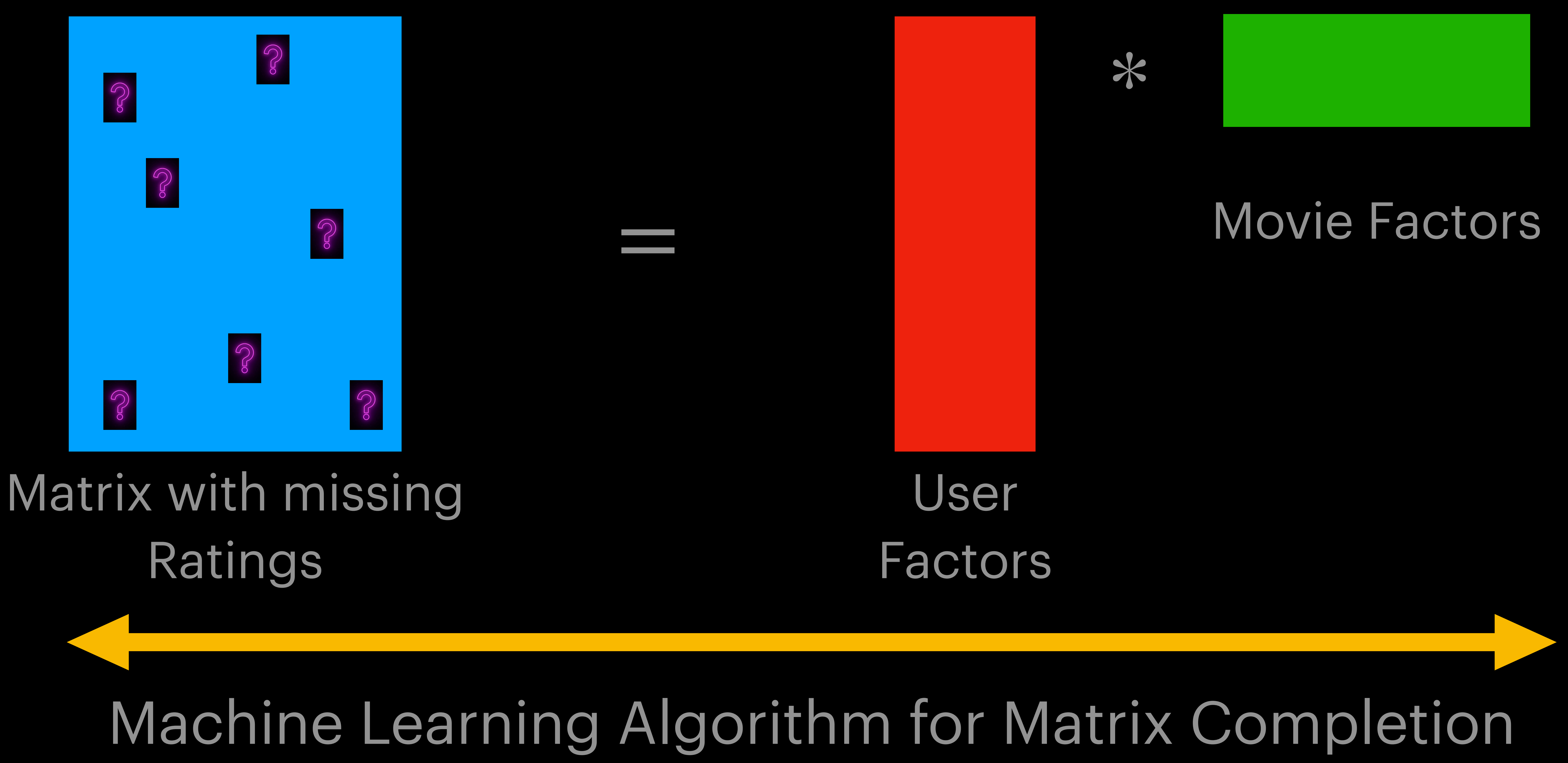
Collaborative Filtering

Through Matrix Completion!



Collaborative Filtering

Through Matrix Completion!



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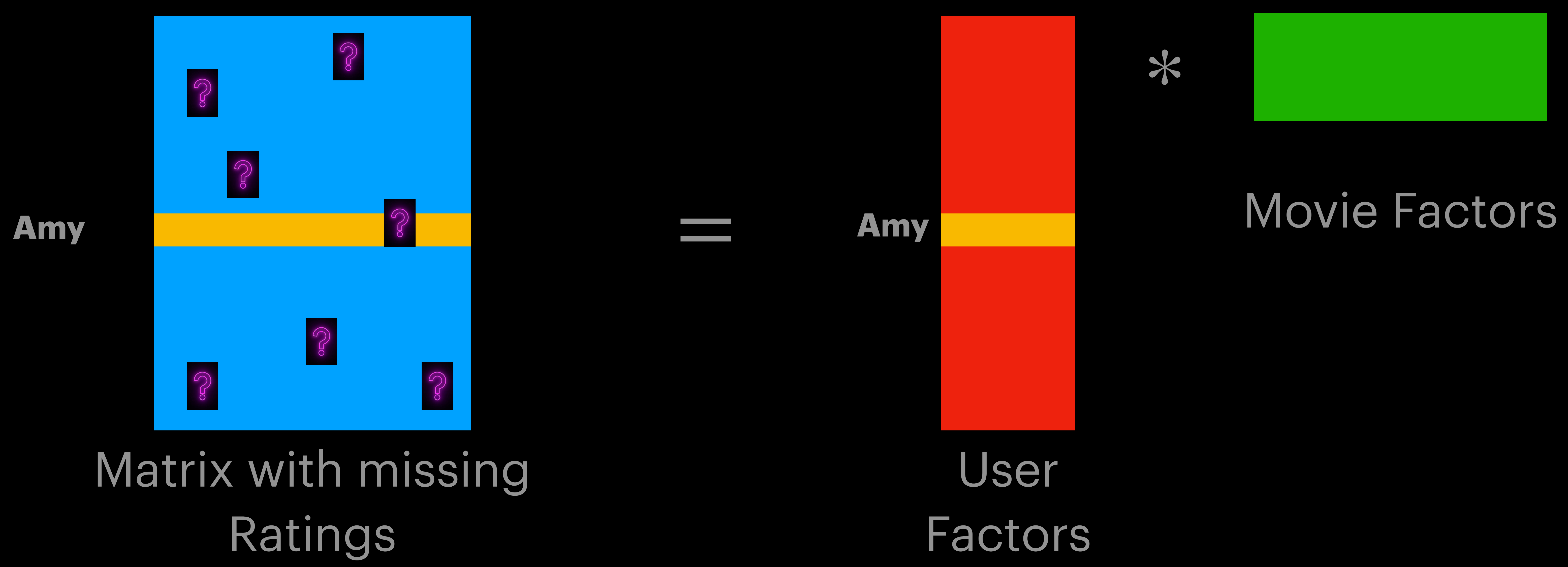
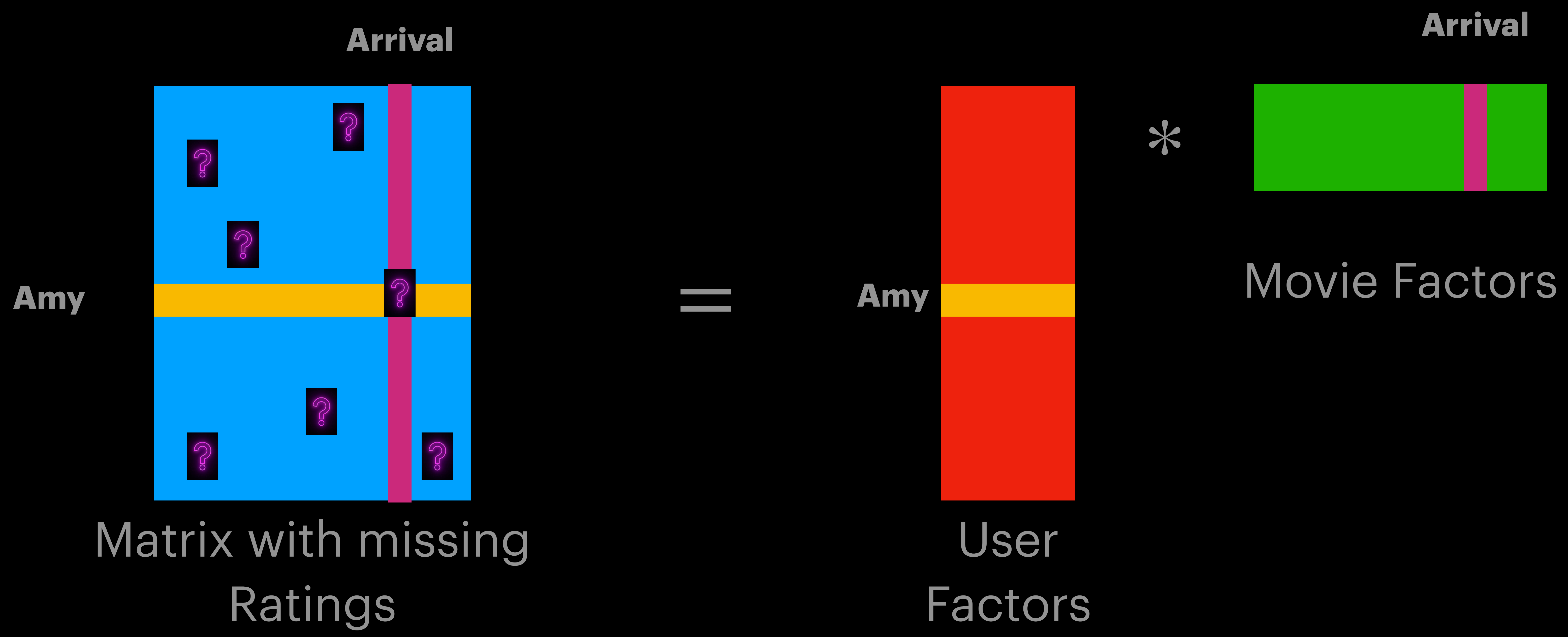
Through Matrix Completion!



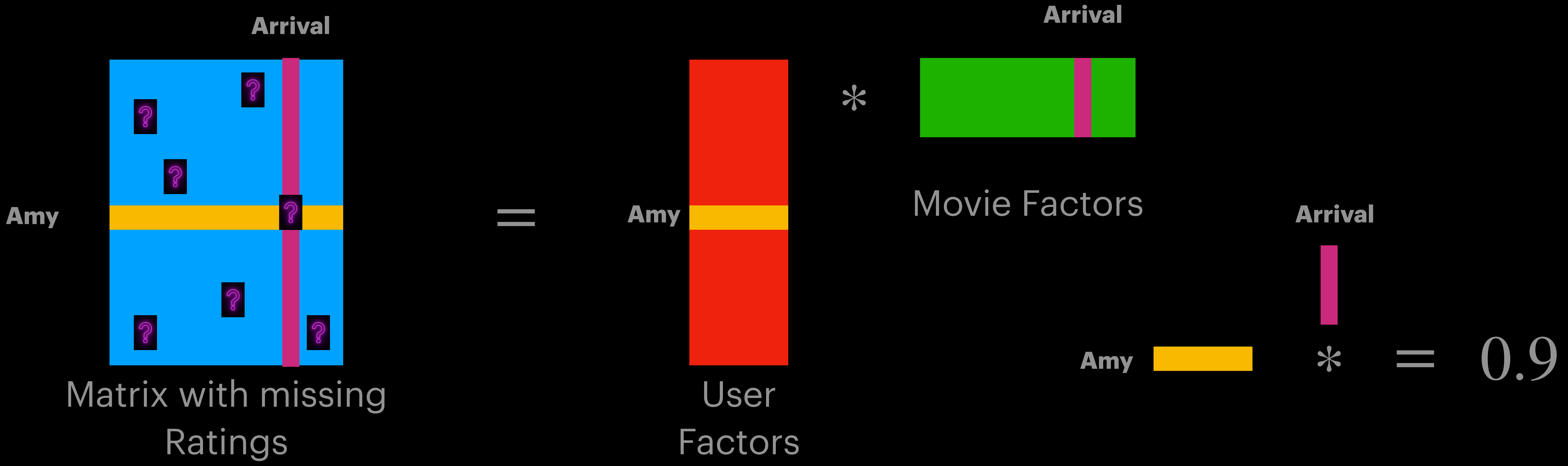
Collaborative Filtering

Through Matrix Completion!



Collaborative Filtering

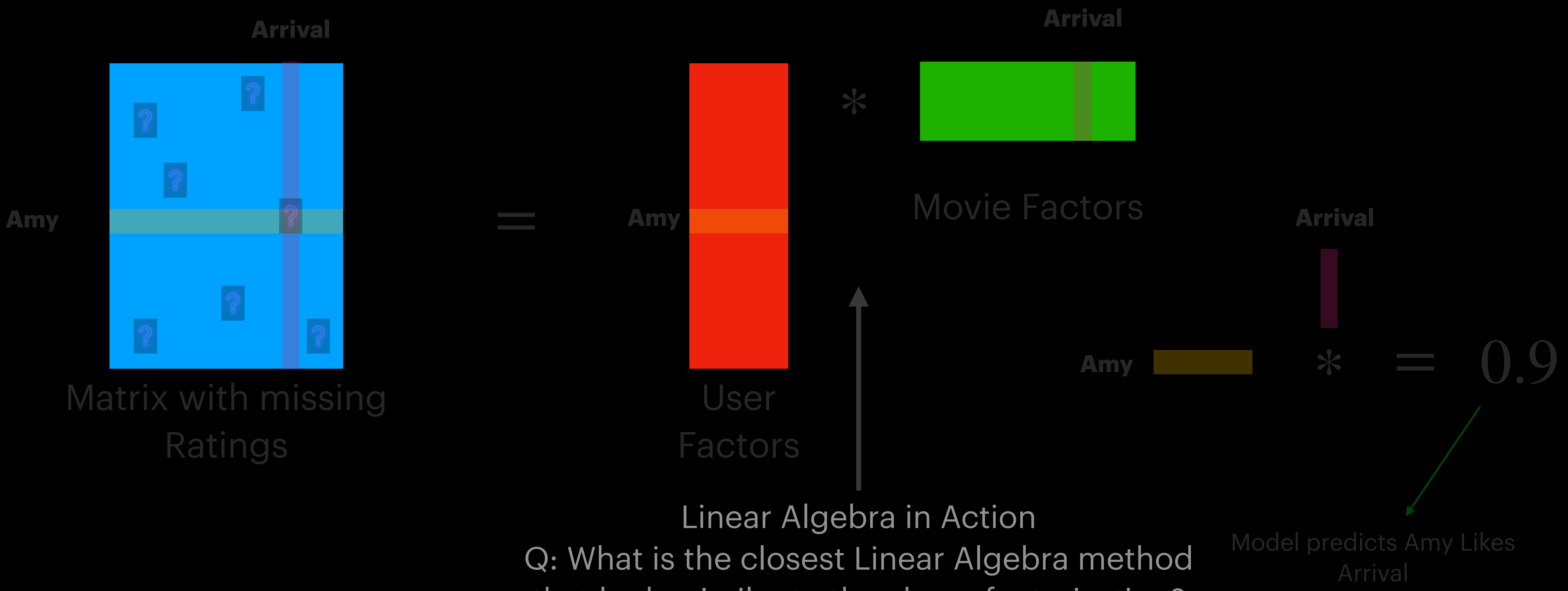
Through Matrix Completion!



Collaborative Filtering

Through Matrix Completion!

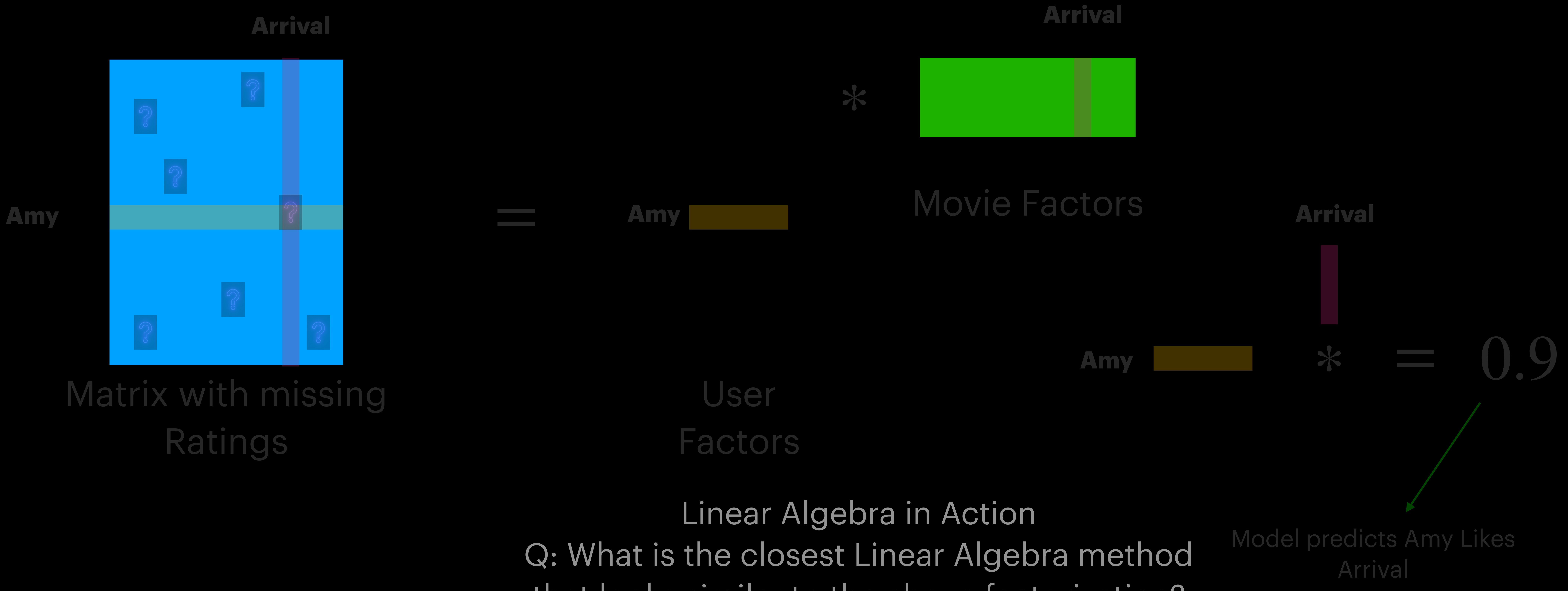
Collaborative Filtering
Through Matrix Completion!



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

Collaborative Filtering

Through Matrix Completion!

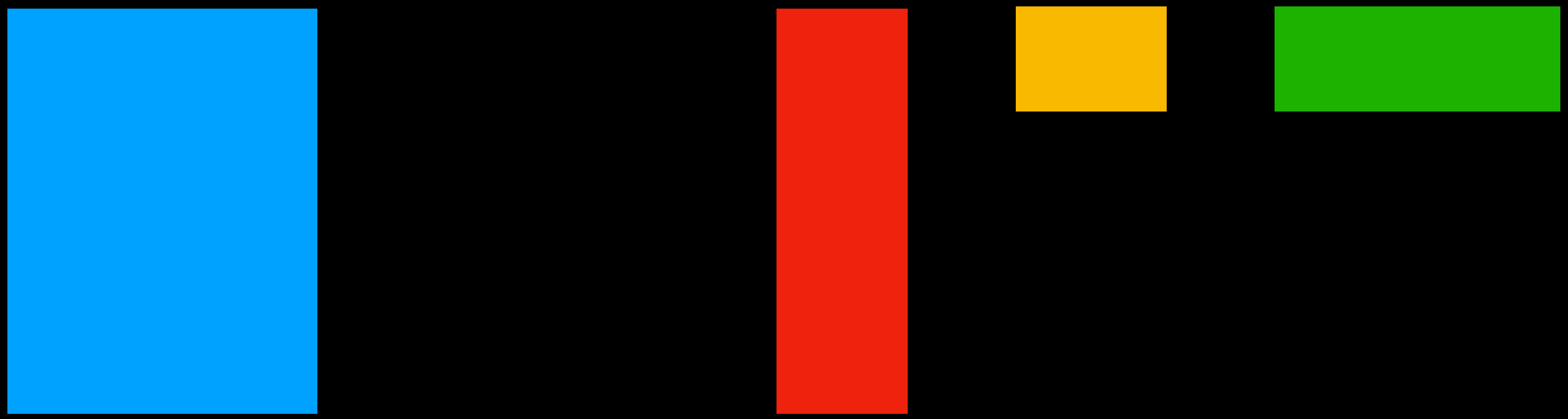


Linear Algebra in Action

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

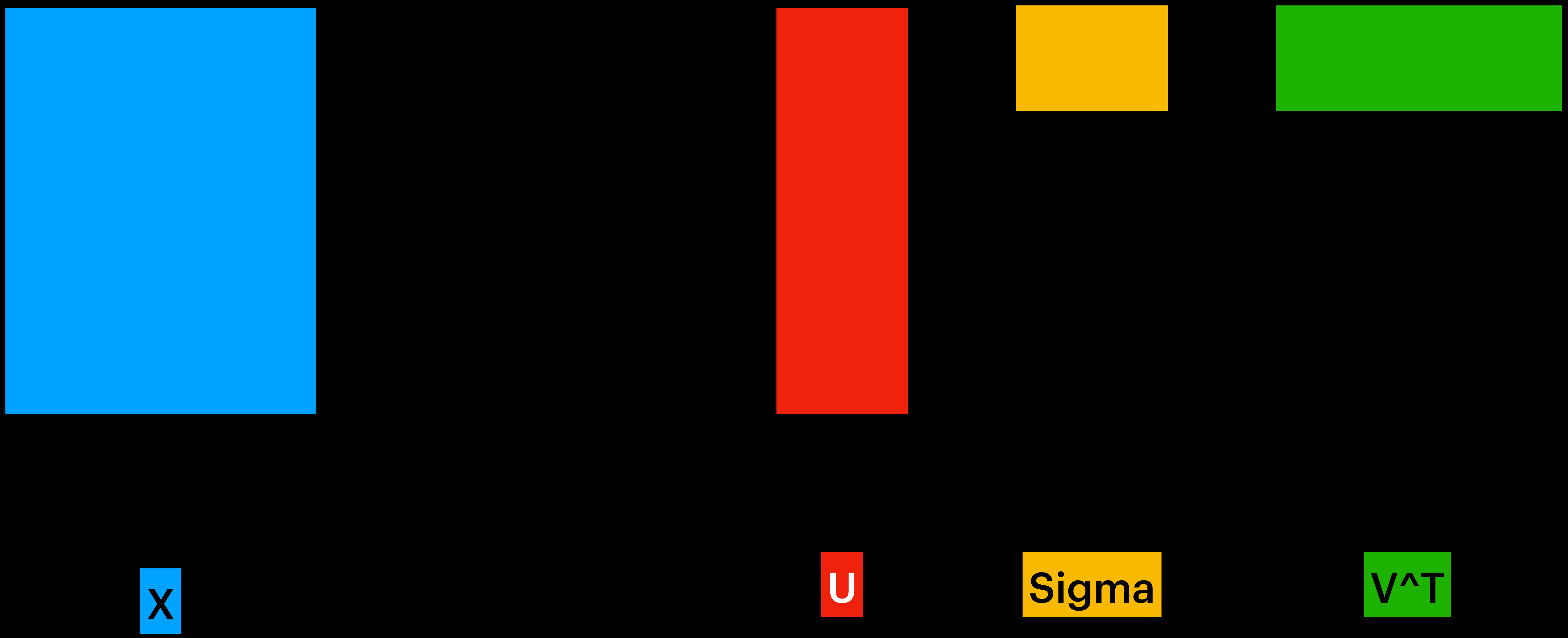
A: SVD = Singular Value Decomposition

SVD of a matrix



SVD of a matrix

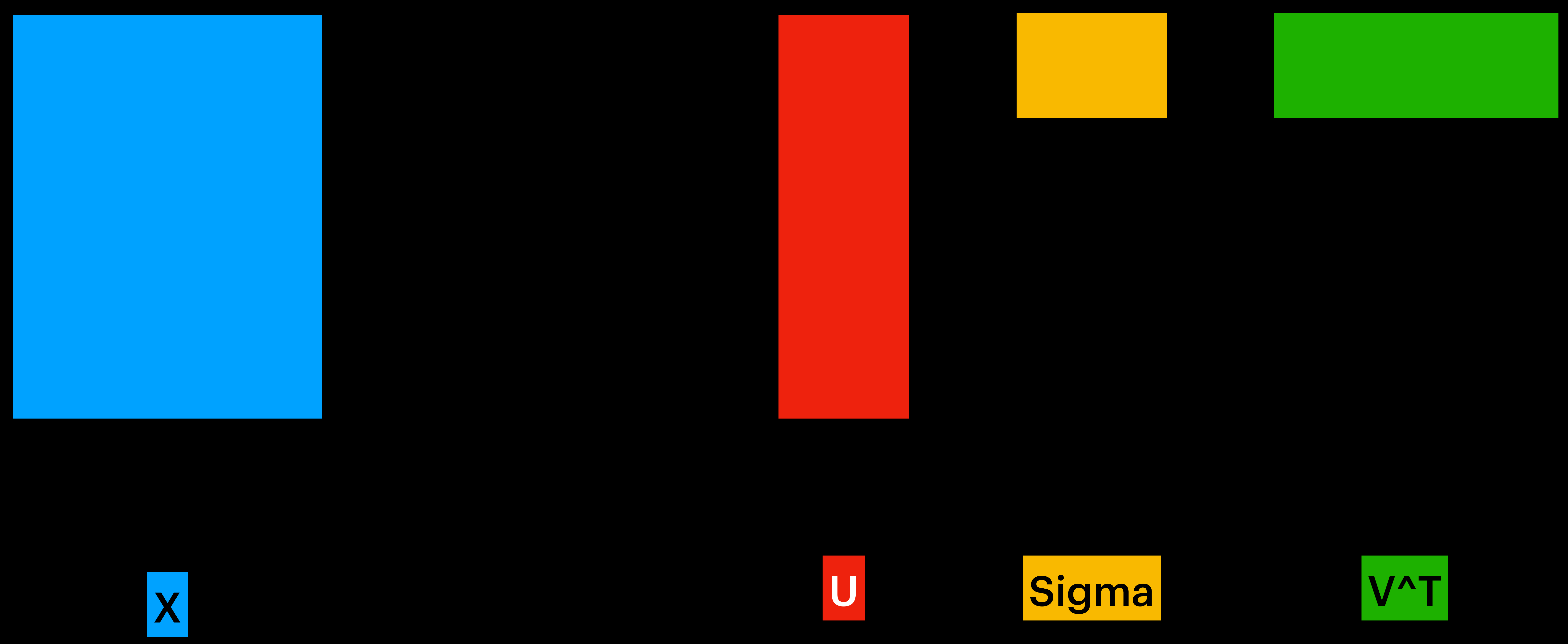
SVD of a matrix



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

SVD of a matrix

Every matrix has an SVD!



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

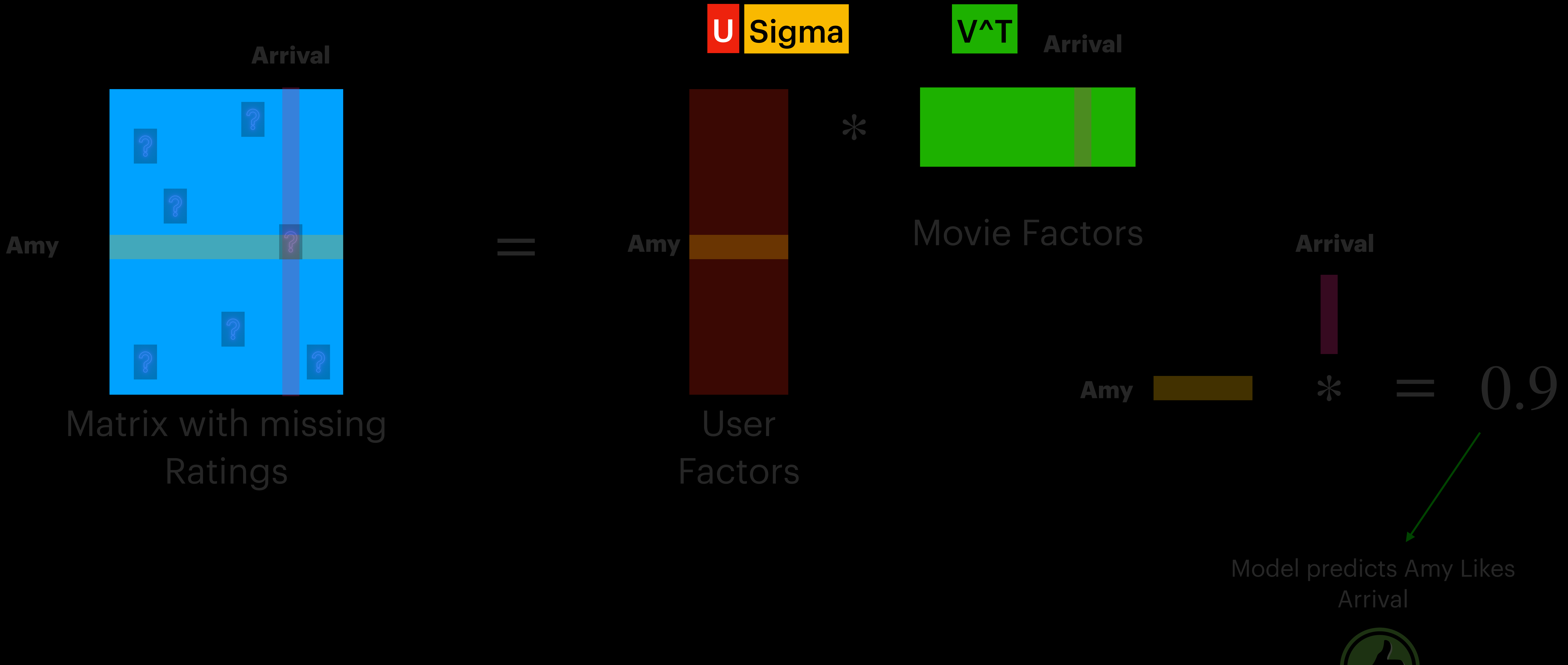
SVD of a matrix

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

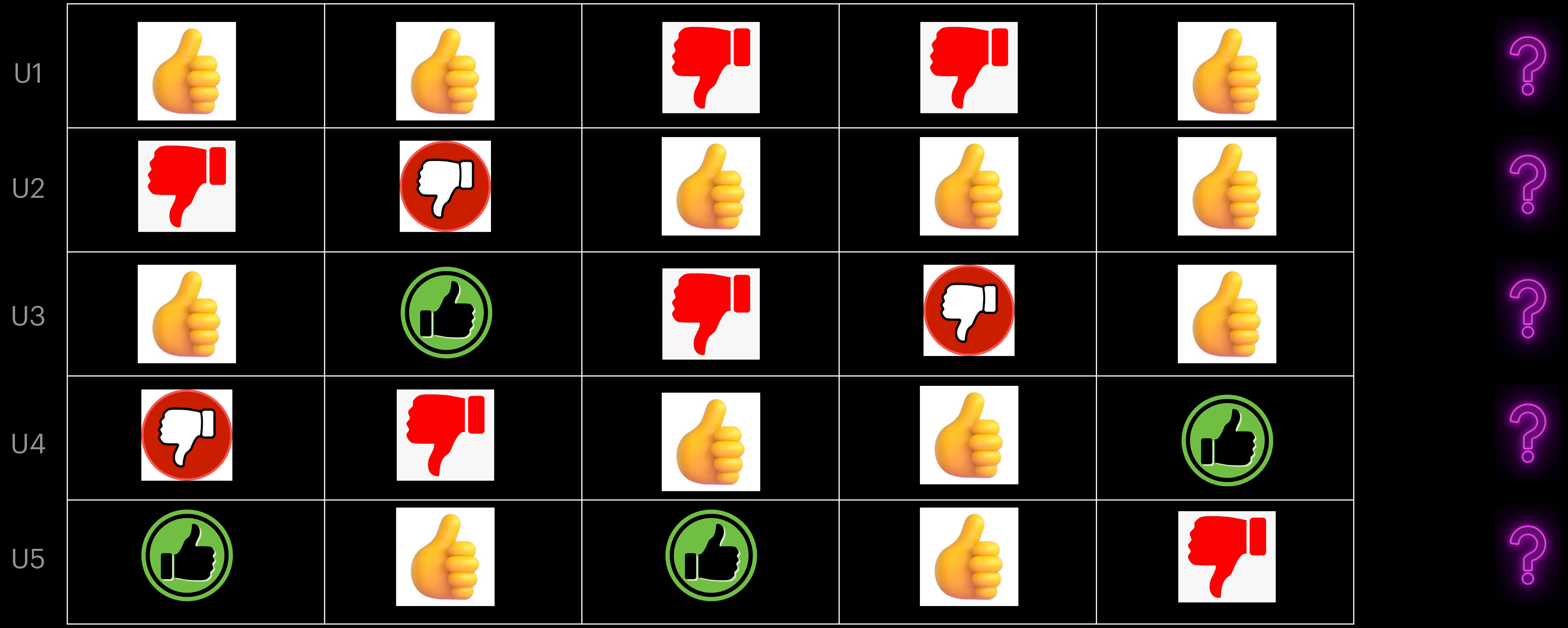
Minions

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



Collaborative Filtering

Content Based Filtering

vs Collaborative Filtering

Avatar

Arrival

When Harry

Before Sunrise

Minions

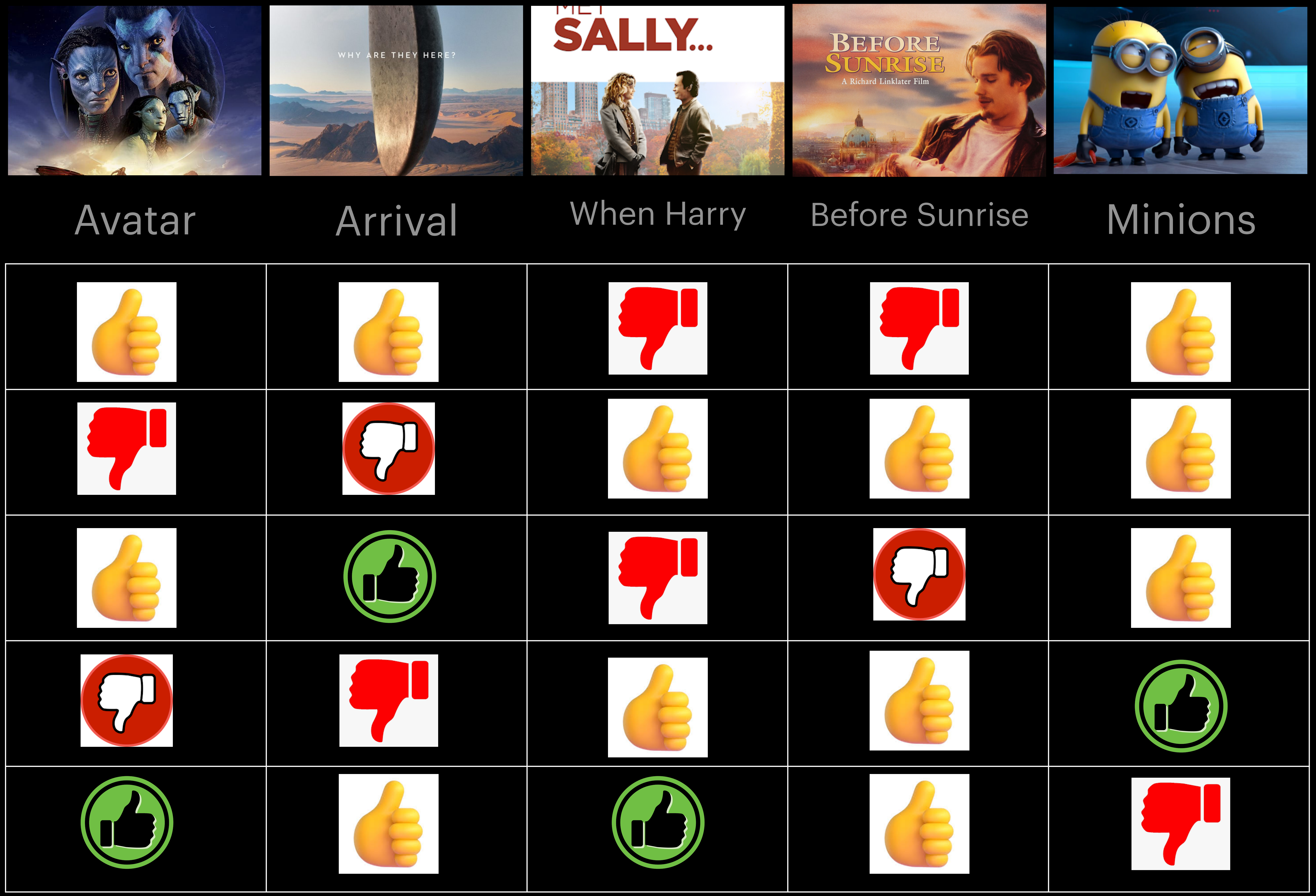
Men in Black

Karthik

U1	👍	👍	👎	👎	👍
U2	👎	👎	👍	👍	👍
U3	👍	👍	👎	👎	👍
U4	👎	👎	👍	👍	👍
U5	👍	👍	👍	👍	👎

Content Based Filtering

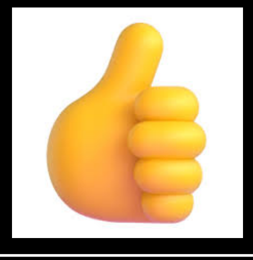
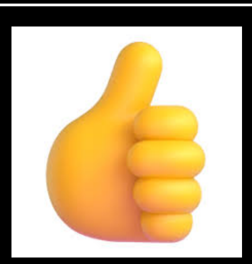
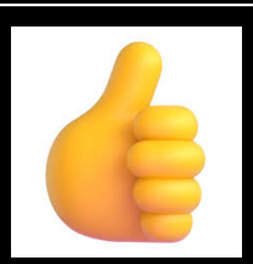
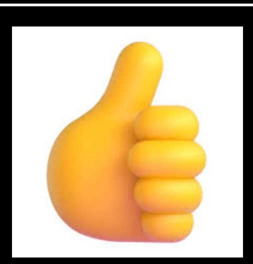
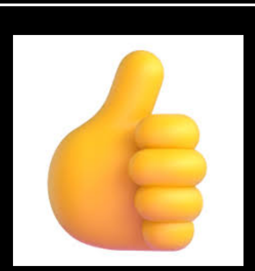
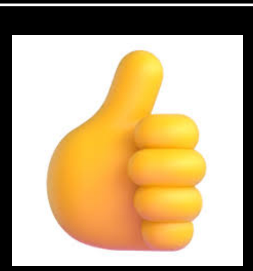
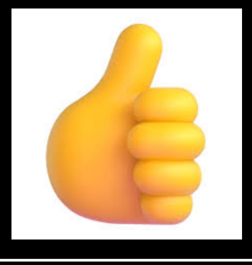
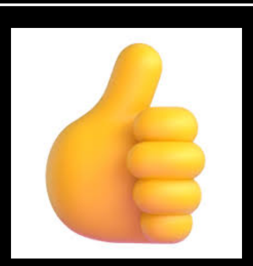
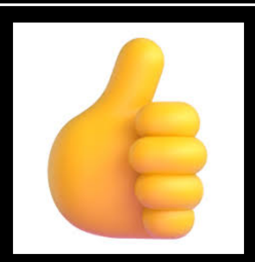
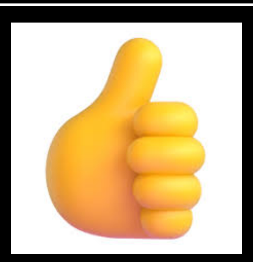
vs Collaborative Filtering



Karthik

Content Based Filtering

vs Collaborative Filtering

	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
U1	👍	👍	👎	👎	👍
U2	👎	👎	👍	👍	👍
U3	👍	👍	👎	👎	👍
U4	👎	👎	👍	👍	👍
U5	👍	👍	👍	👍	👎

Karthik

Watched

Arrival

Men in Black

Content Based Filtering

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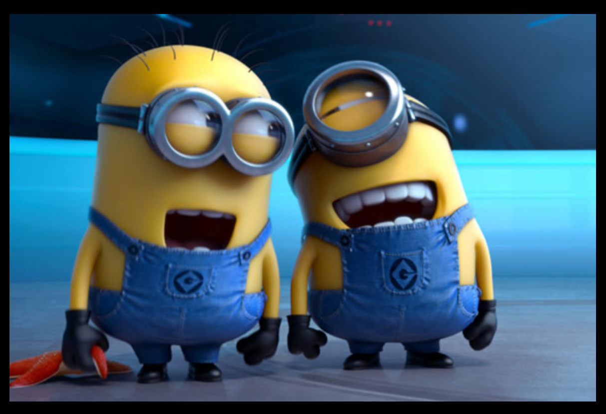
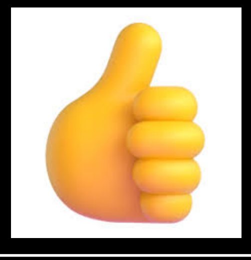
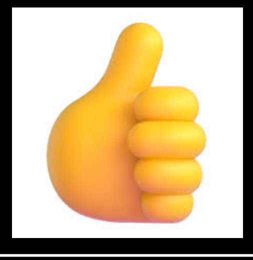
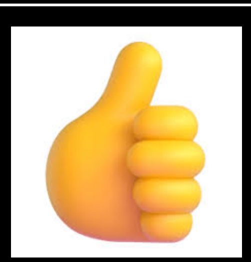
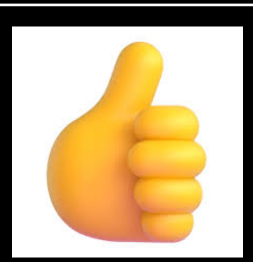
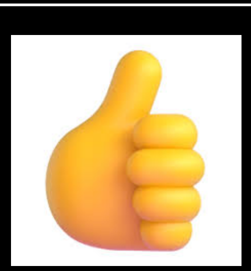
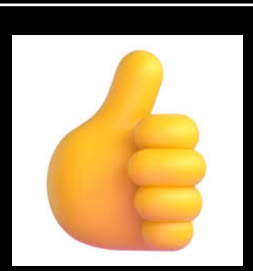
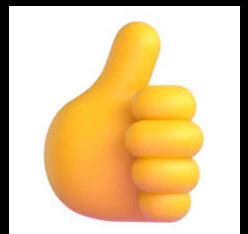
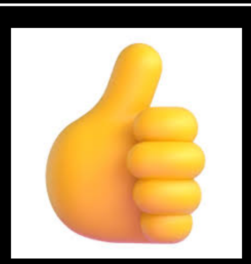
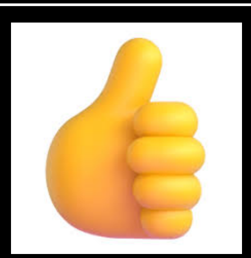
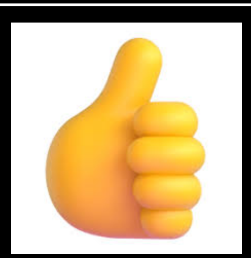


	Avatar	Arrival	When Harry	Before Sunrise	Minions
U1					
U2					
U3					
U4					
U5					

Karthik

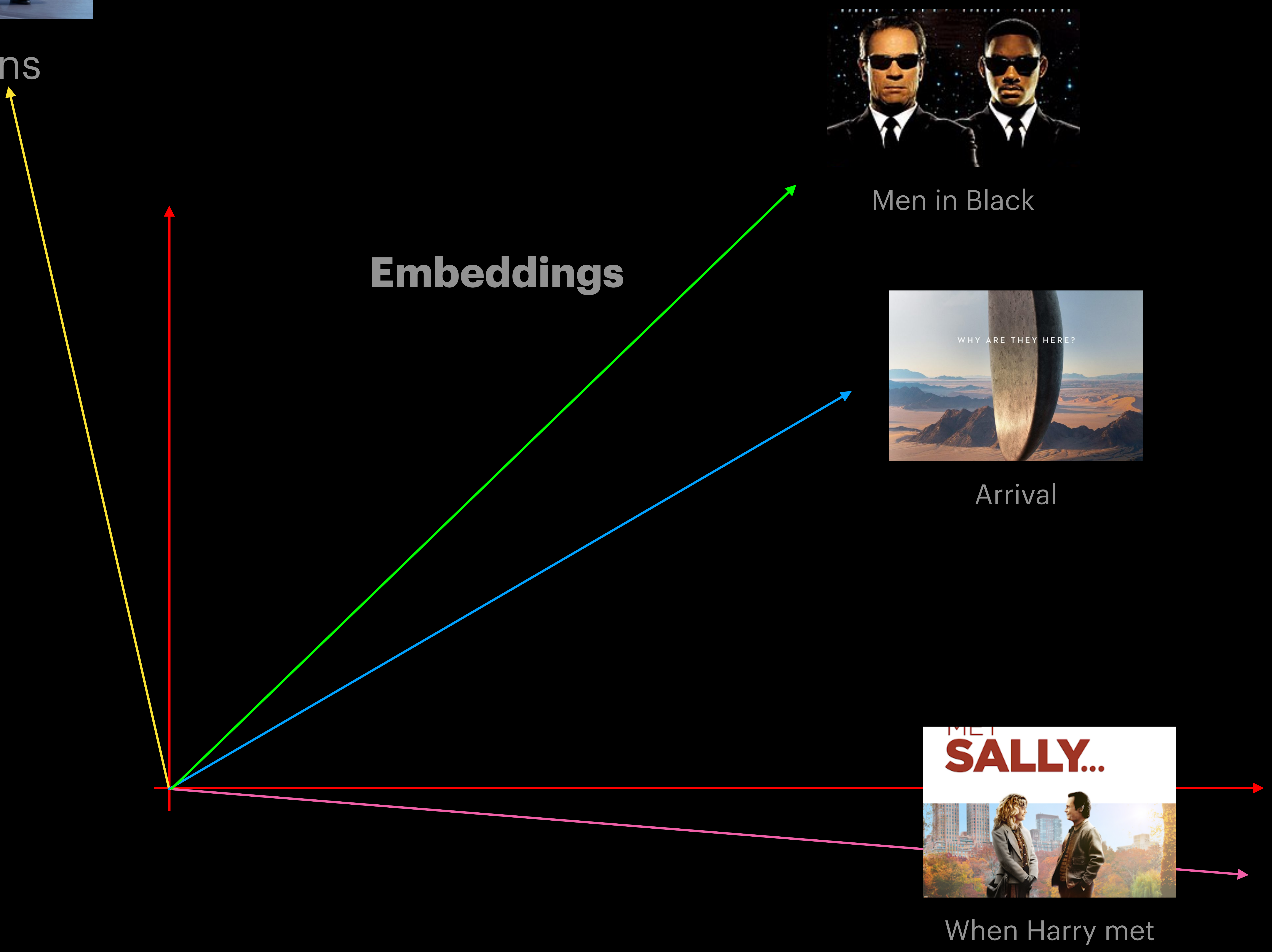
Watched

Arrival

Likely
To
Watch

Men in Black

Content Based Filtering



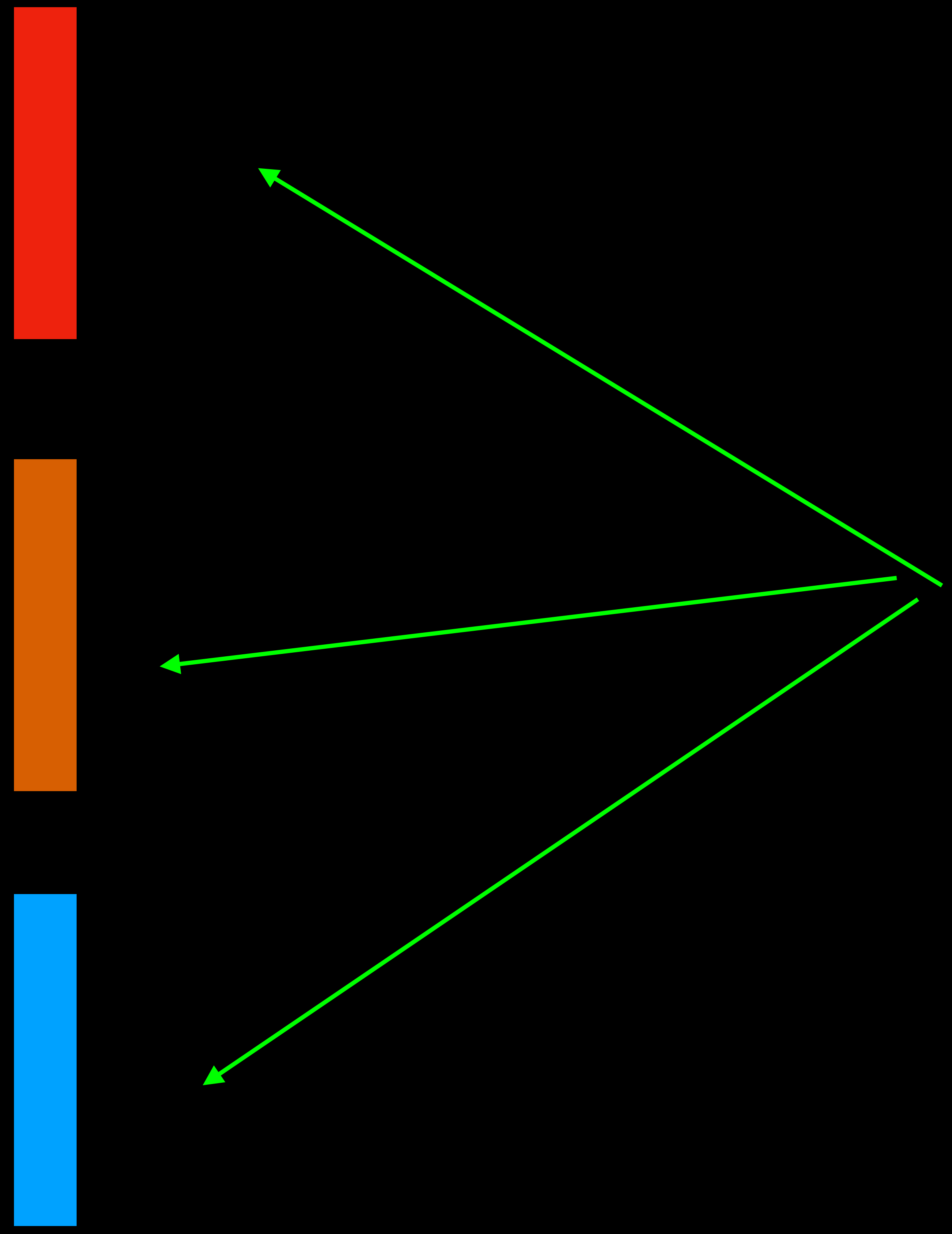
Content Based Filtering

Embeddings

Men in Black

Arrival

When Harry met



Typically 128 or 256 latent dimensions

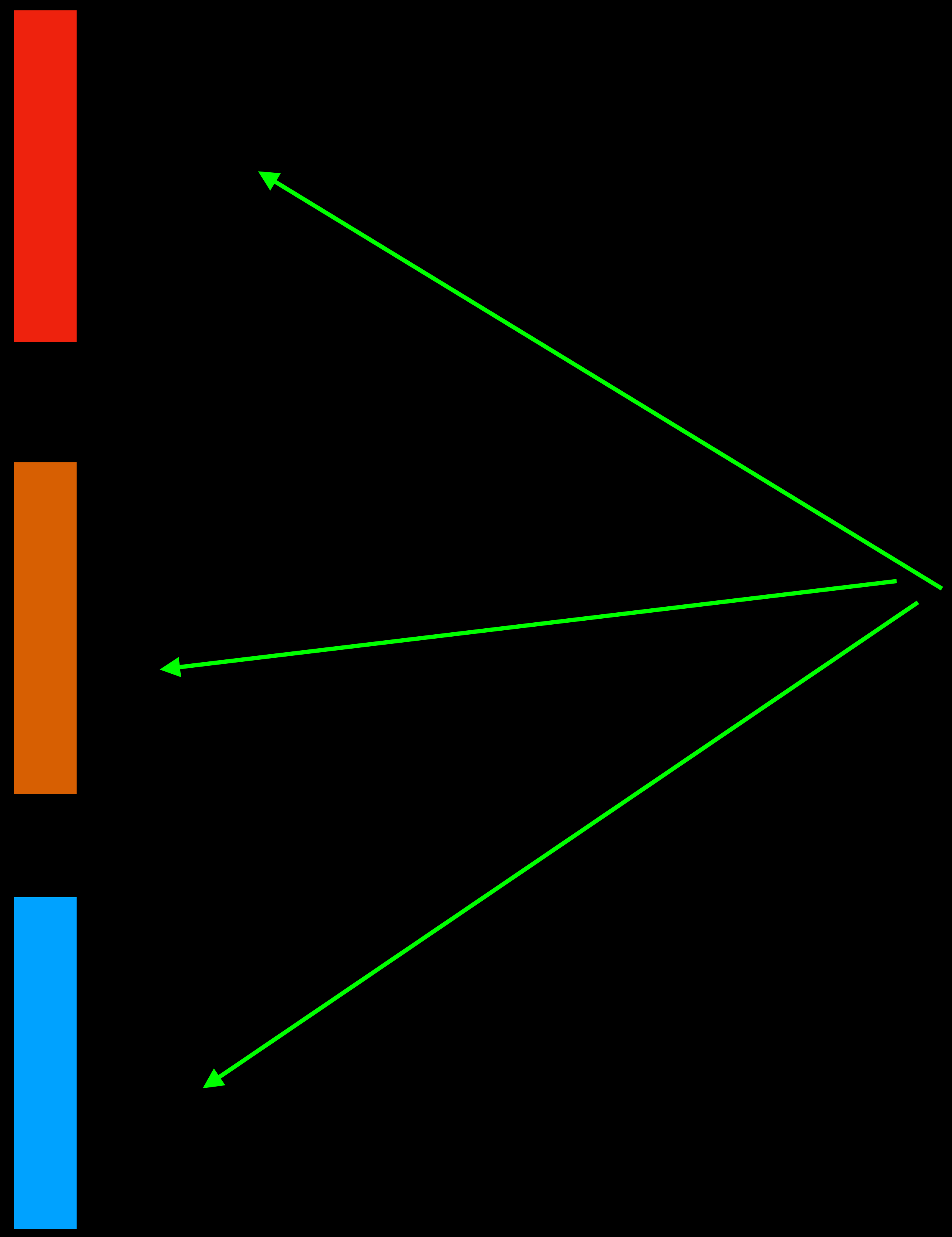
Content Based Filtering

Embeddings

Men in Black

Arrival

When Harry met



How do we
Obtain these embeddings?

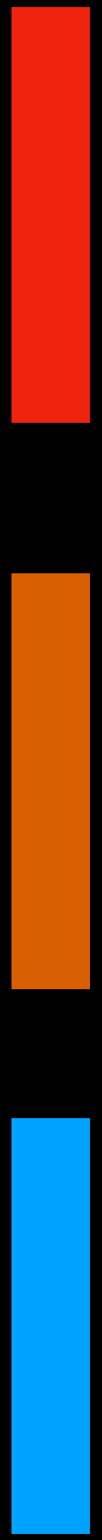
Content Based Filtering

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

Embeddings | **Latent Dimensions** → **Interpretation**

?
?
?
?
⋮

Comedy + Romance
Thriller + Adventure
Comedy + Thriller
Adventure
⋮

Men in Black

Arrival

When Harry met

Embeddings | Vector Representations

Embeddings

Latent Dimensions → Interpretation

?
?
?
?
⋮

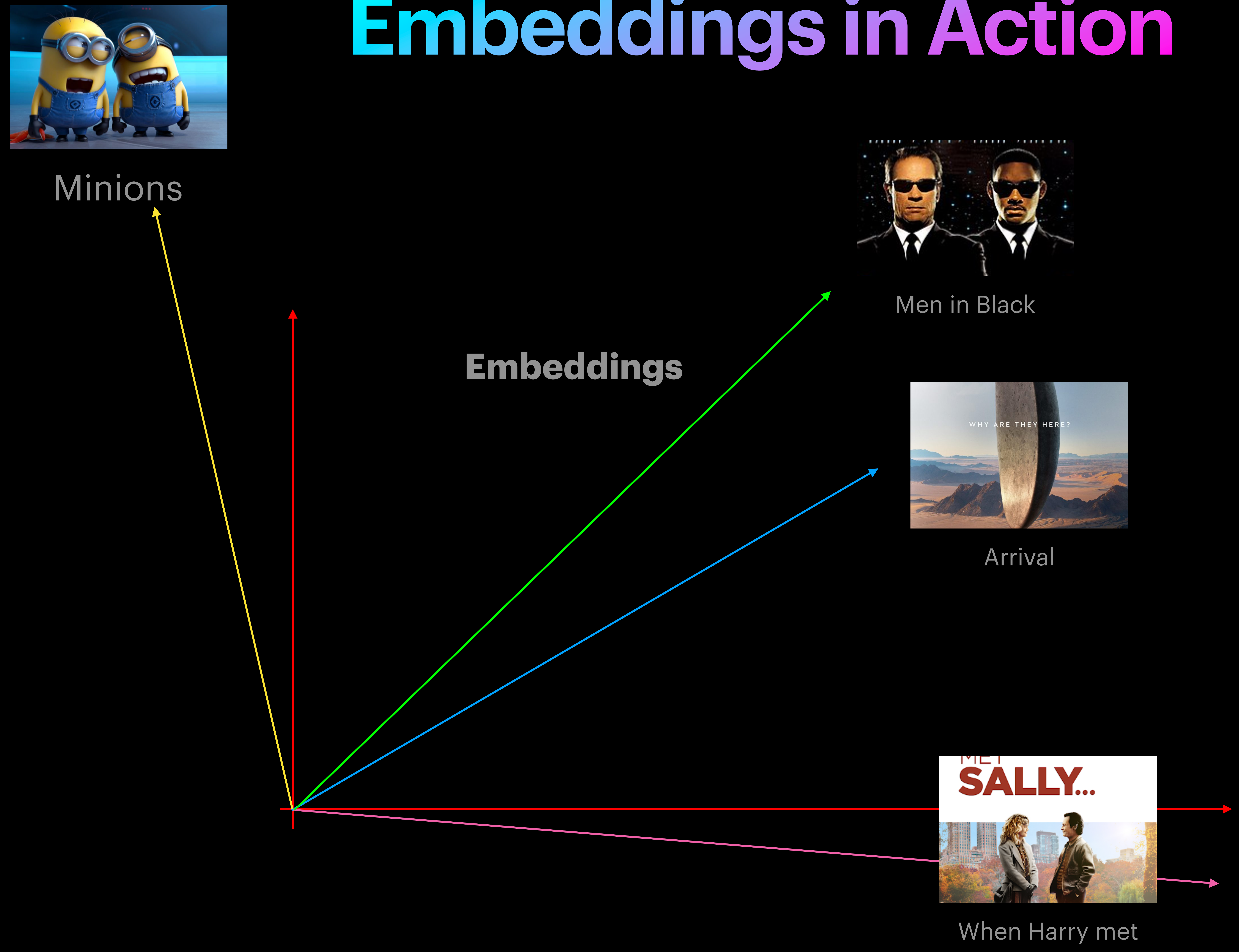
Comedy + Romance
Thriller + Adventure
Comedy + Thriller
Adventure
⋮

Men in Black

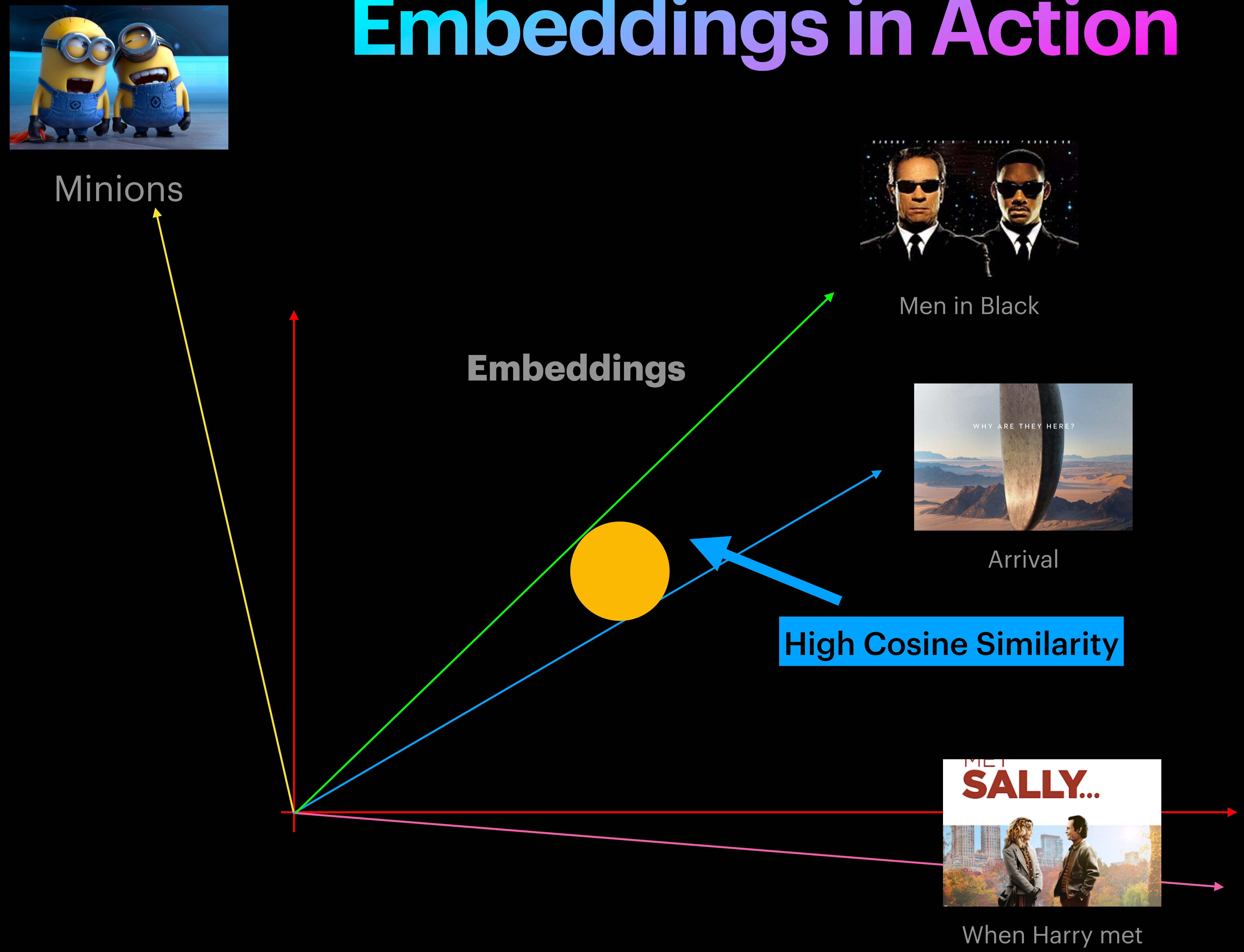
Arrival

When Harry met

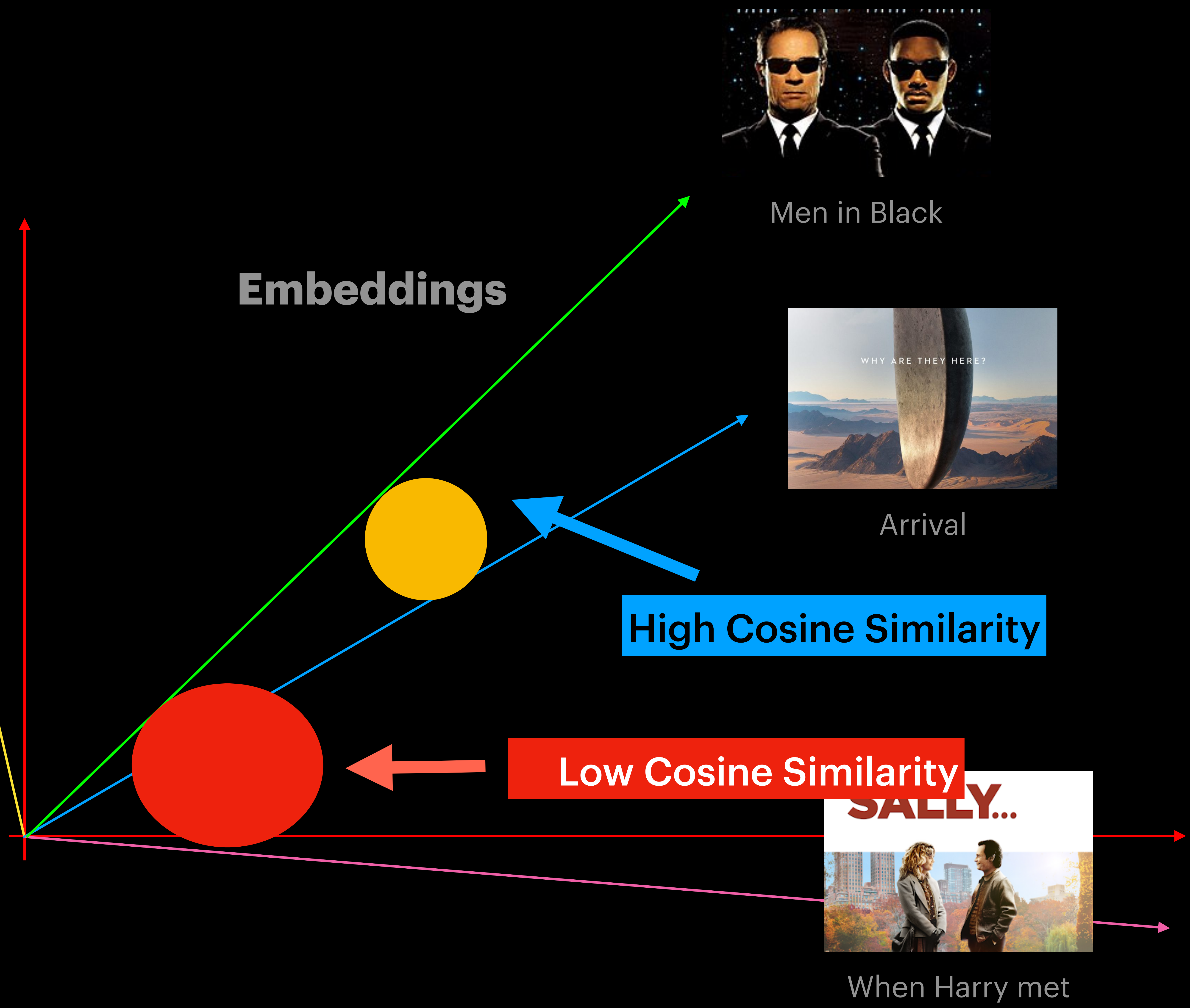
Embeddings in Action



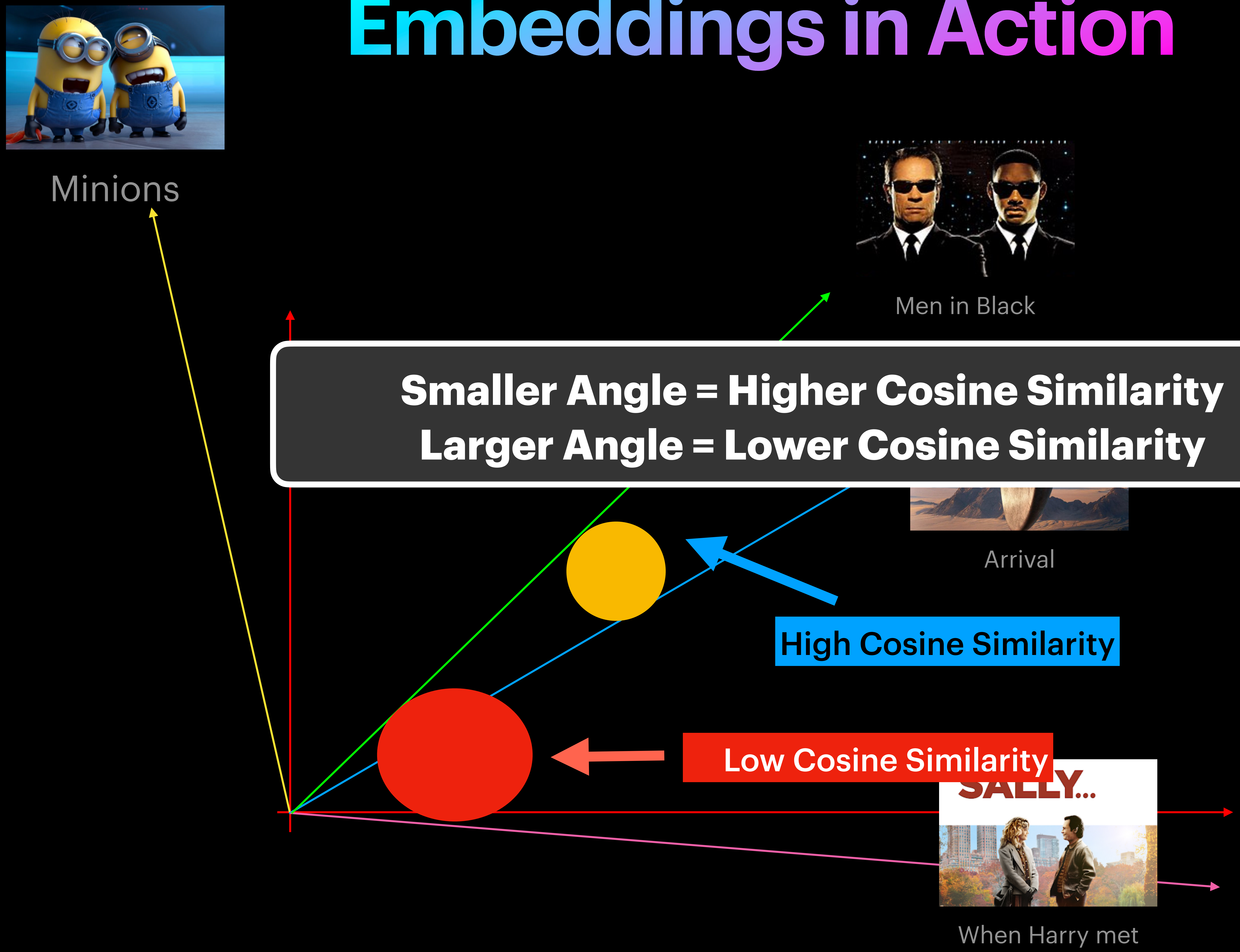
Embeddings in Action



Embeddings in Action



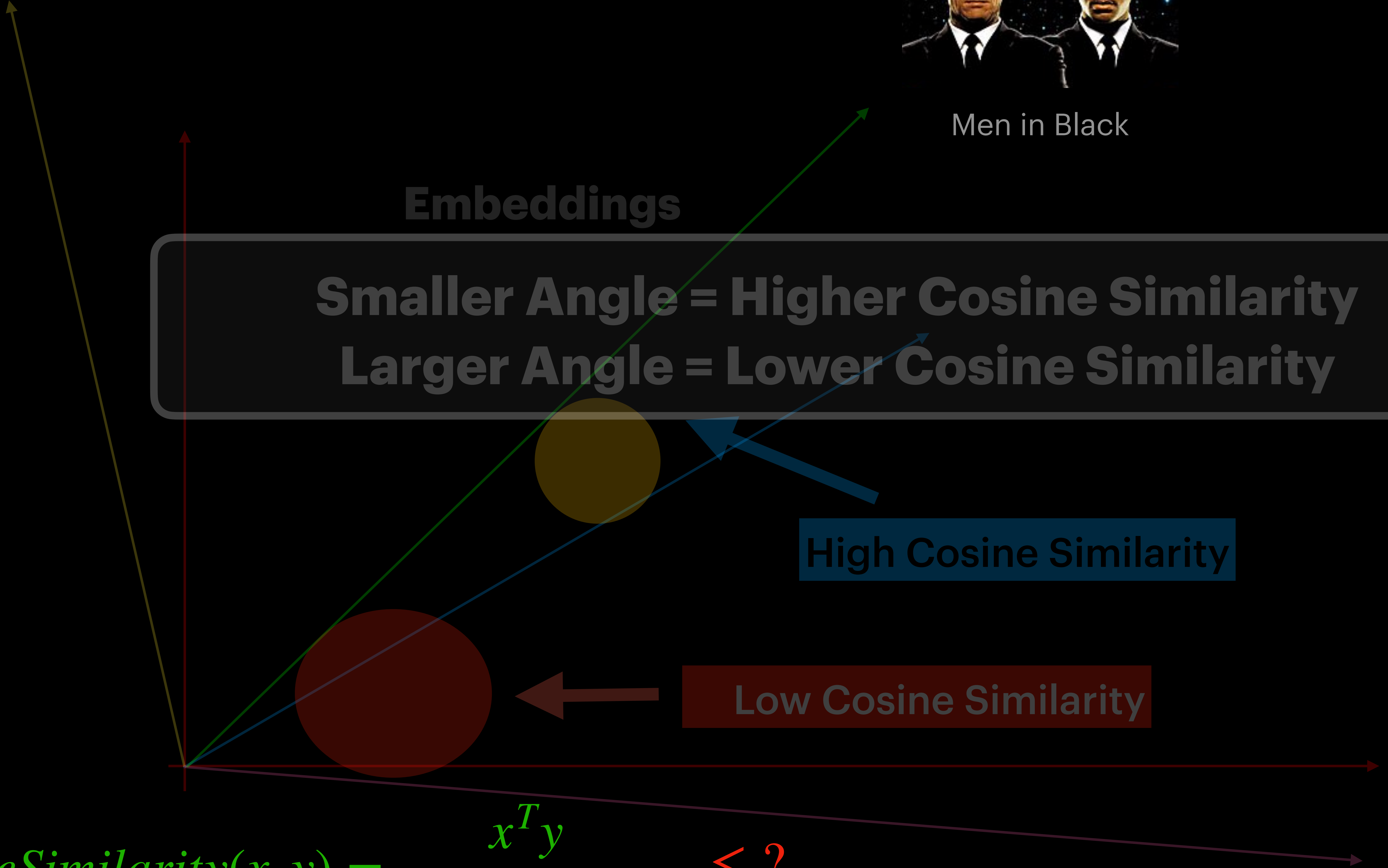
Embeddings in Action



Embeddings in Action

Minions

Men in Black



Men in Black

Arrival

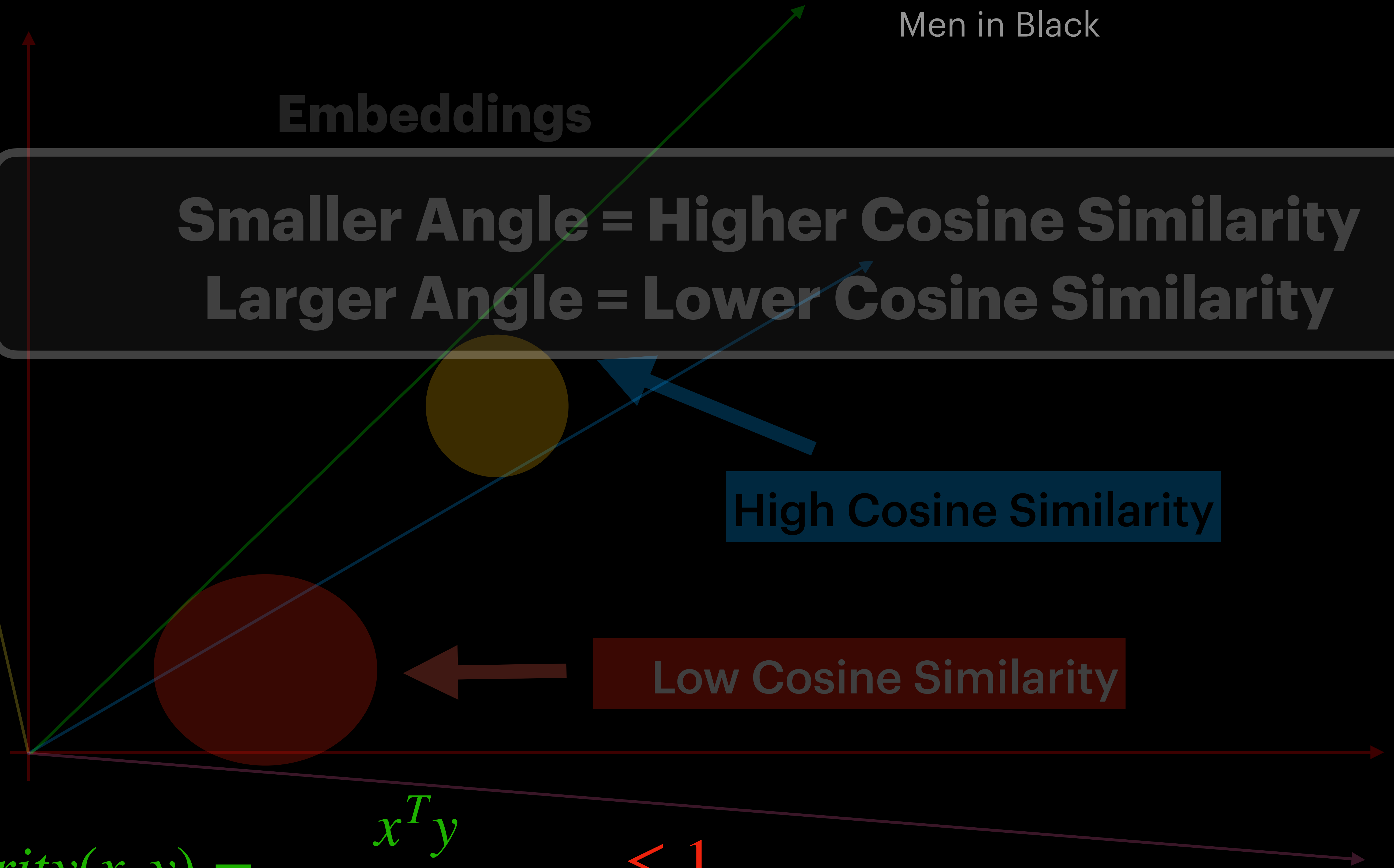
When Harry met

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

Embeddings in Action

Minions

Men in Black



Embeddings

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

High Cosine Similarity

Low Cosine Similarity

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

Men in Black

Arrival

When Harry met

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!

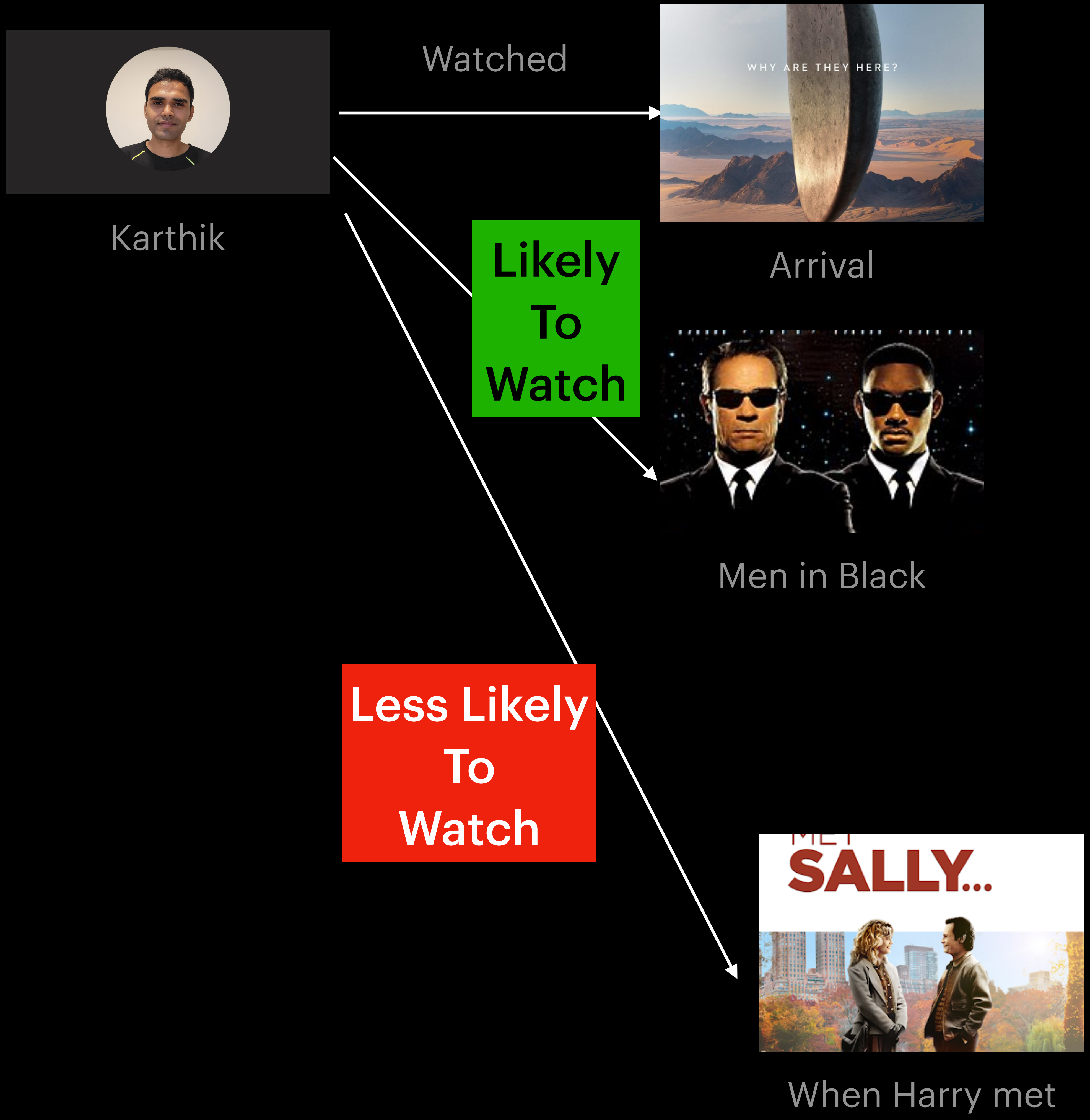
$$-1 \leq \; CosineSimilarity(x, y) = \frac{x^T y}{||x||\,||y||} \leq 1$$

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

$$||x||_2$$

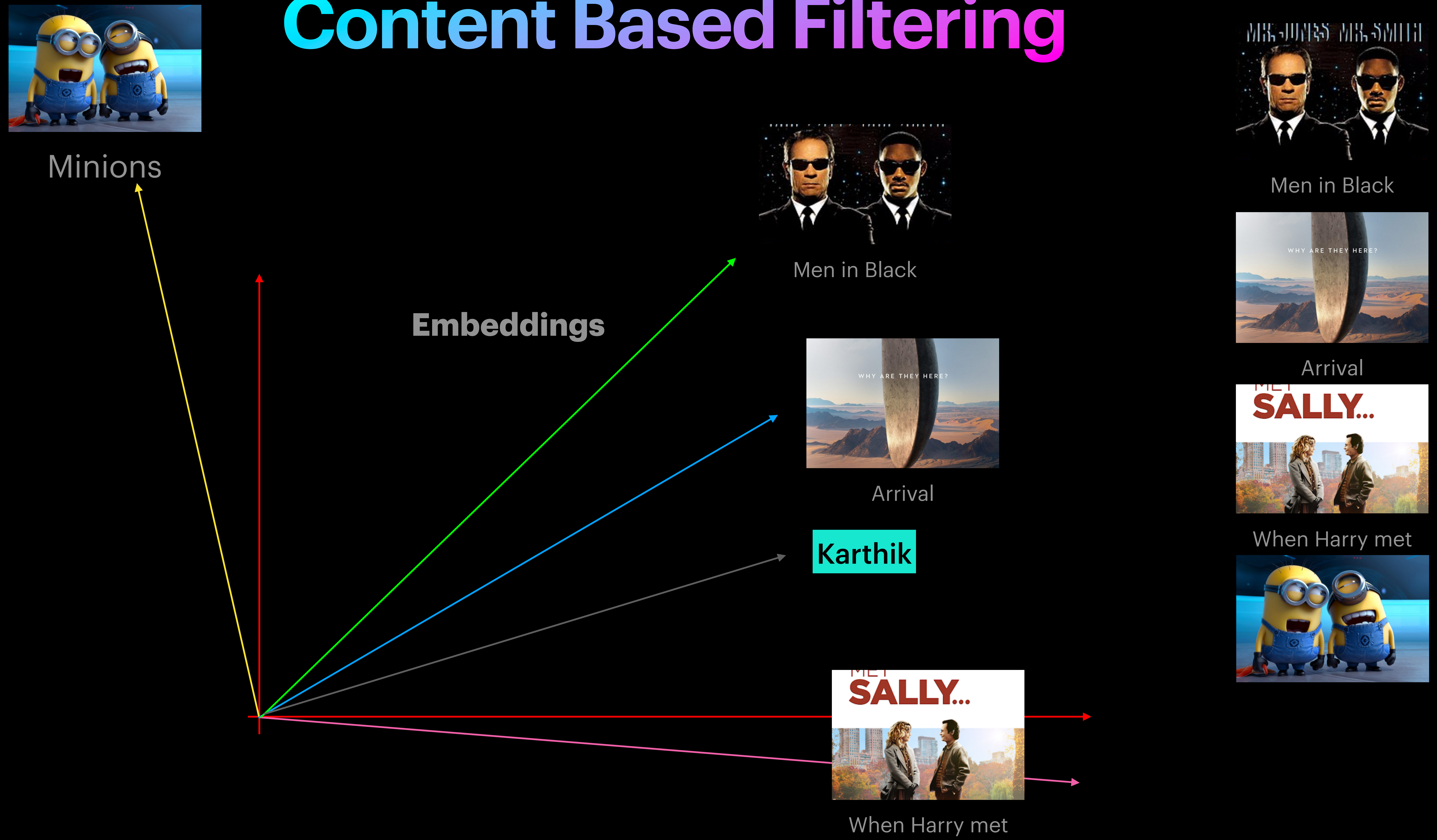
Euclidean Norm of x

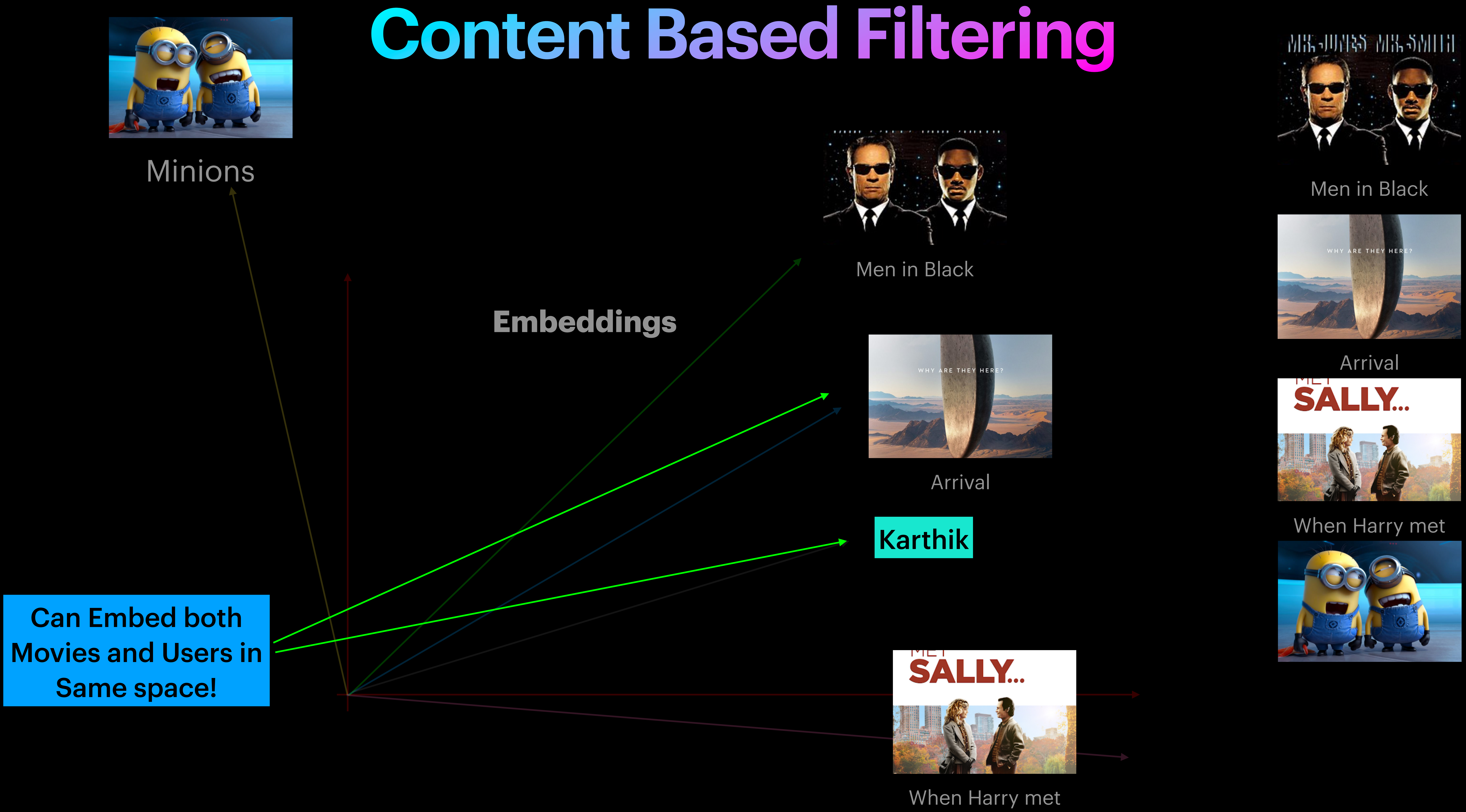
Embeddings in Action



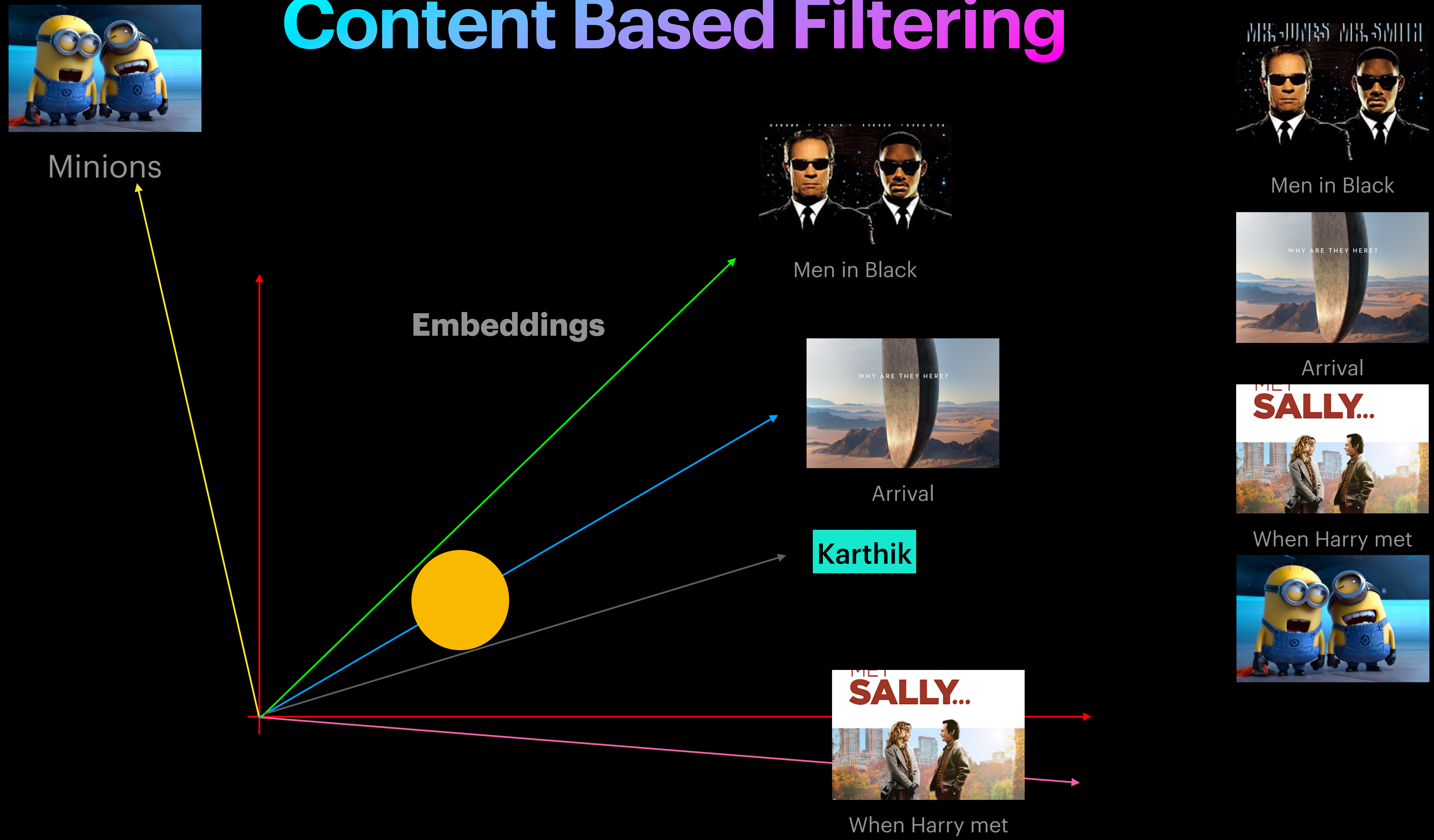
What if I like both sci-fi and romance?

Content Based Filtering



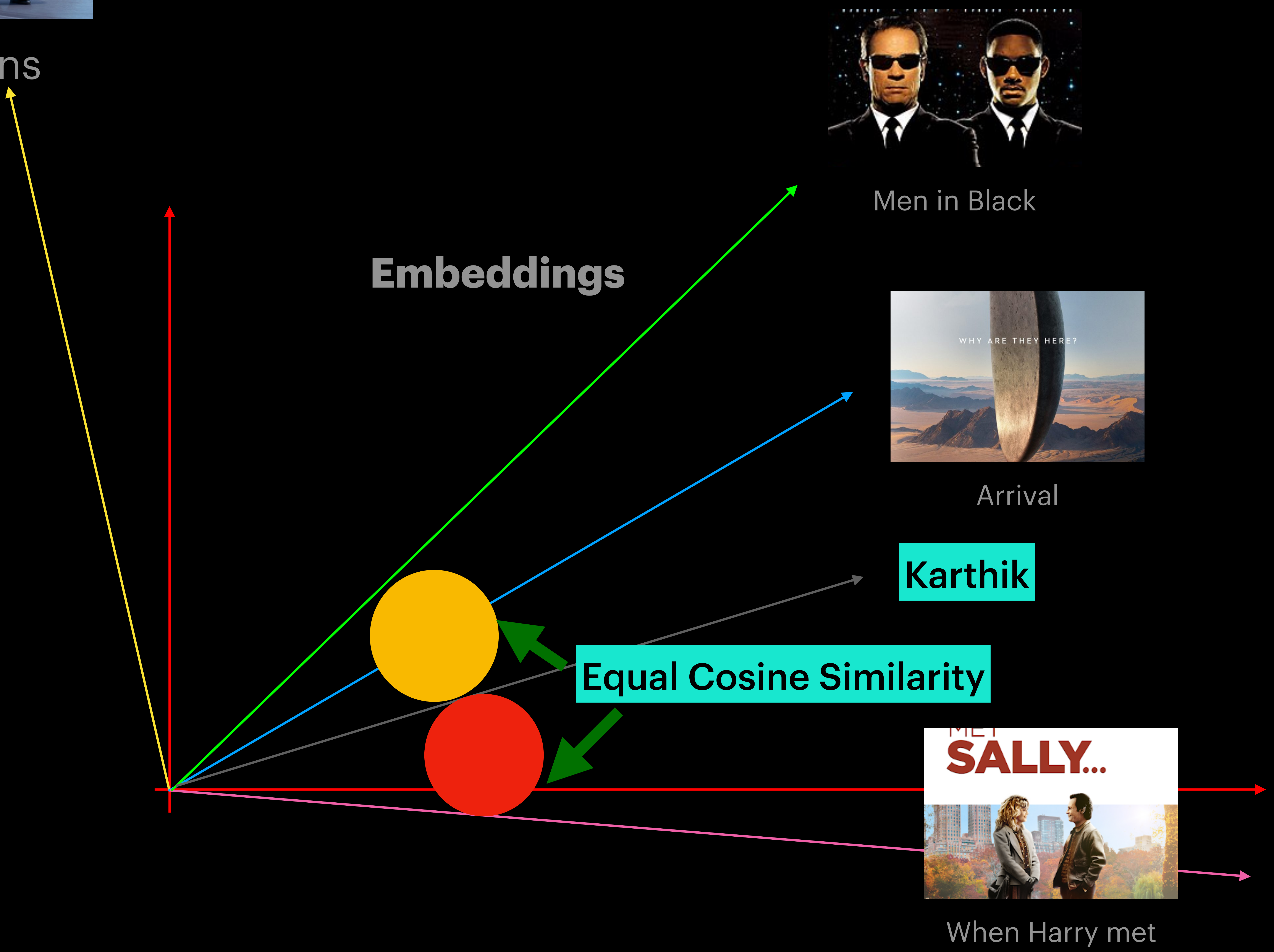

Content Based Filtering
Minions
Embeddings
Men in Black
WHY ARE THEY HERE?
Arrival
Karthik
SALLY...
When Harry met
Can Embed both Movies and Users in Same space!
MR. JONES MR. SMITH
Men in Black
WHY ARE THEY HERE?
Arrival
SALLY...
When Harry met

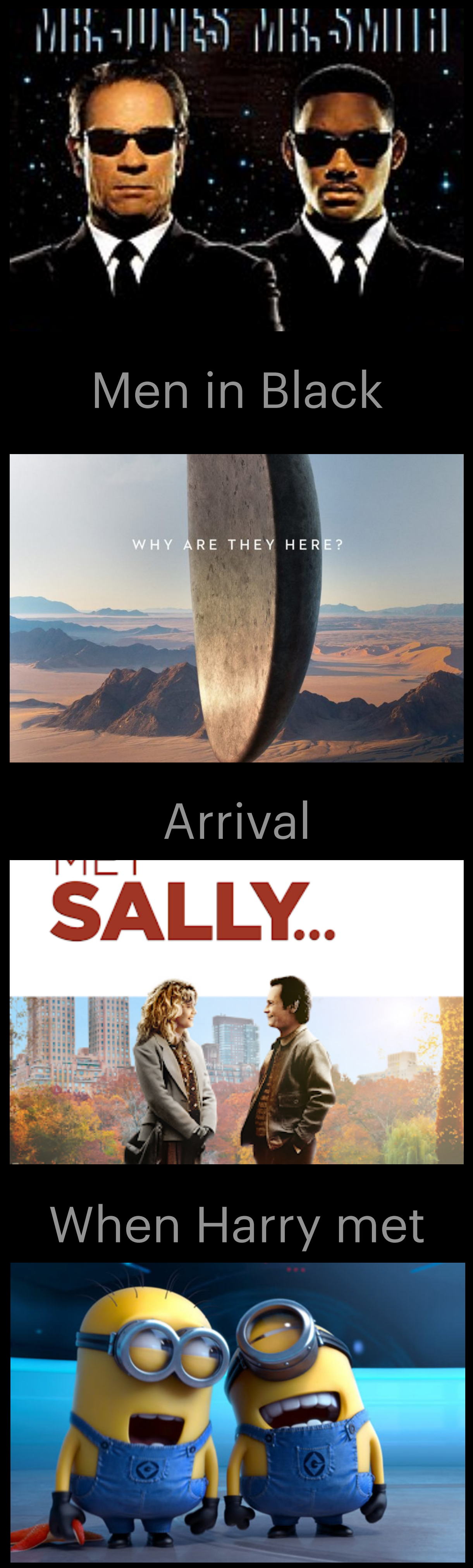
Content Based Filtering



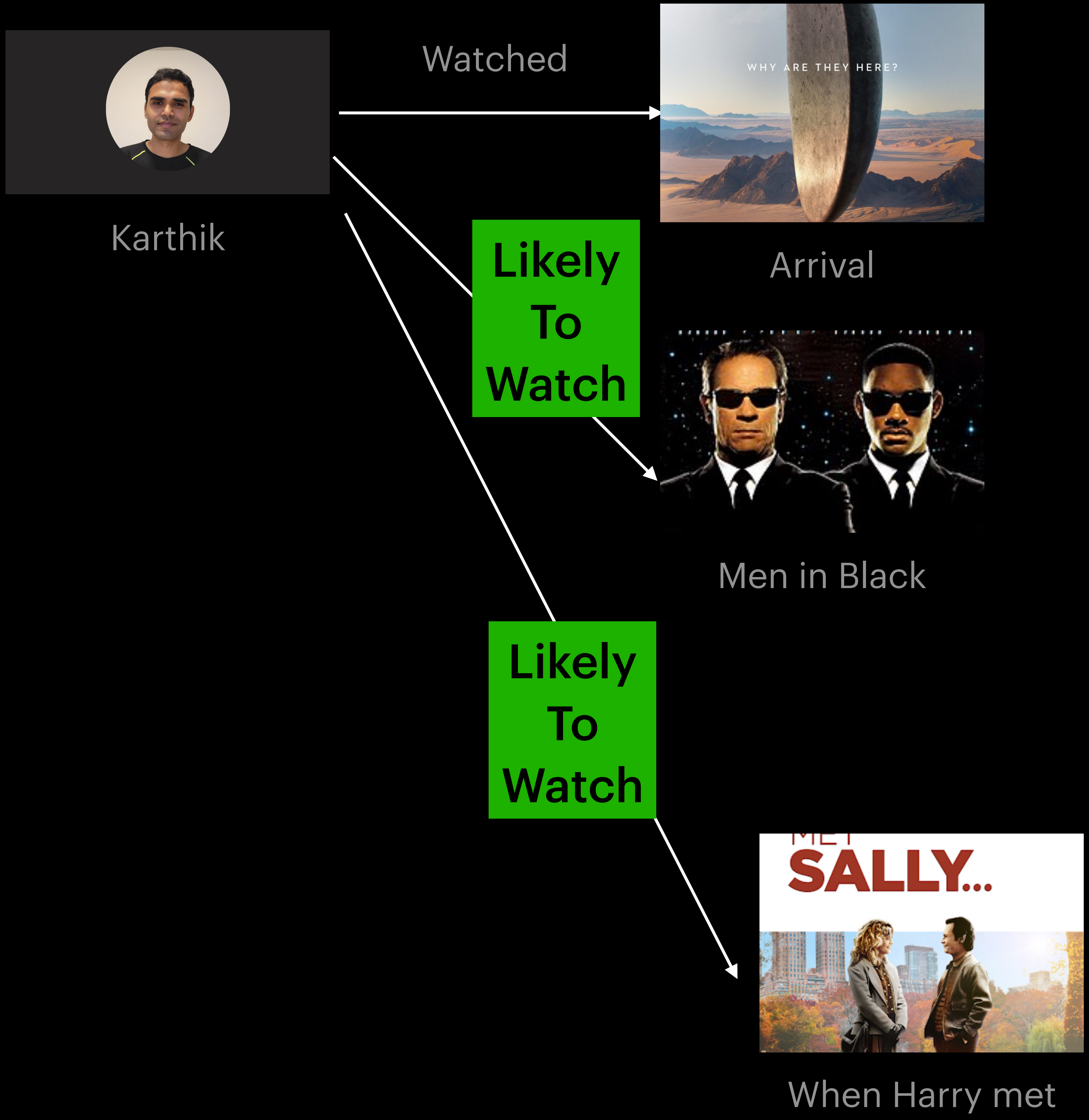
Content Based Filtering

Minions

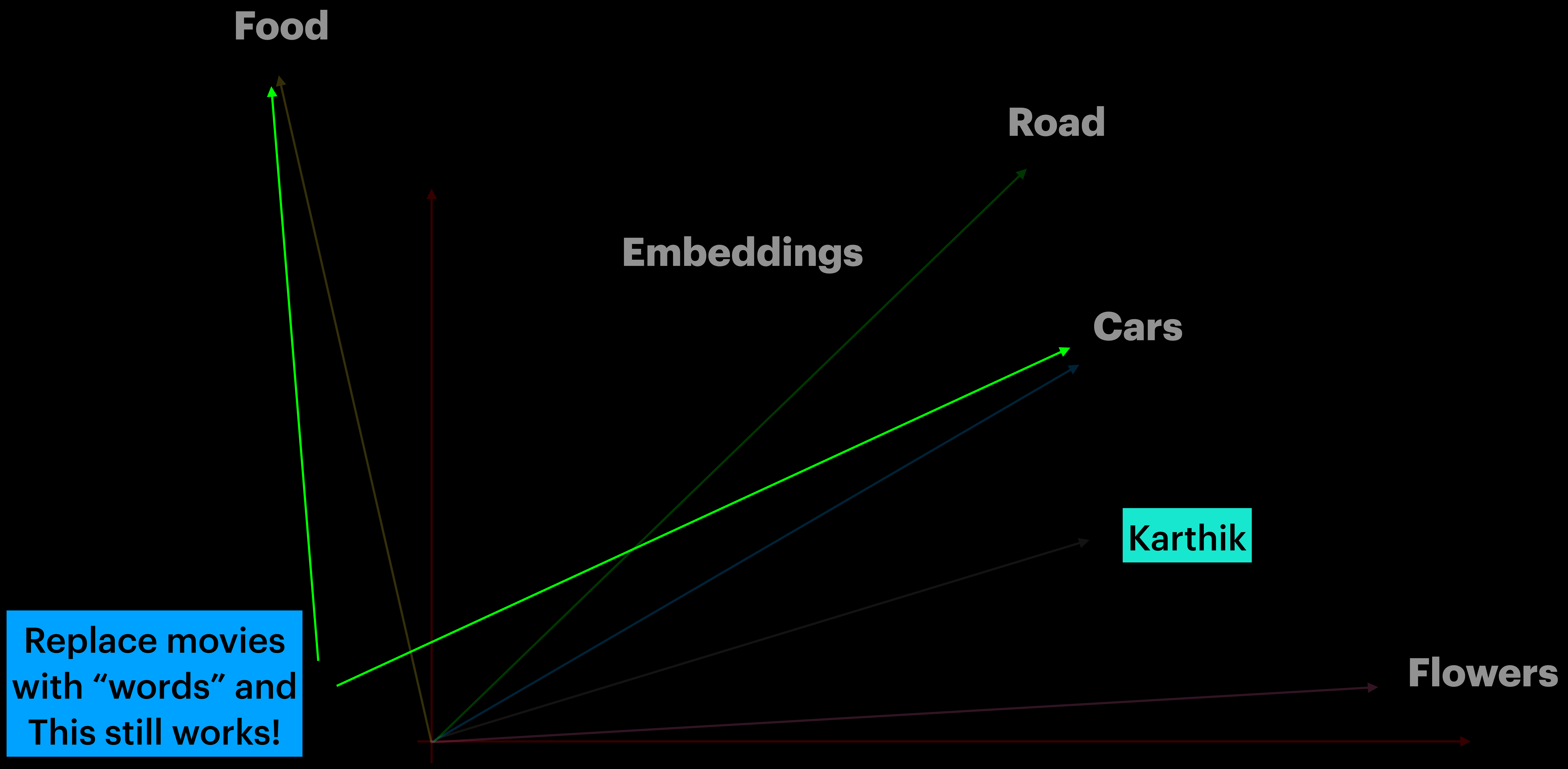




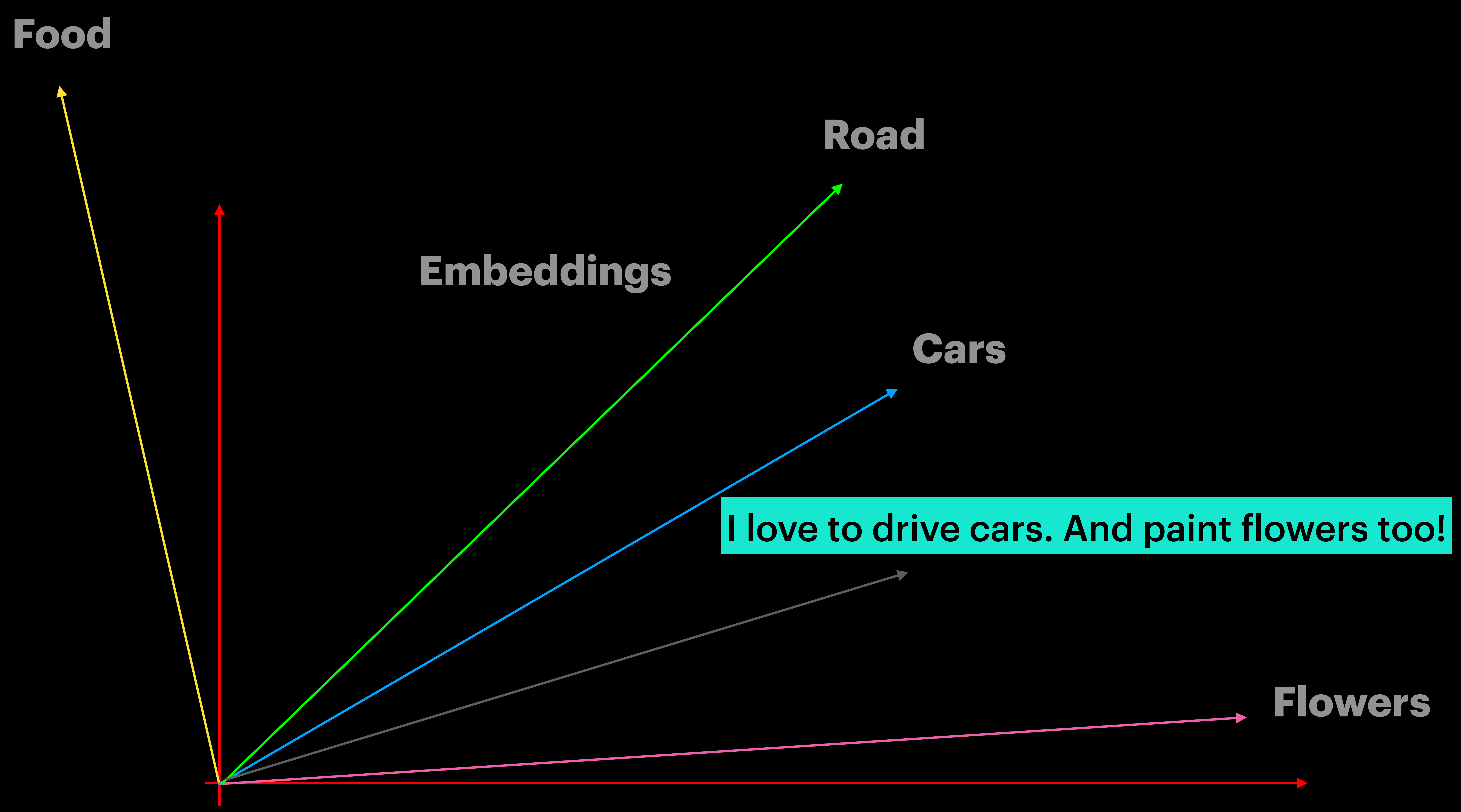
Like both Sci-fi and Romance



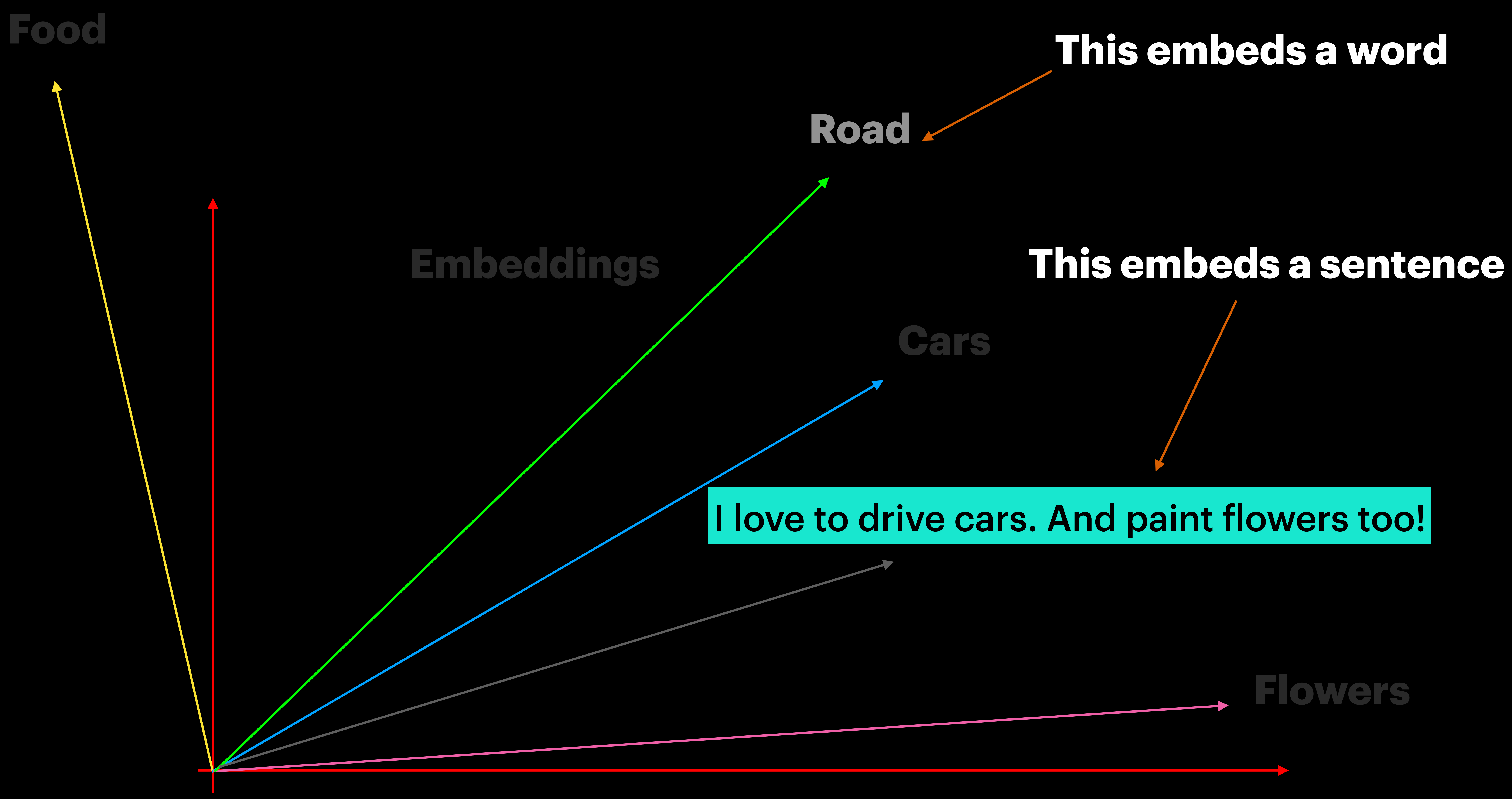
Word Embeddings



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?

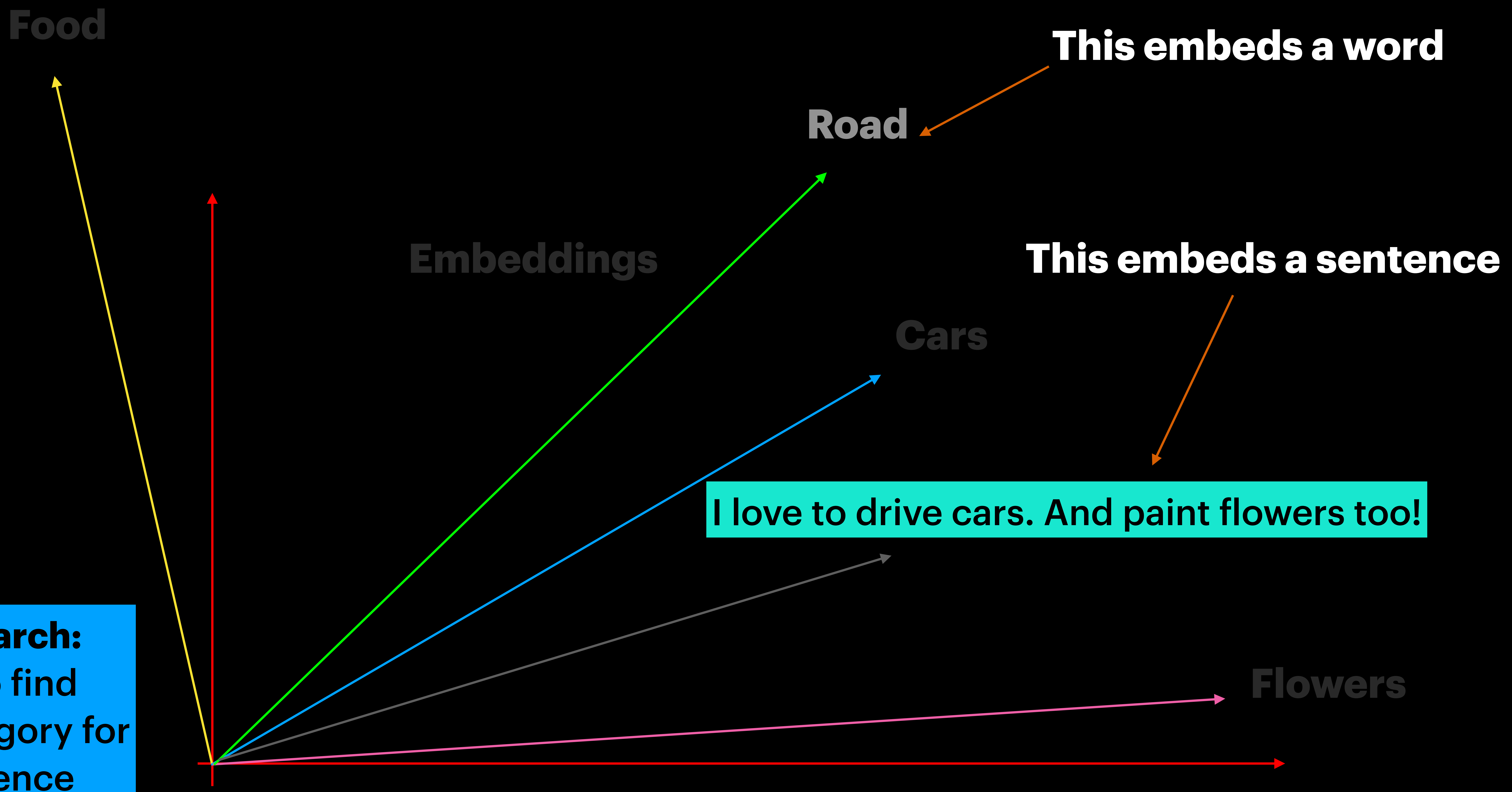
A: Through a DL model!
Maybe last but one hidden layer activations

Glove Embeddings

Sentence
BERT

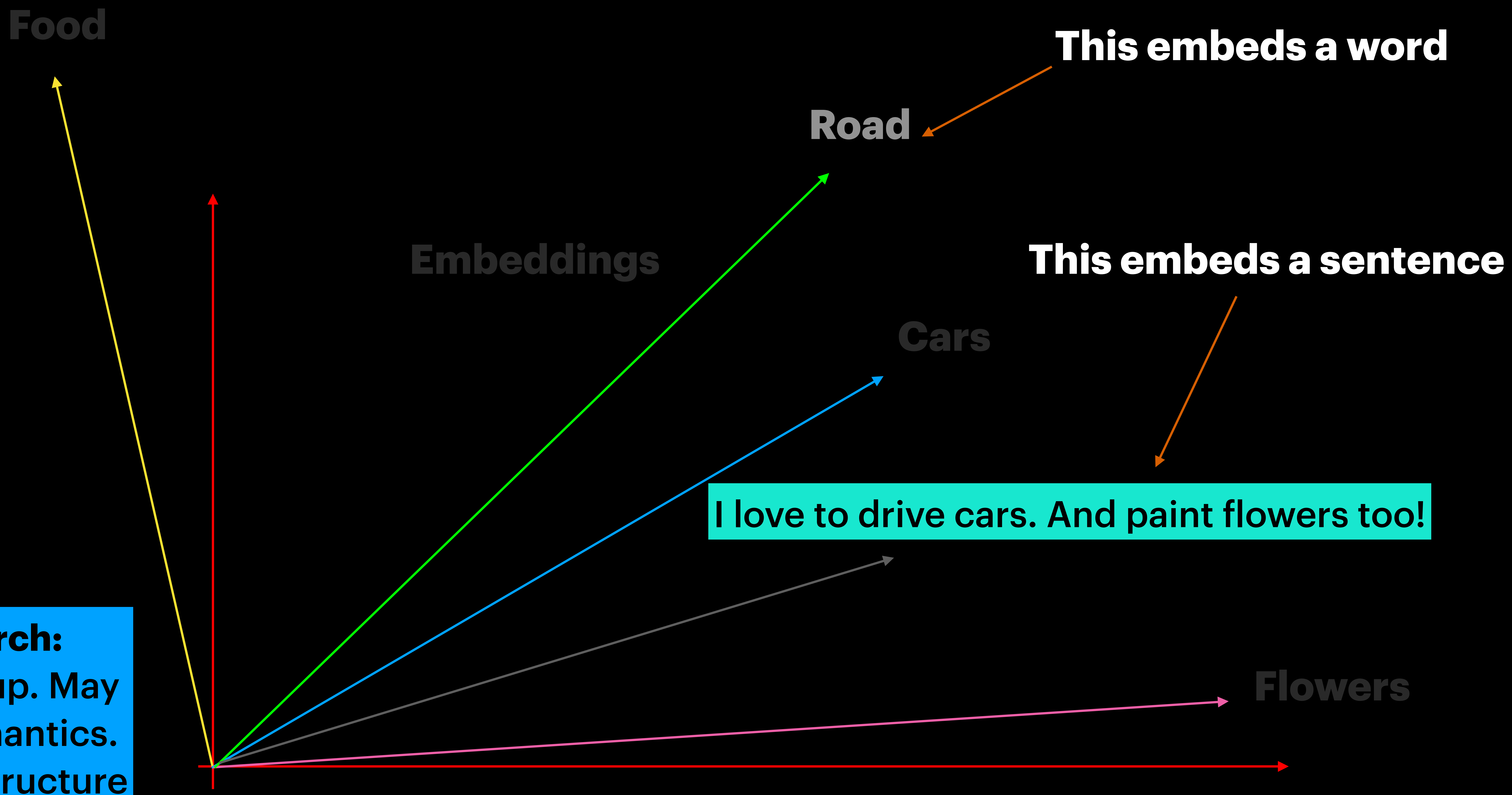
We will cover Sentence BERT when we
Get to Transformers!

Semantic Search | Vector Search



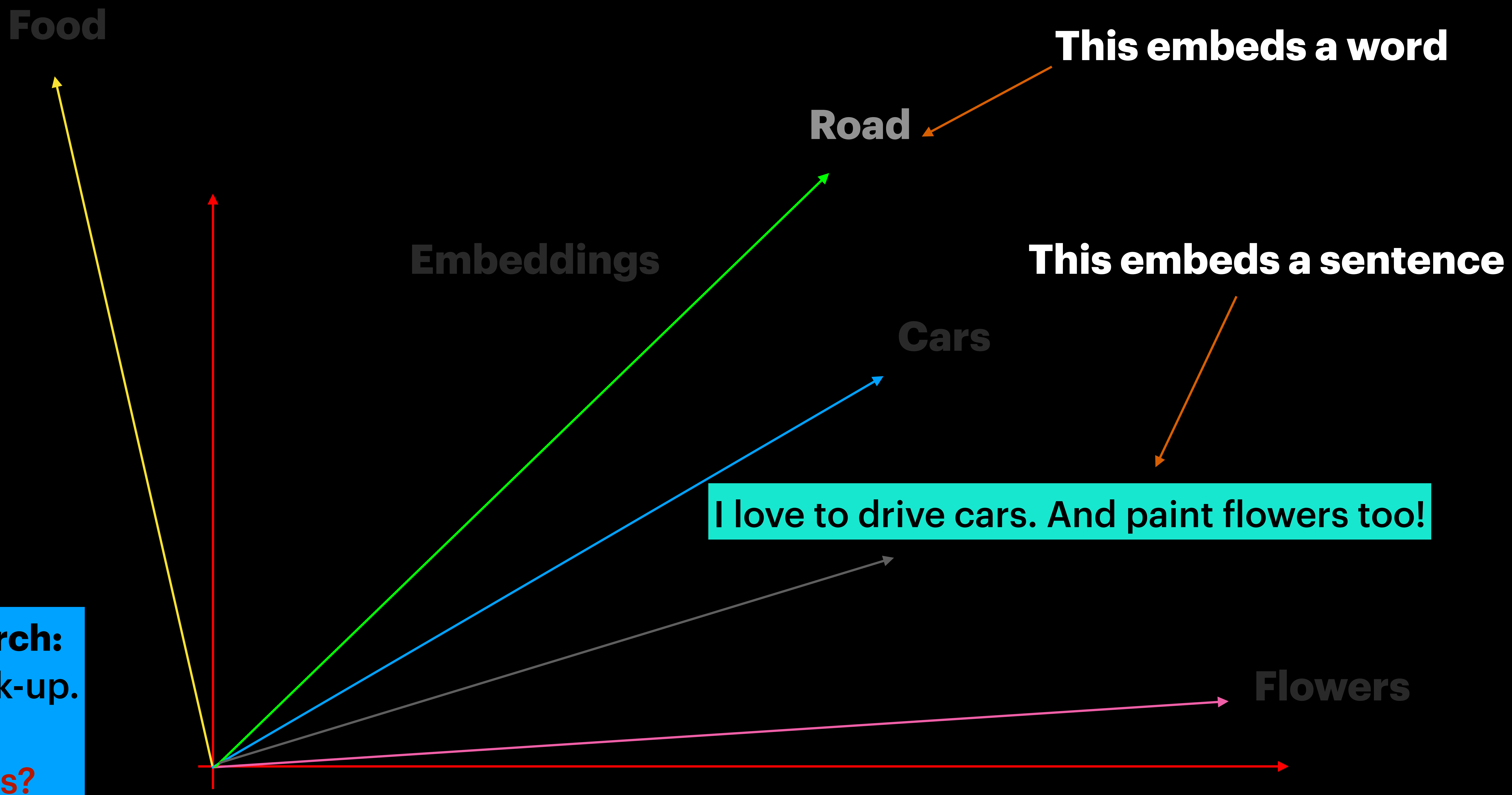
Semantic Search:
Enables us to find
the closest category for
A given sentence

Semantic Search | Vector Search



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

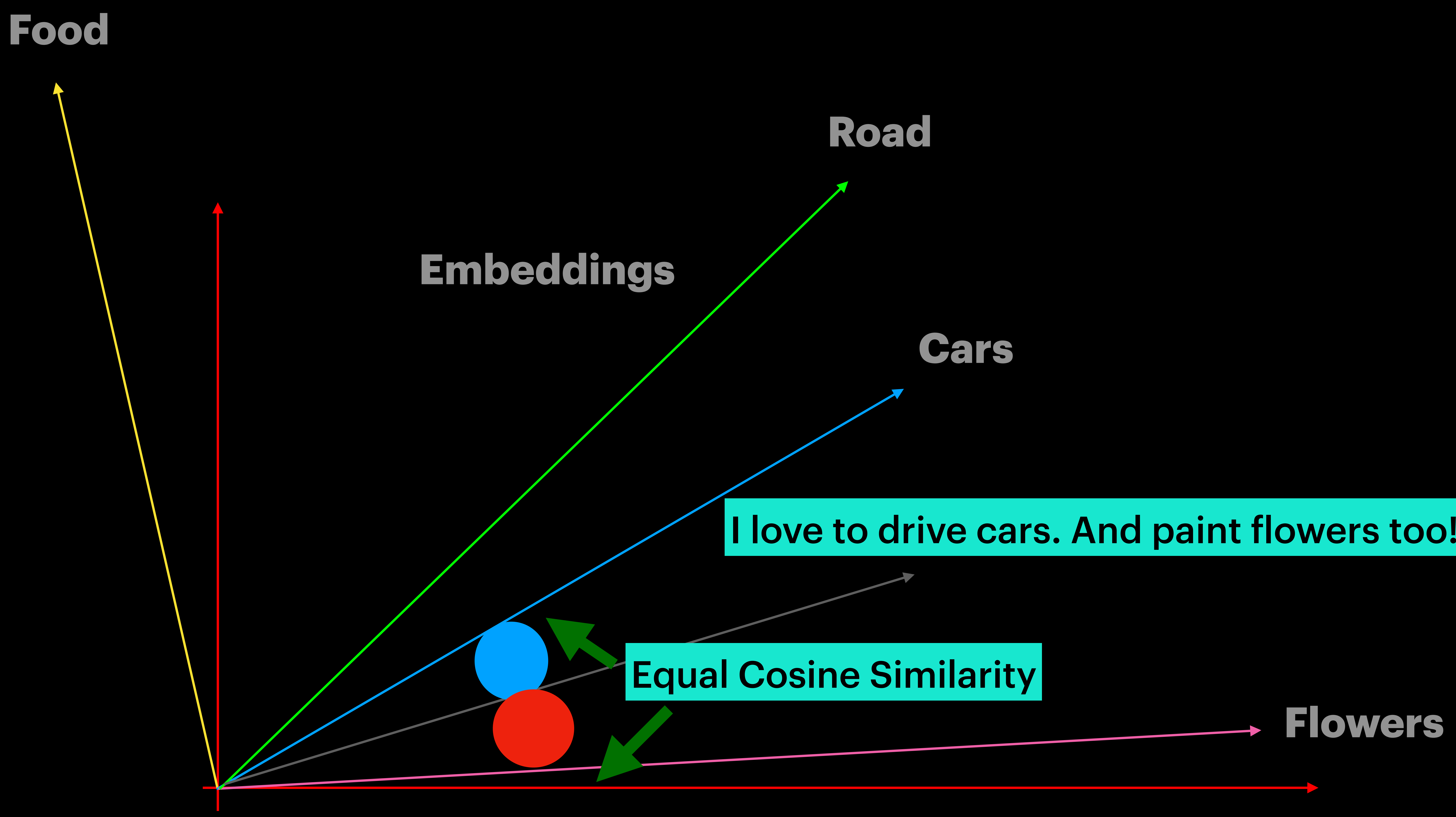
Semantic Search | Vector Search



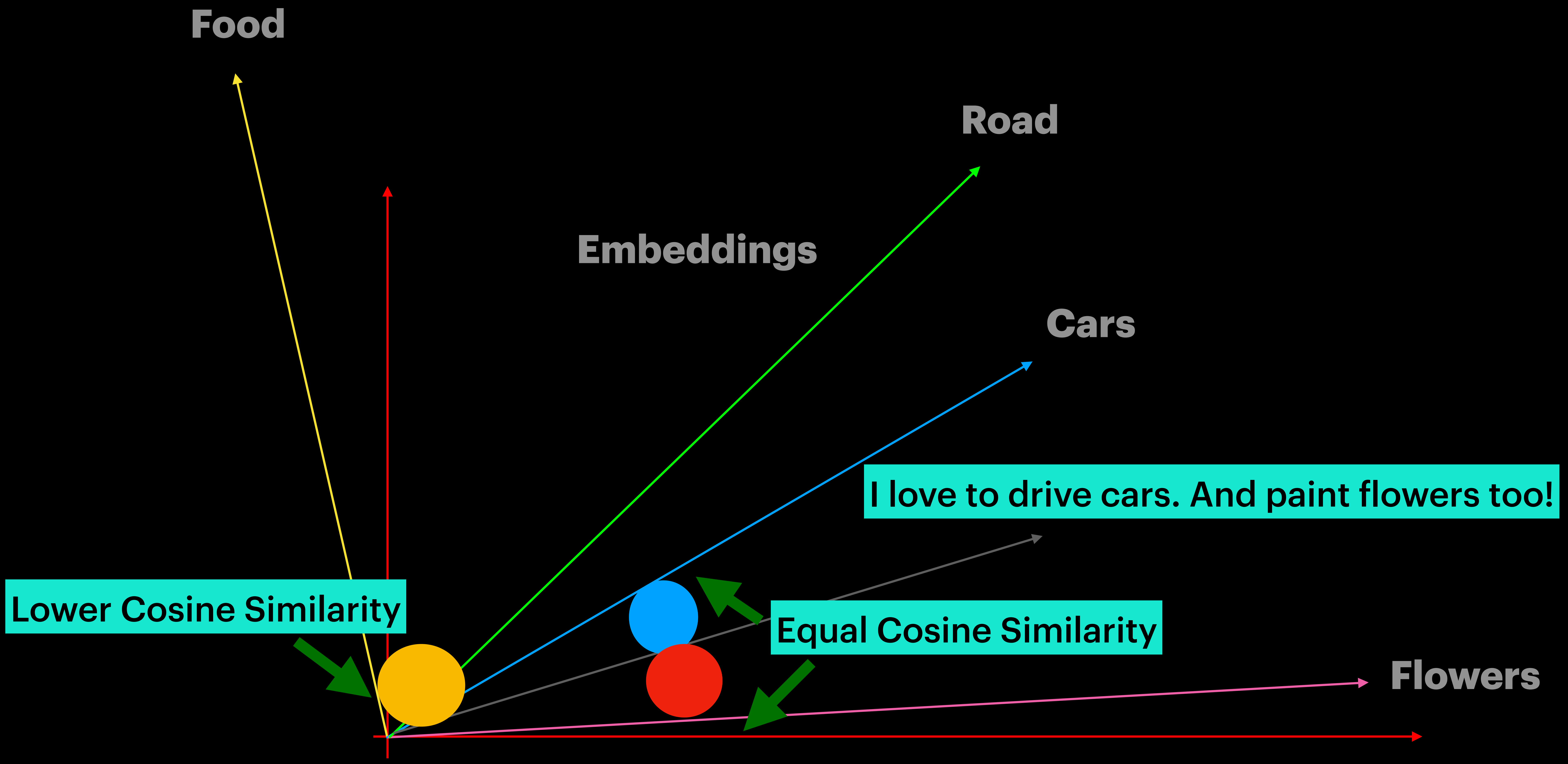
Typical Search:
Based on look-up.

Down-sides?

Semantic Search | Vector Search

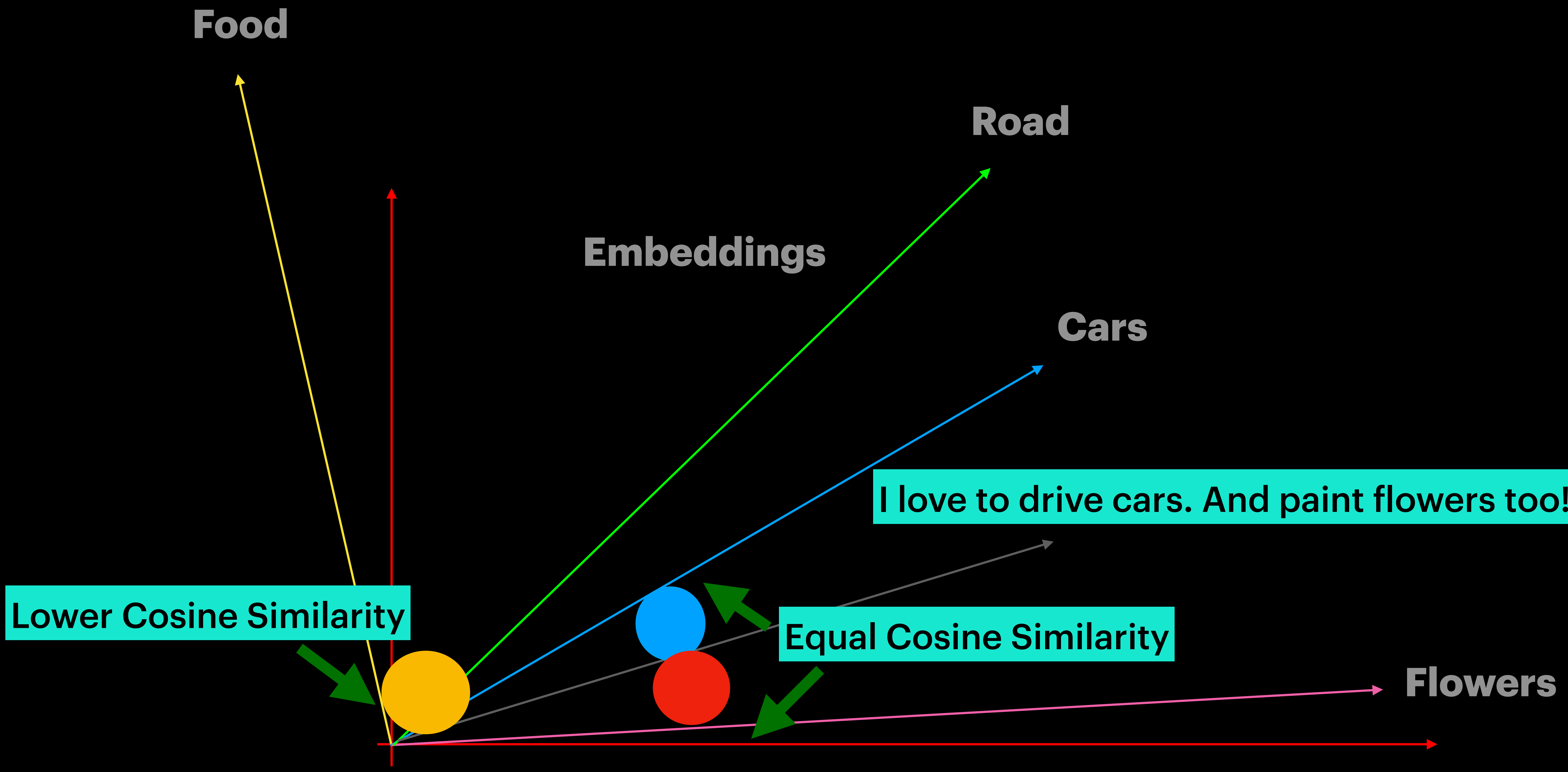


Semantic Search | Vector Search



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