



Carnegie Mellon University
Language Technologies Institute



Text as a Virtual Knowledge Base

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Work done with: Haitian Sun, Manzil Zaheer, Vidhisha Balachandran,
Graham Neubig, Russ Salakhutdinov, William Cohen

Question Answering

When did Kendrick Lamar's first album come out?

A. July 2, 2011



Sources of Information

Text

Knowledge Bases



WIKIPEDIA
The Free Encyclopedia



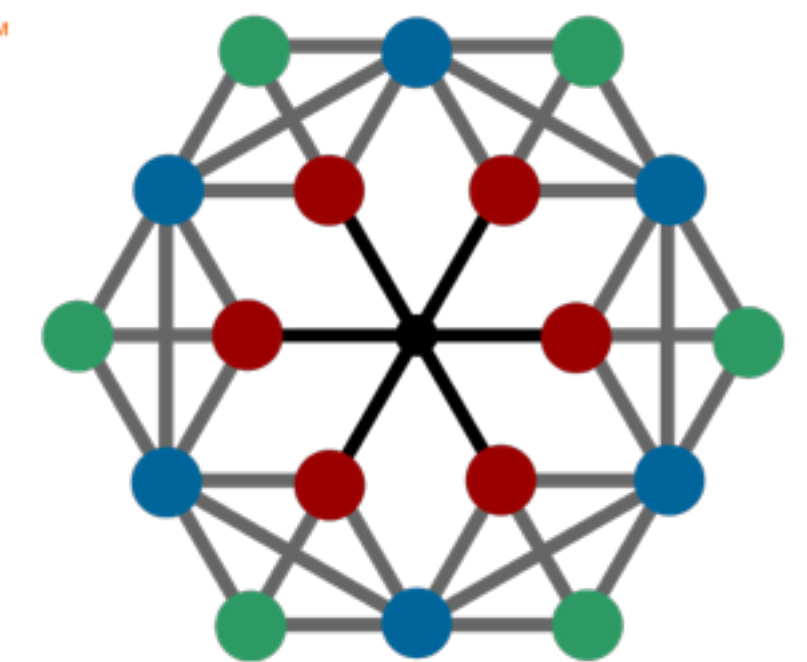
REUTERS



reddit



 **Freebase**TM



WIKIDATA



yAGO
select knowledge 

Sources of Information

Text

[Moldovan, 2002], [Voorhees, 1999],
[Ferrucci, 2012], [Yih, 2013],
[Hermann, 2016], [Chen, 2017], [Seo,
2017], [Peters, 2018], [Devlin, 2018] ...

Knowledge Bases

[Kwiatkowski, 2013], [Berant, 2013],
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- Lexical pattern matching
- No grounding
- High recall

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- Clear semantics via parsing
- Grounded
- High precision

Sources of Information

Text

Knowledge Bases

[Gardner & Krishnamurthy, 2017], [Ryu, 2017]
Universal Schema [Riedel, 2013], [Verga, 2016], [Das, 2017] ...

Our Work

- Lexical pattern matching
- No grounding
- High recall

- Clear semantics via parsing
- Grounded
- High precision

Why Text + KBs?

Why Text + KBs?

- Engineering motivation - QA performance
- Text can complete missing information in KBs
- KBs can provide background context for understanding text

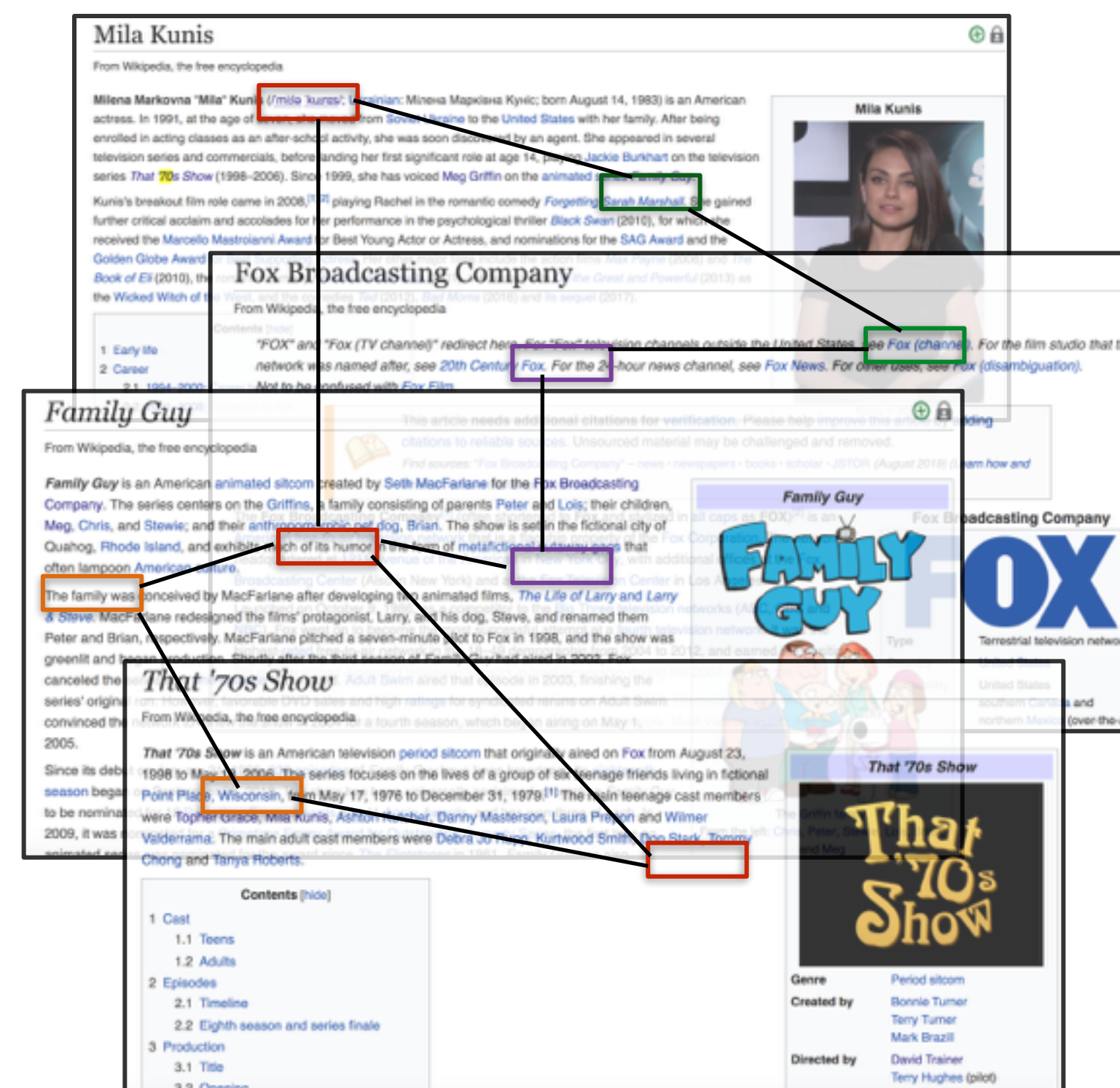
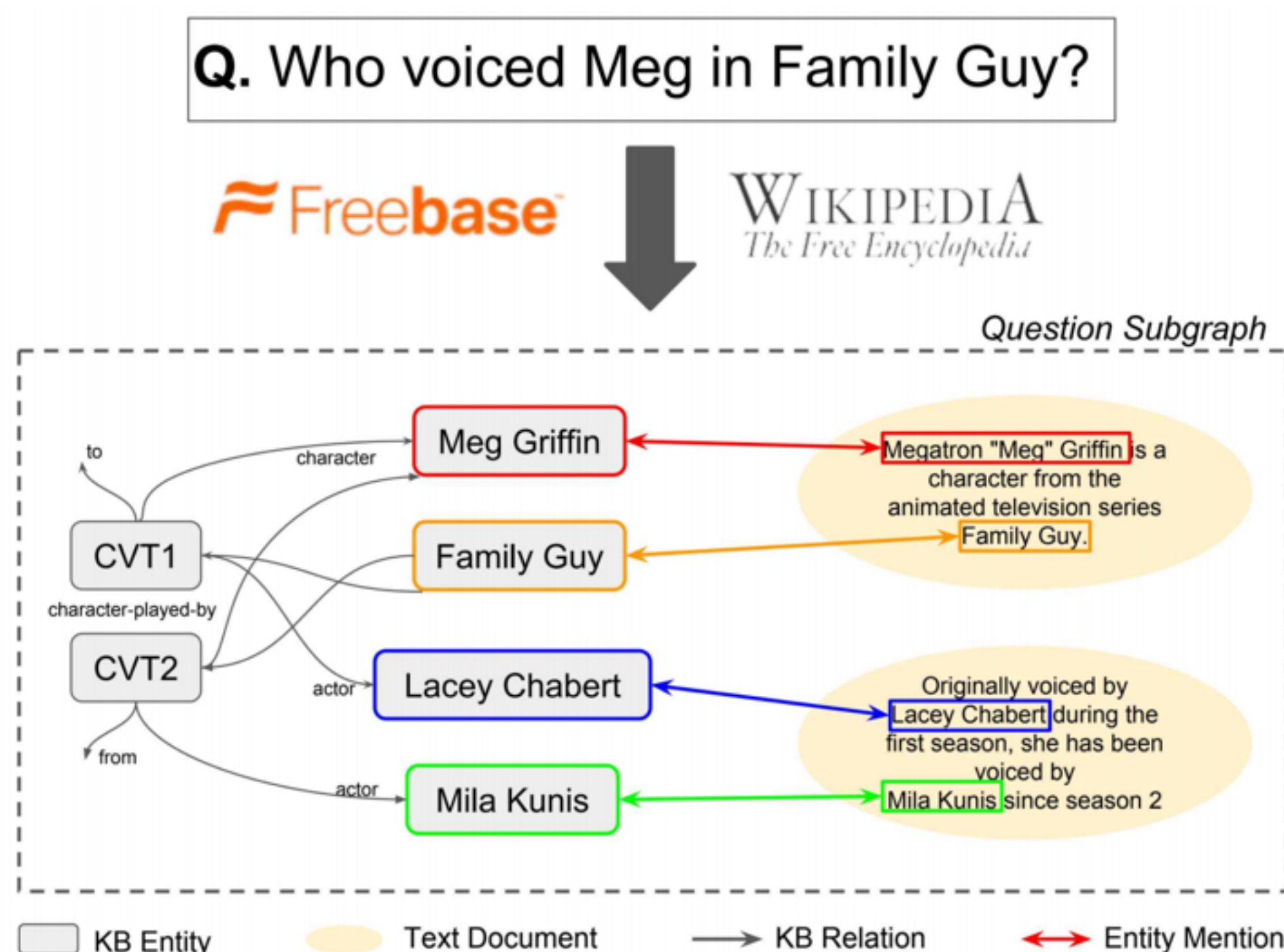
Why Text + KBs?

- Engineering motivation - QA performance
 - Text can complete missing information in KBs
 - KBs can provide background context for understanding text
- Scientific motivation - Knowledge Representation
 - Text is expressive
 - KBs support reasoning

This Talk

1. “Reading” heterogeneous graphs of facts and text [EMNLP’18]

2. Traversing text corpora like KBs [ongoing]



Open-domain QA using Early Fusion of KBs & Text

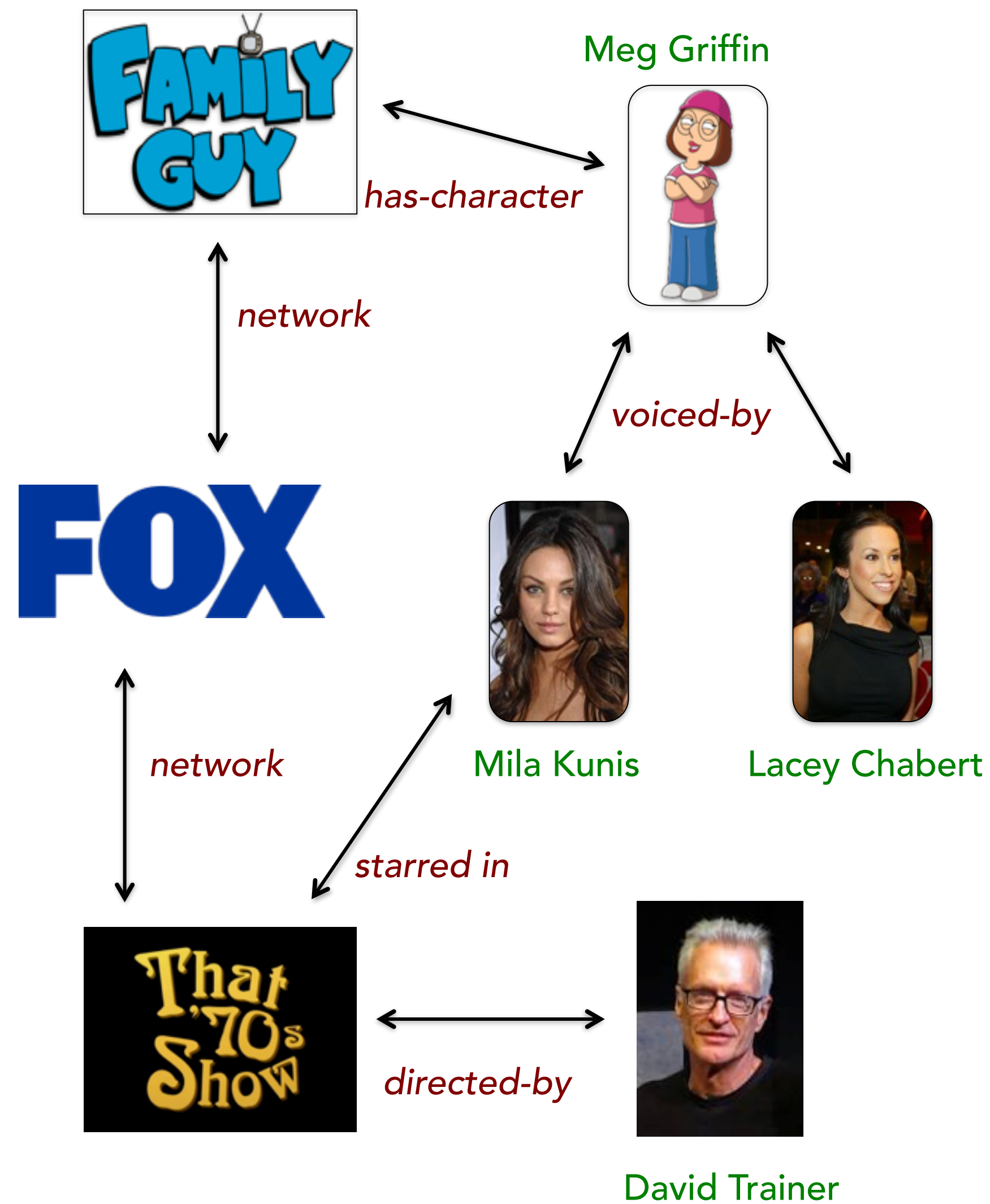
Haitian Sun*, Bhuwan Dhingra*, Manzil Zaheer,
Kathryn Mazaitis, Ruslan Salakhutdinov, William Cohen

**equal contribution*

EMNLP 2018



Entity-Relation Knowledge Bases

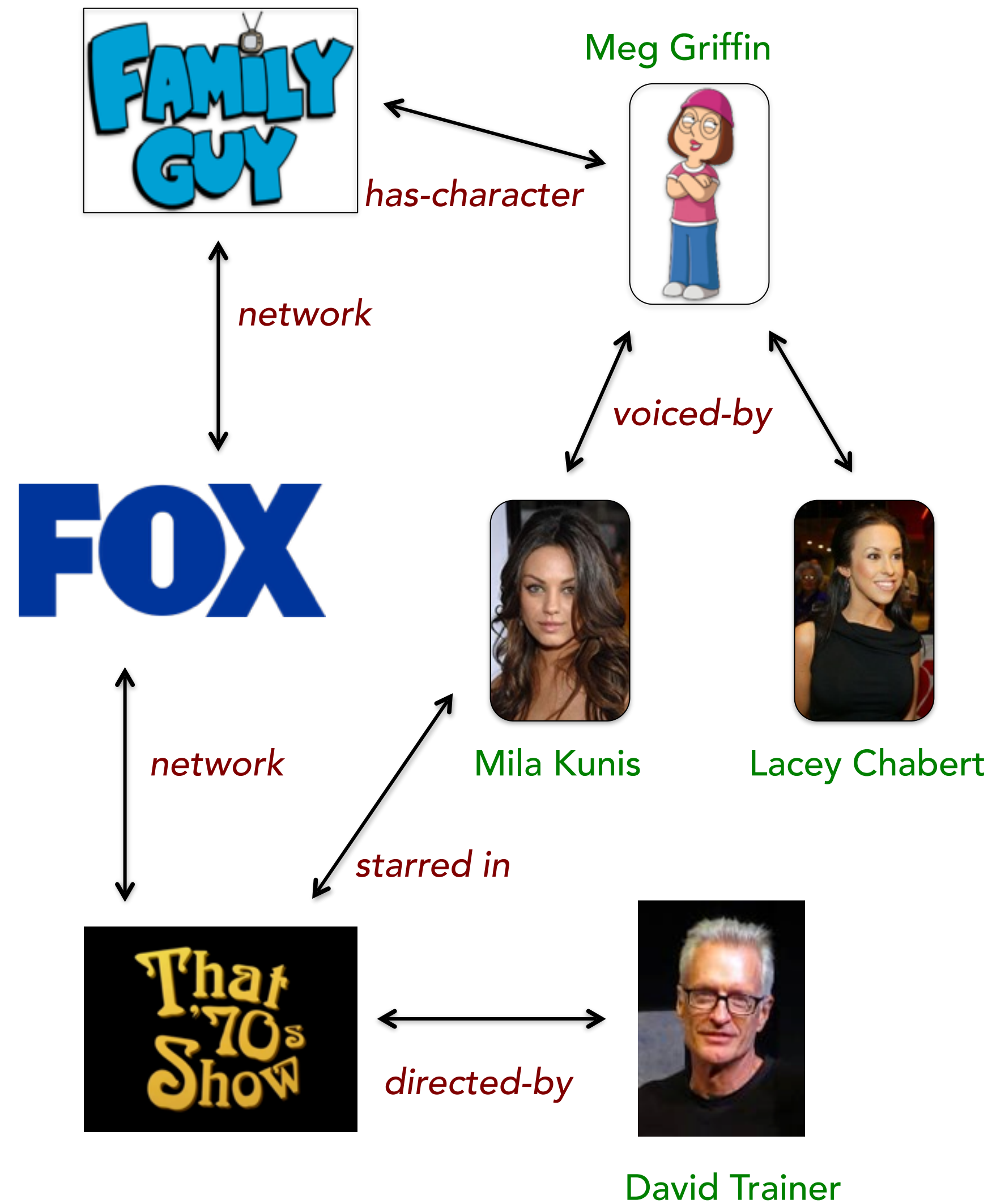


- Collection of *(subject, relation, object)* facts
- Organize information around *entity* nodes
- Freebase: 44M entities, >2B facts

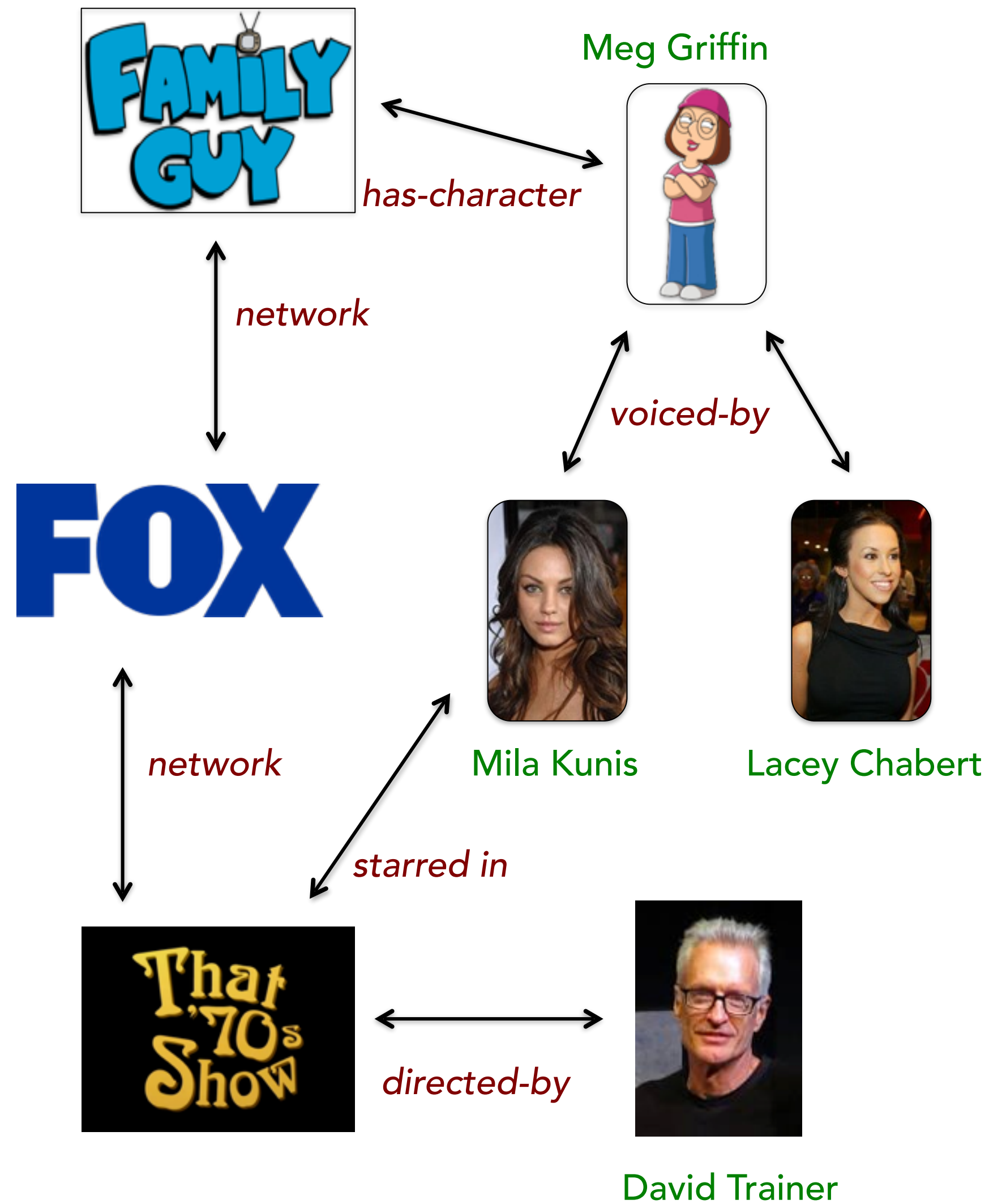
Reasoning in KBs

Relation following operation:

$$Y = X.\text{follow}(R) = \{x' : \exists x \in X \text{ s.t. } R(x, x') \text{ holds}\}$$



Reasoning in KBs



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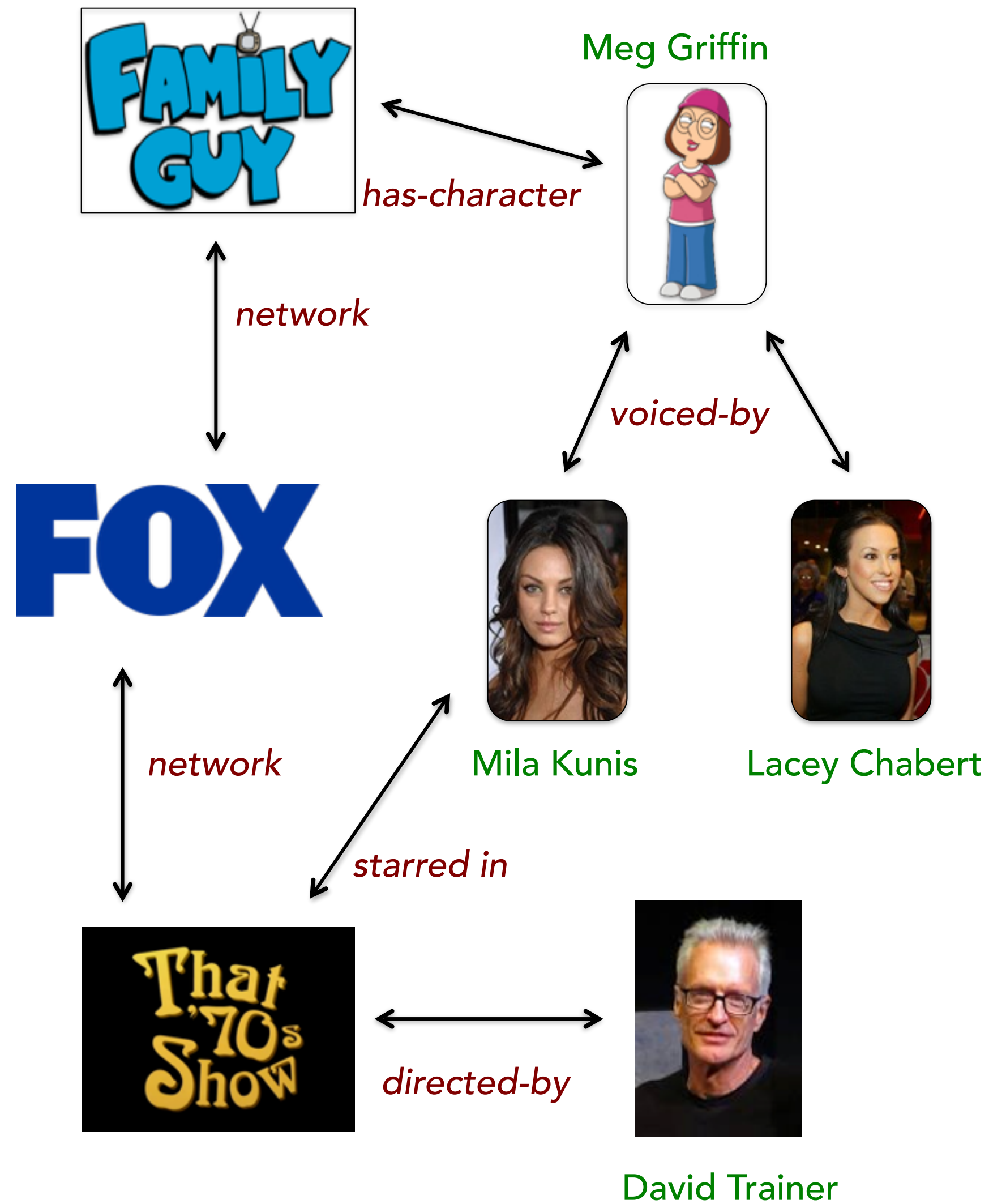
- Given a set of entities X

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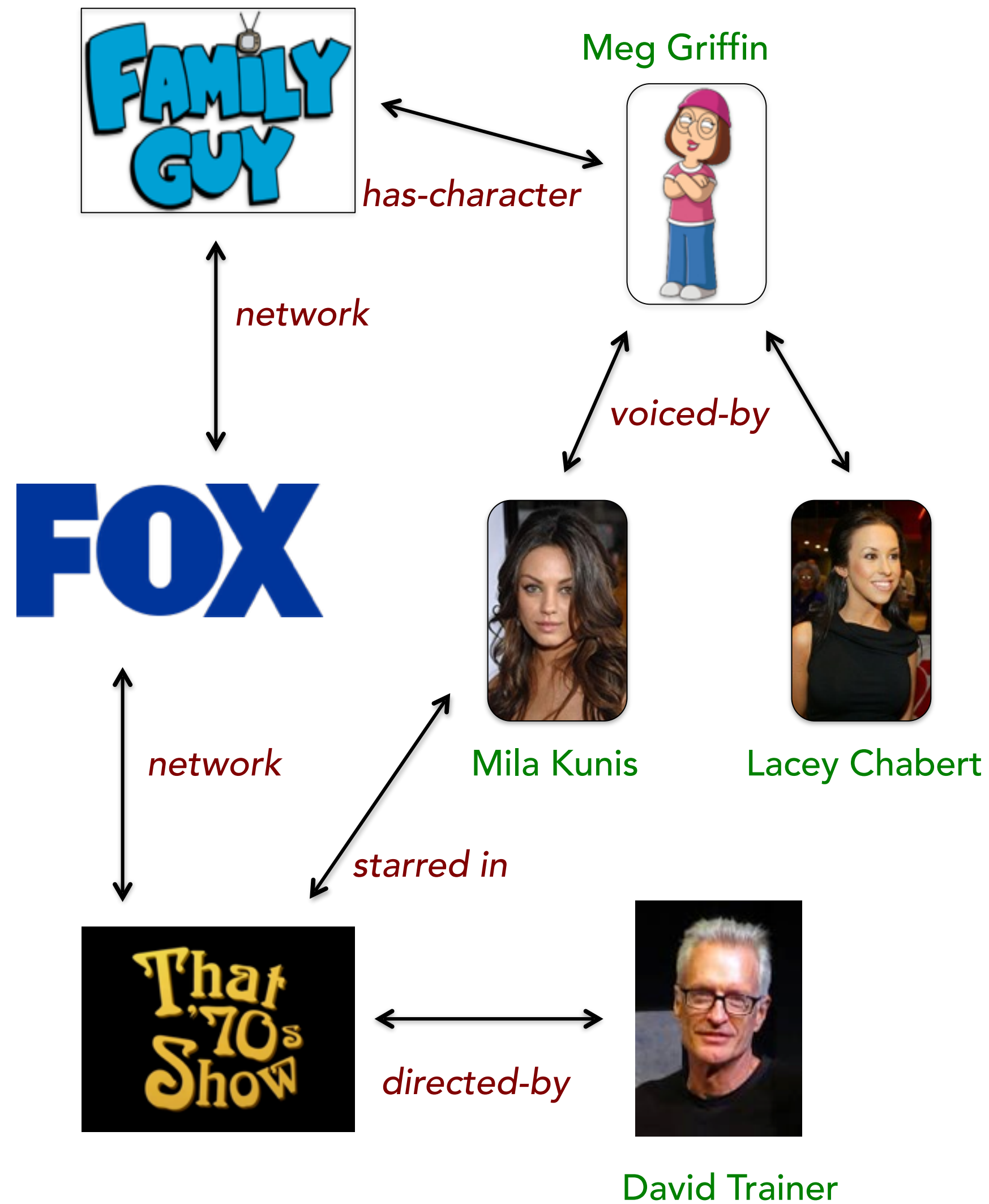
- Given a set of entities X
- Follow edges labeled with the relation R



Reasoning in KBs

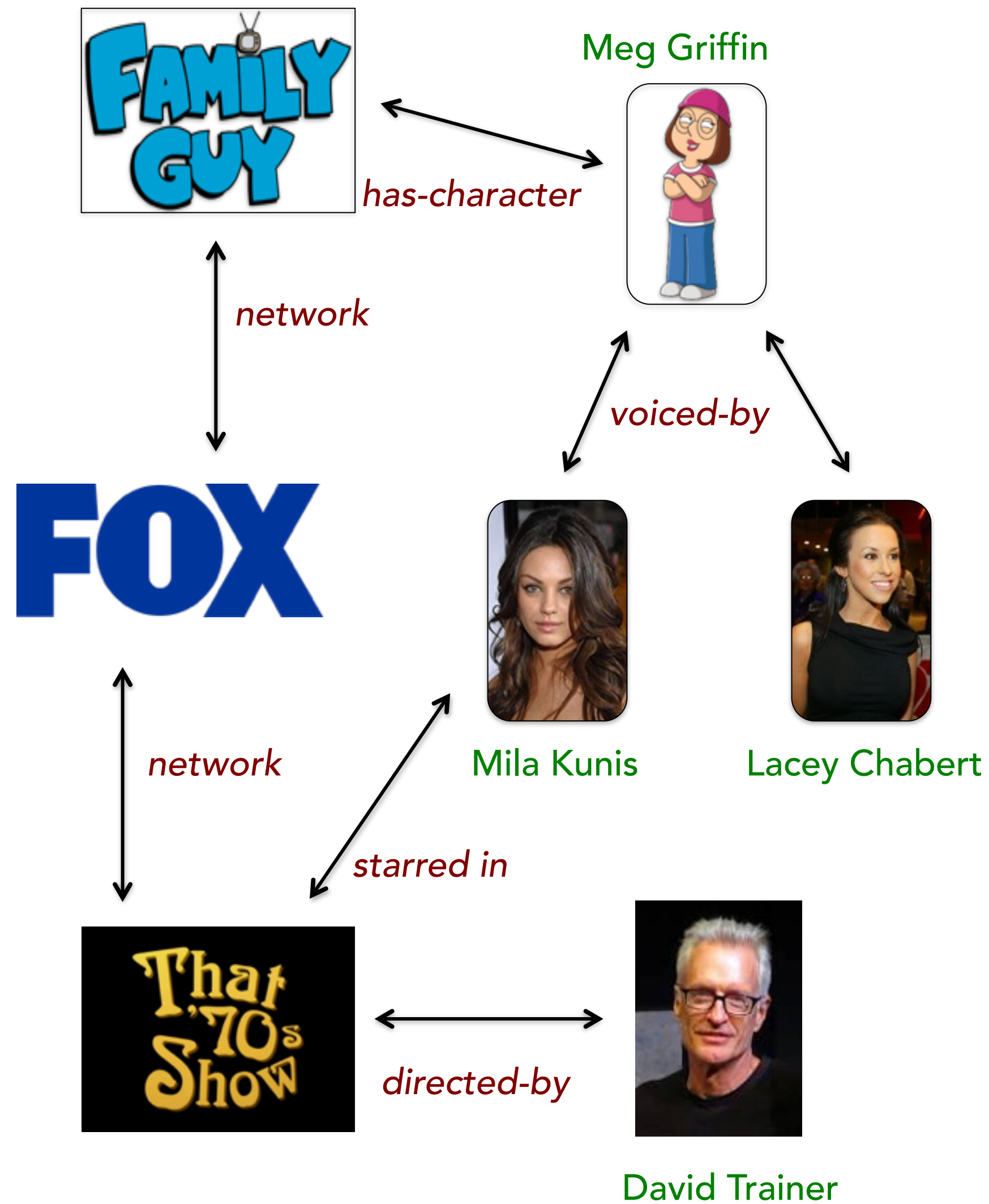
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- To arrive at a set of entities Y

Reasoning in KBs



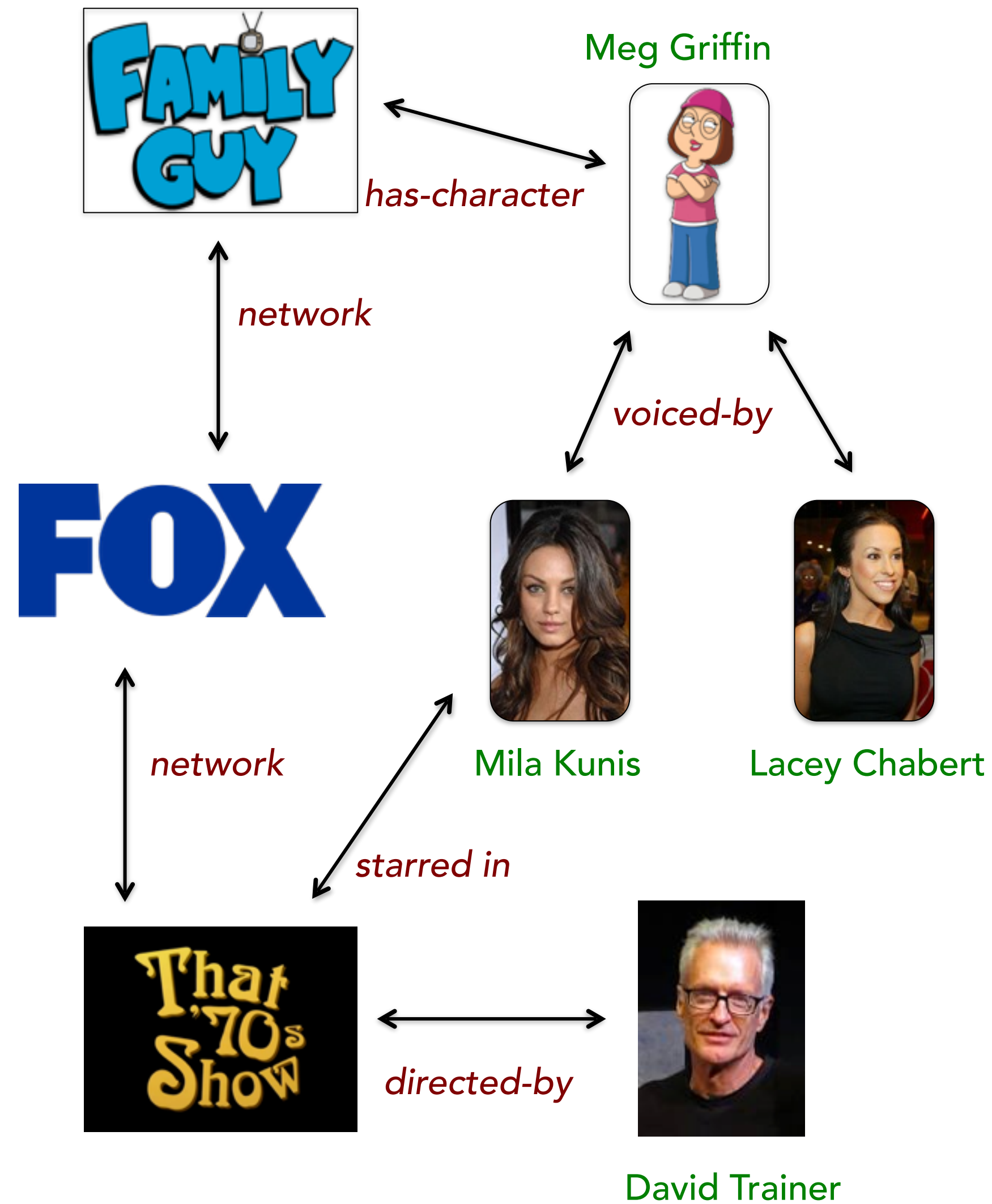
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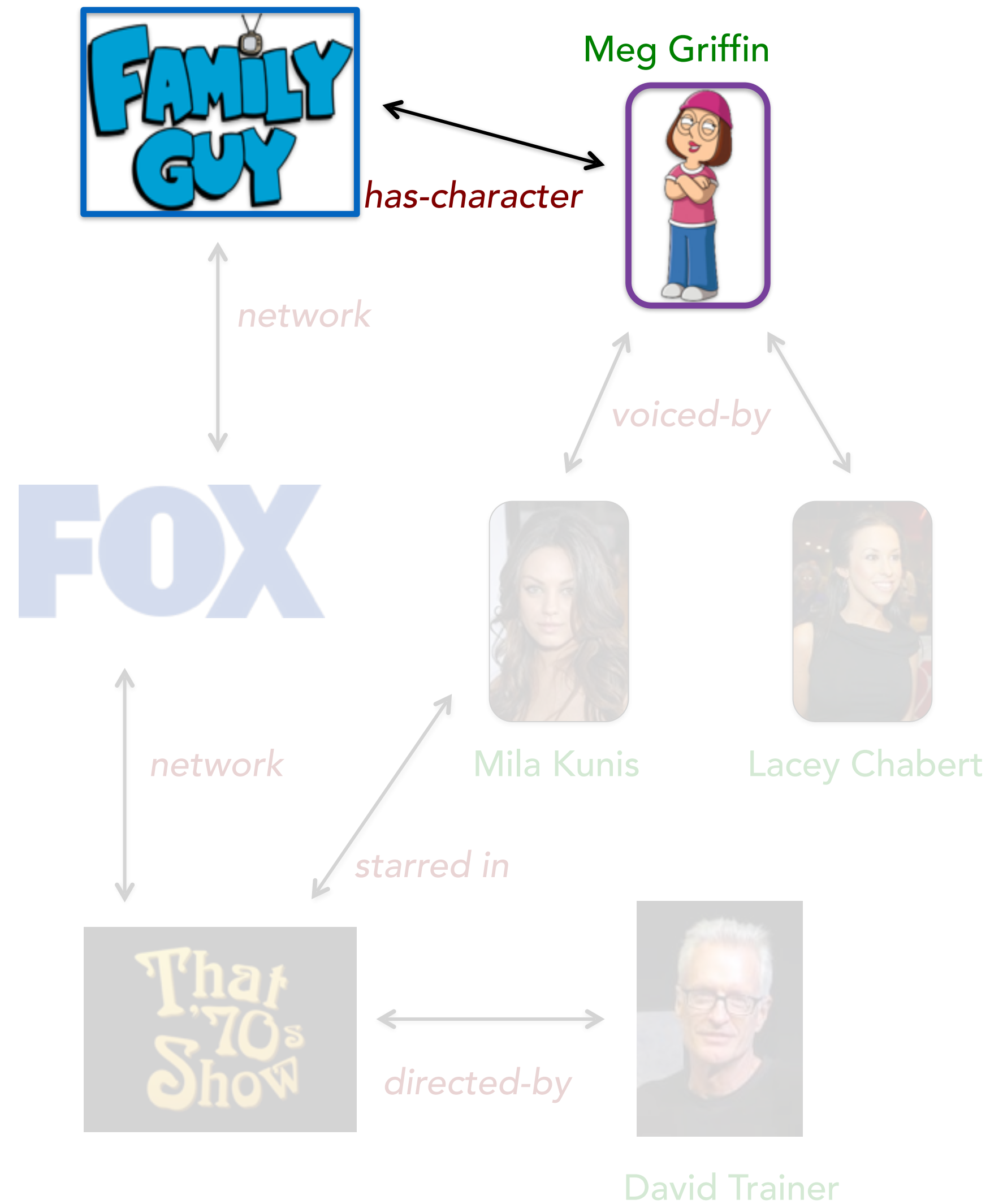
E.g. $\{\text{Family_Guy}, \text{That_70s_Show}\}.\text{follow}(\text{network}) = \{\text{Fox}\}$

Question Answering



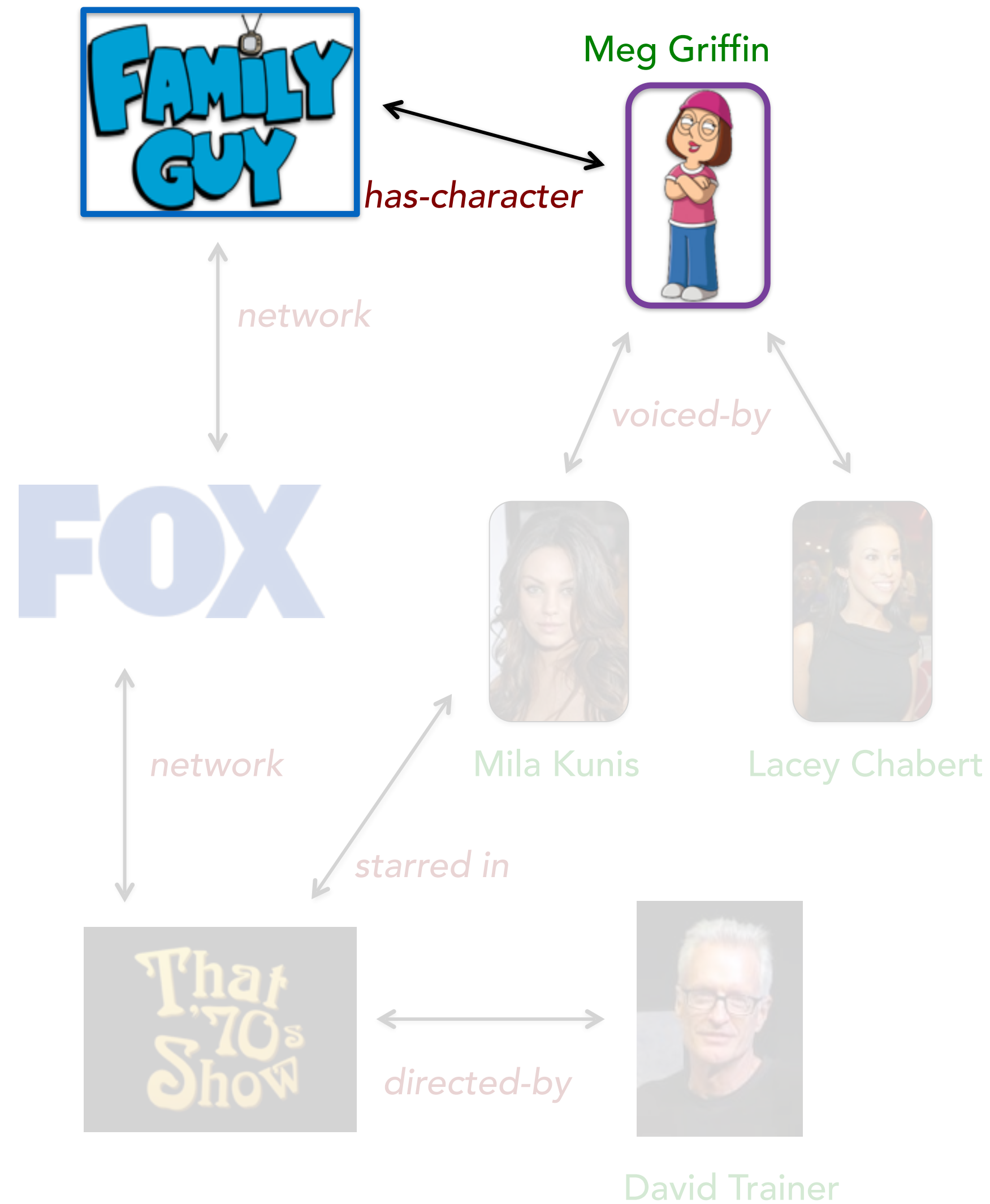
Who voiced **Meg** in **Family Guy**?

Question Answering



Who voiced **Meg** in **Family Guy**?

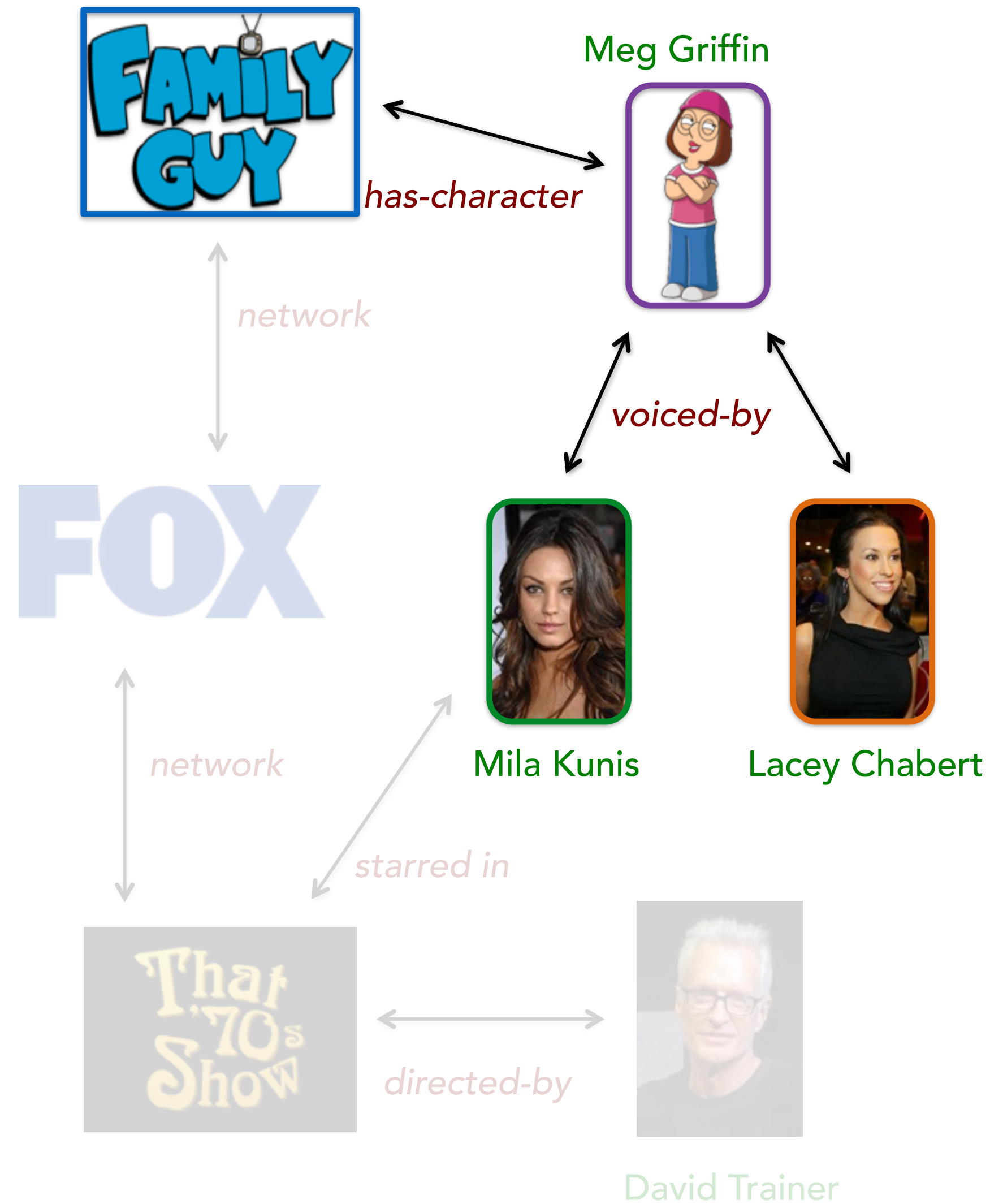
Question Answering



Who voiced **Meg** in **Family Guy**?

`{Meg_Griffin}.follow(voiced-by)`

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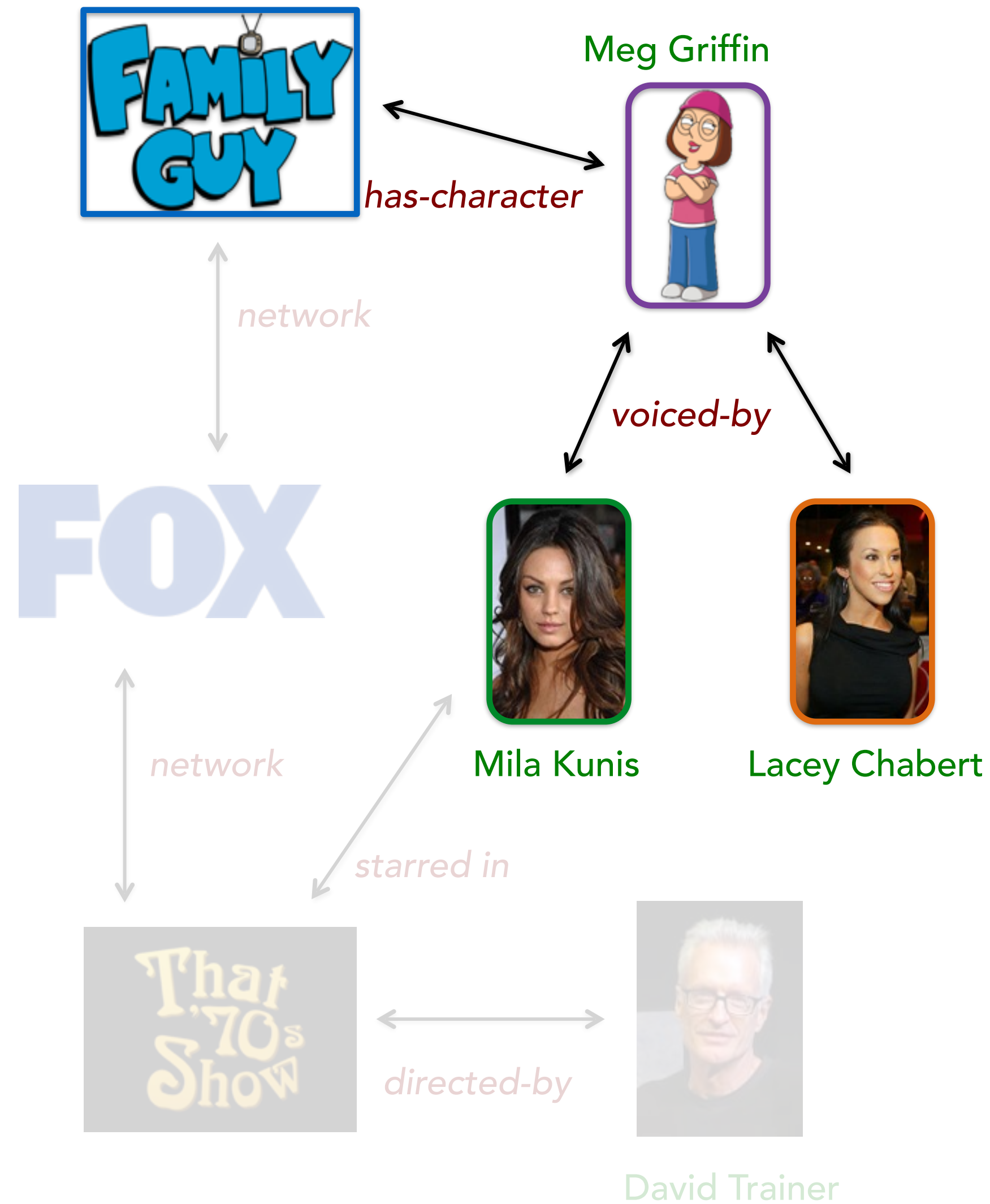


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`{Mila_Kunis, Lacey_Chabert}`

Question Answering



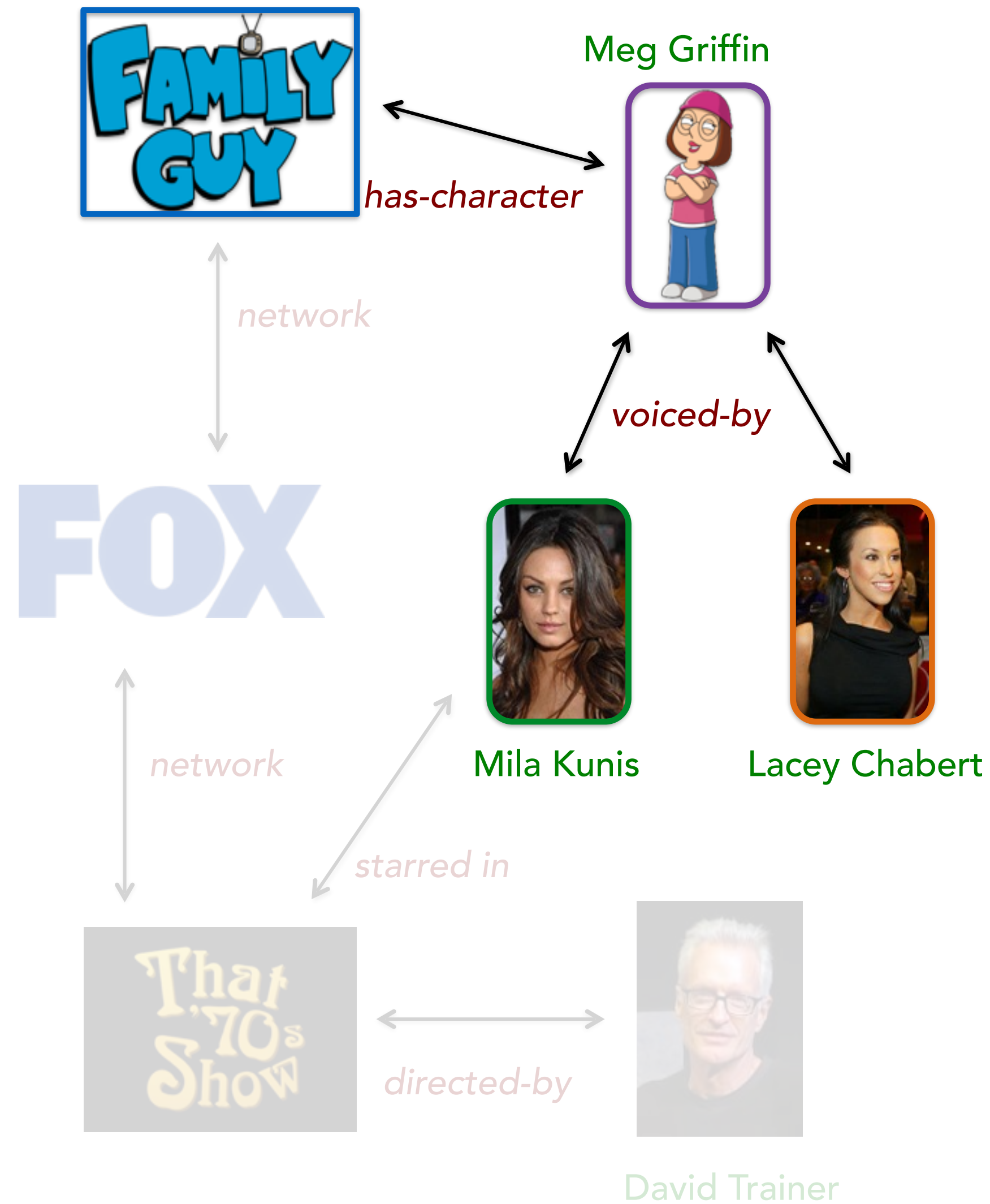
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Annotating semantic parses of questions is expensive

```
{Meg_Griffin}.follow(voiced-by)
```

```
{Mila_Kunis, Lacey_Chabert}
```

Question Answering



Who voiced **Meg** in **Family Guy**?

Search for parses which lead to the correct answer in the KB

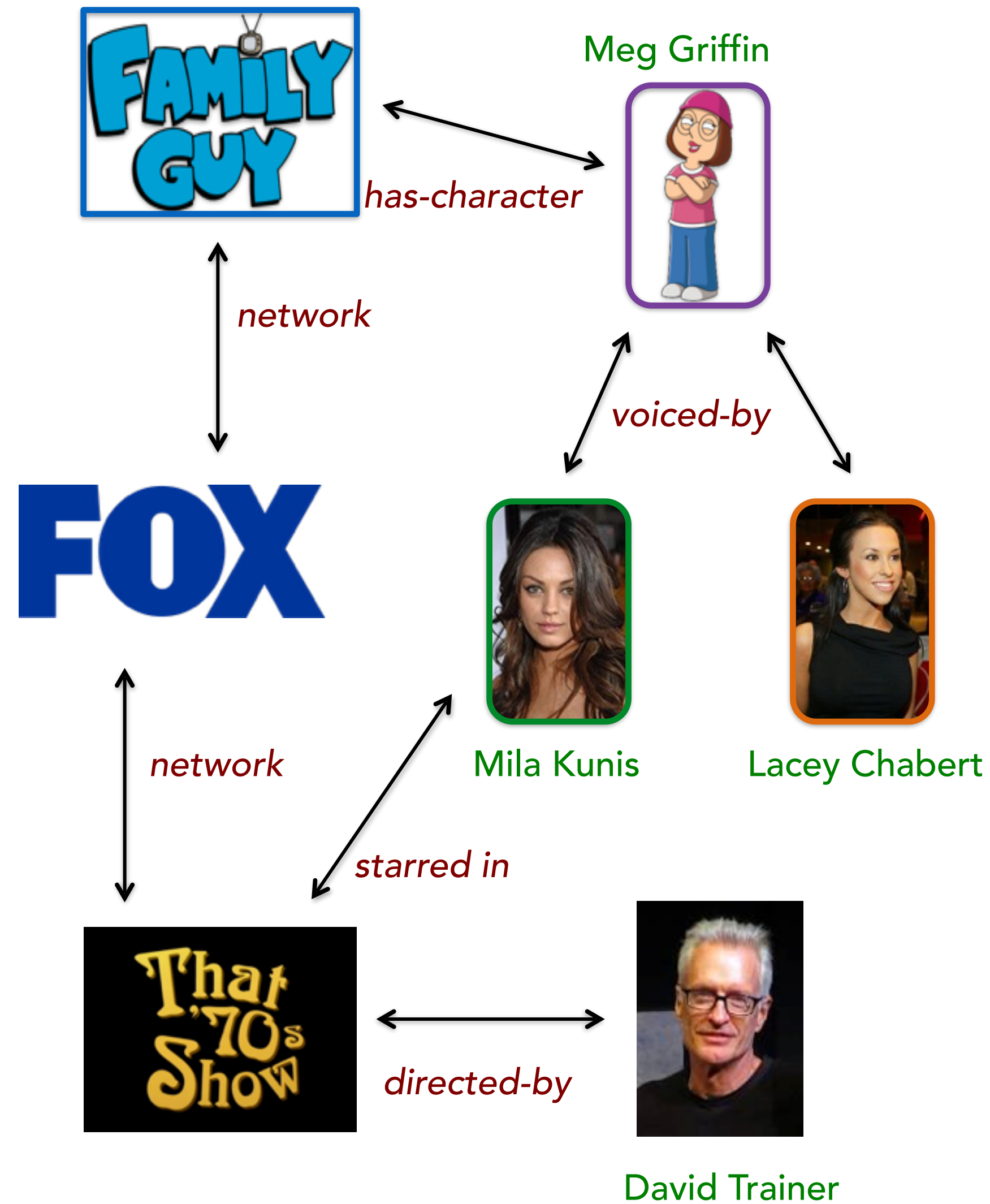


{Mila_Kunis, Lacey_Chabert}

Learning from Denotations

[Liang, 2011], [Berant, 2013], [Reddy, 2014],
[Krishnamurthy, 2017]

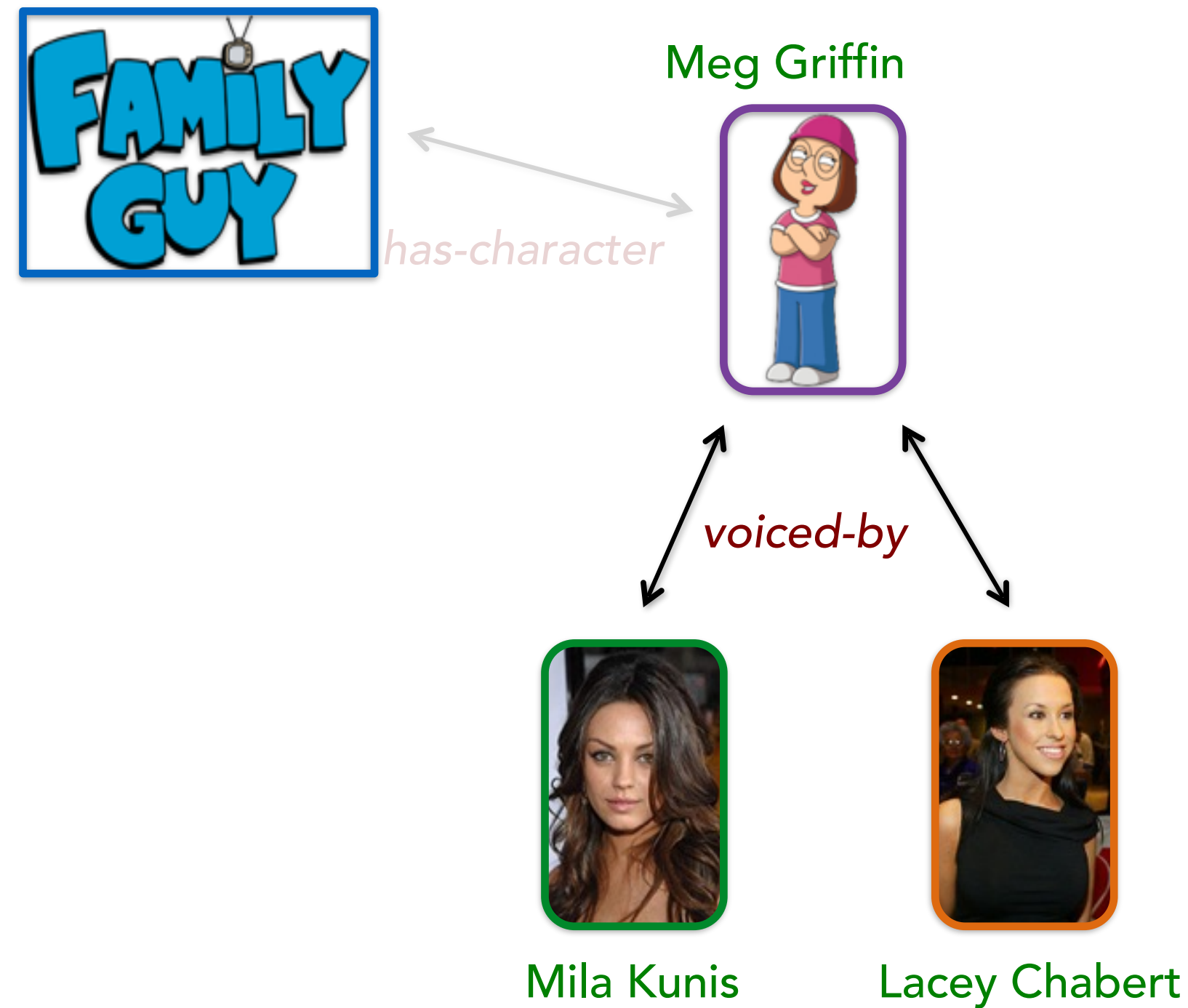
But KBs are often incomplete



Freebase relation types	Incompleteness
/people/person/education	0.792
/people/person/employment_history	0.923
/people/person/nationality*	0.785
/people/person/parents*	0.988
/people/person/place_of_birth*	0.938
/people/person/places_lived*	0.966

Min et al, NAACL 2013

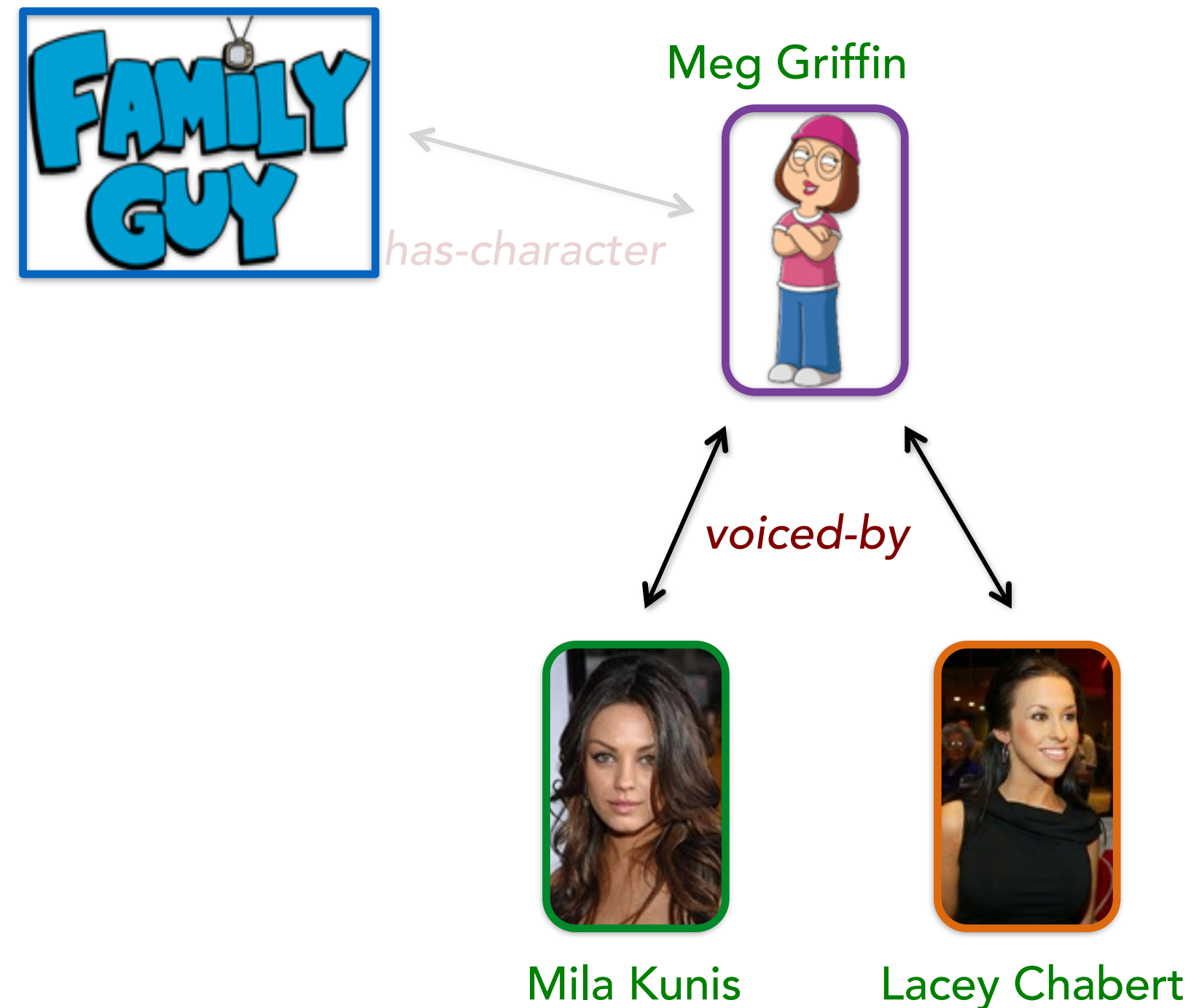
Graphs of Facts and Text



Who voiced **Meg** in **Family Guy**?



Graphs of Facts and Text

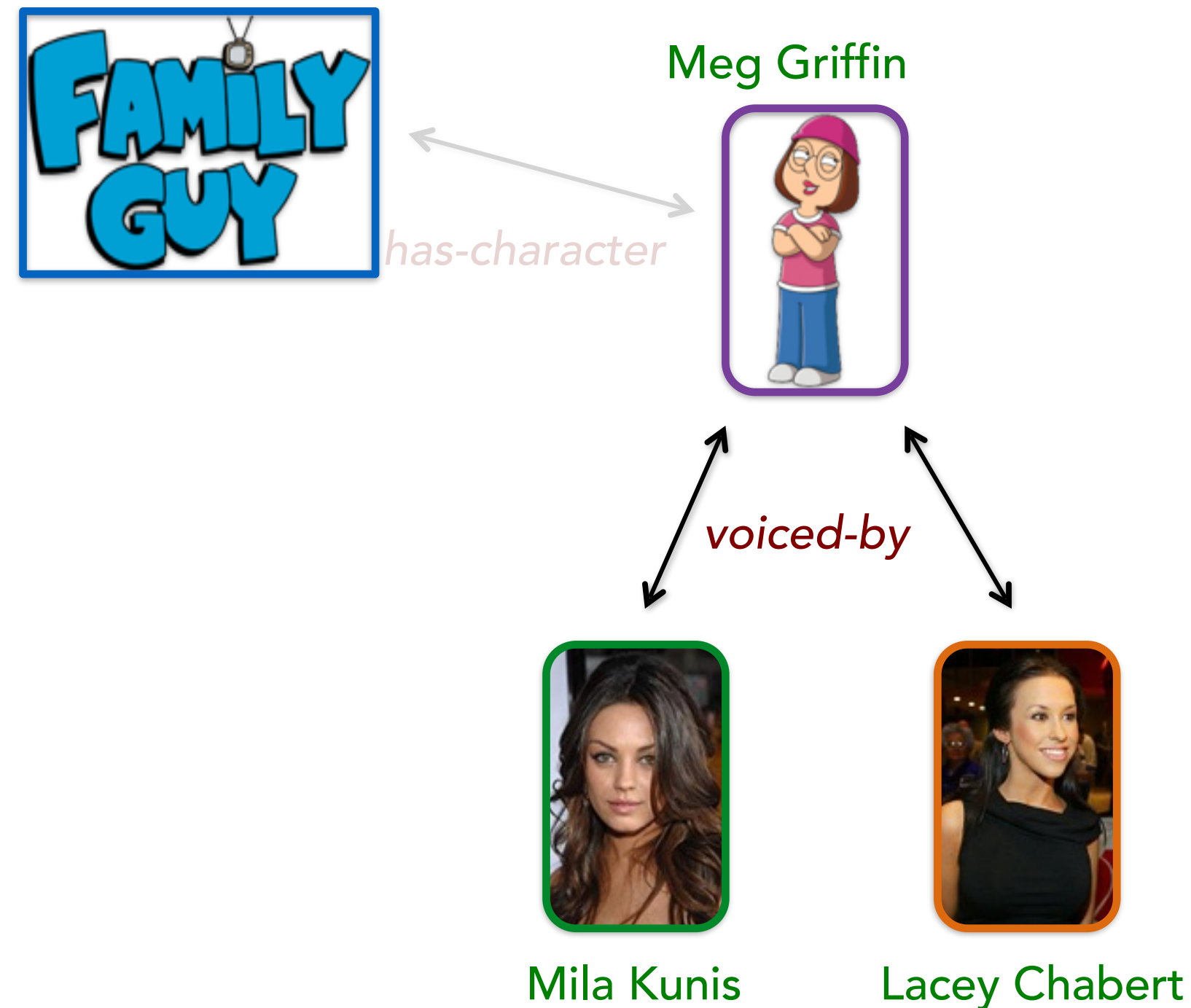


Inject relevant text into the graph

Who voiced **Meg** in **Family Guy**?



Graphs of Facts and Text



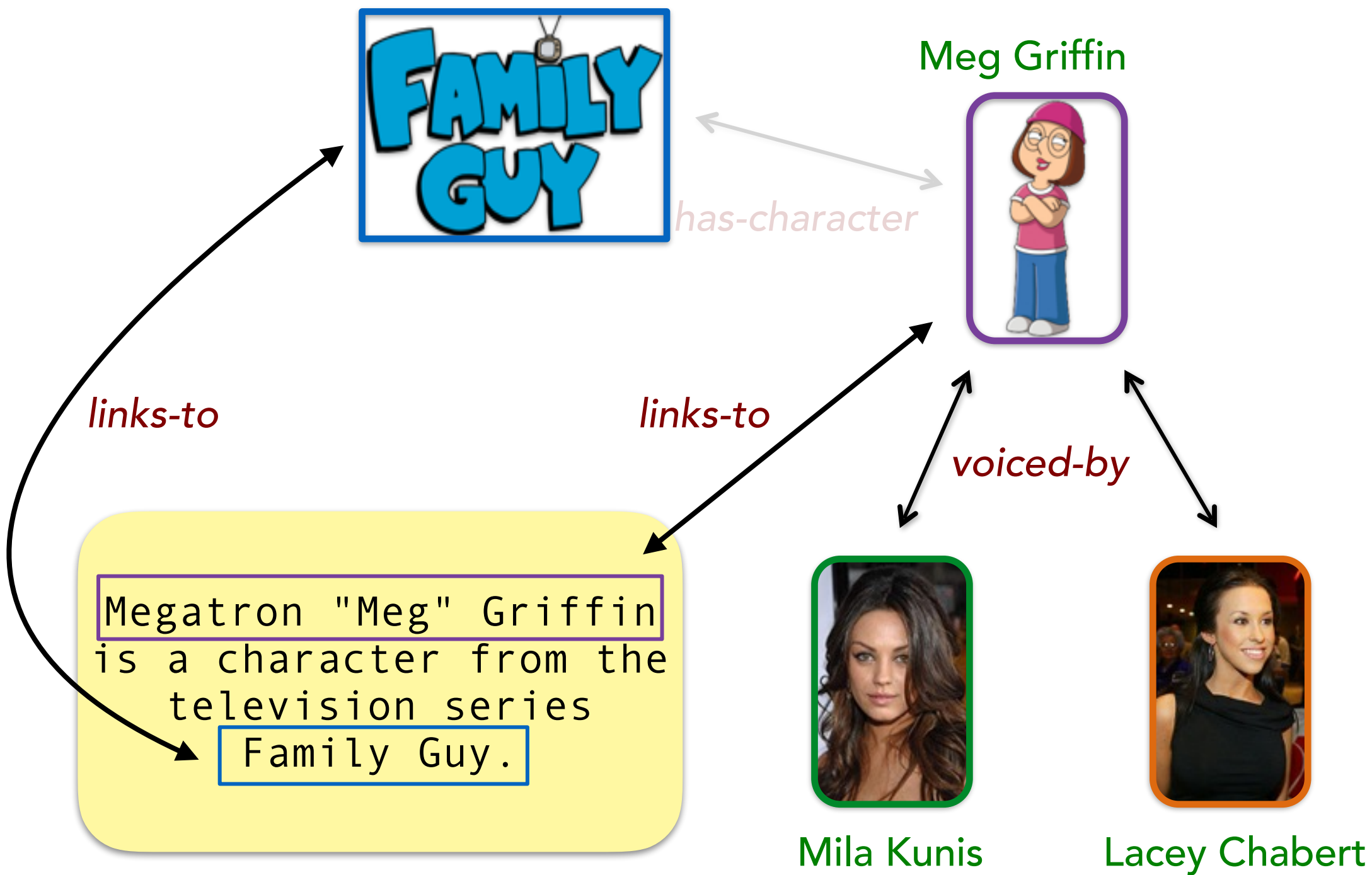
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*TF-IDF
Retrieval*



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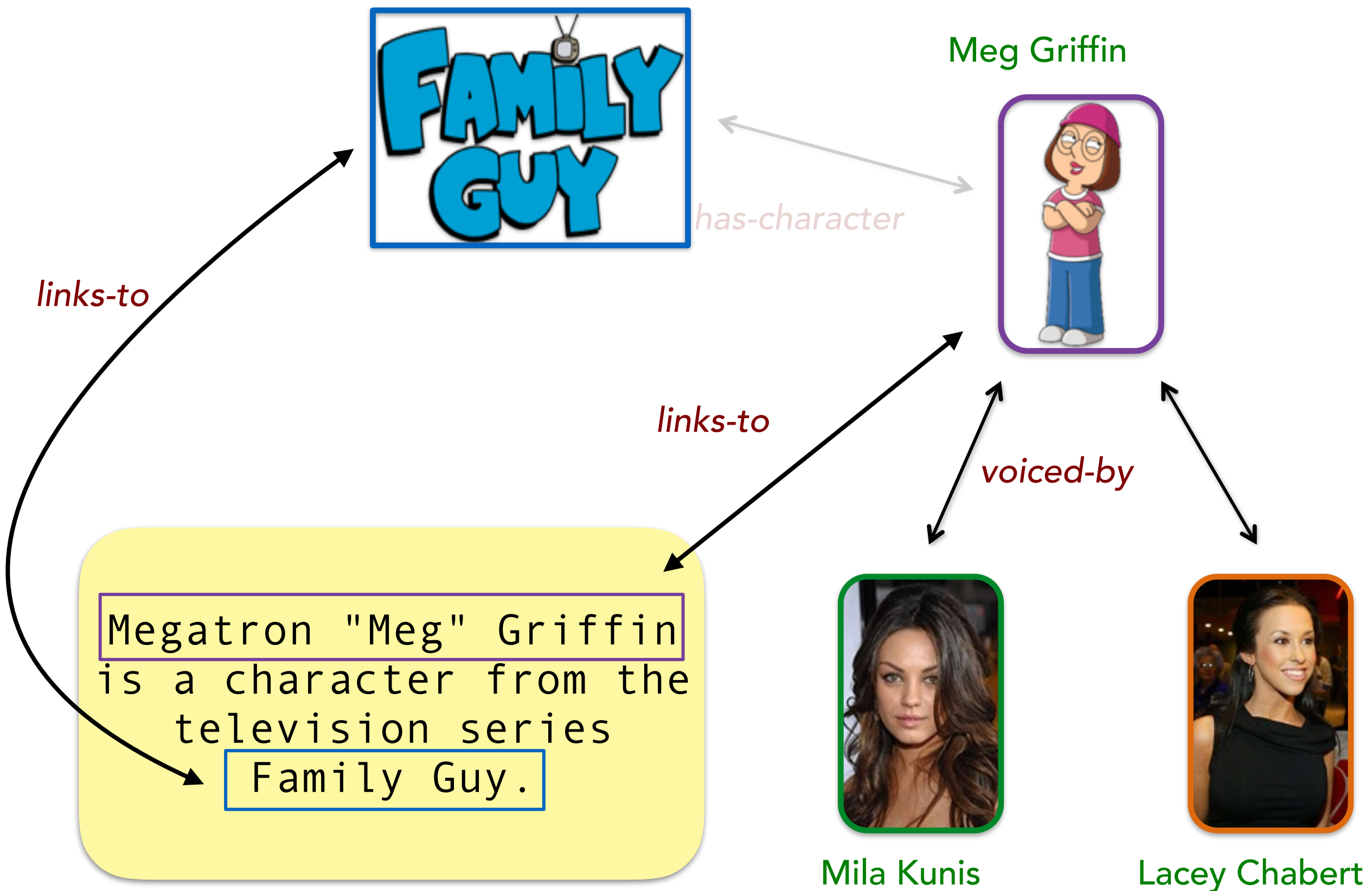
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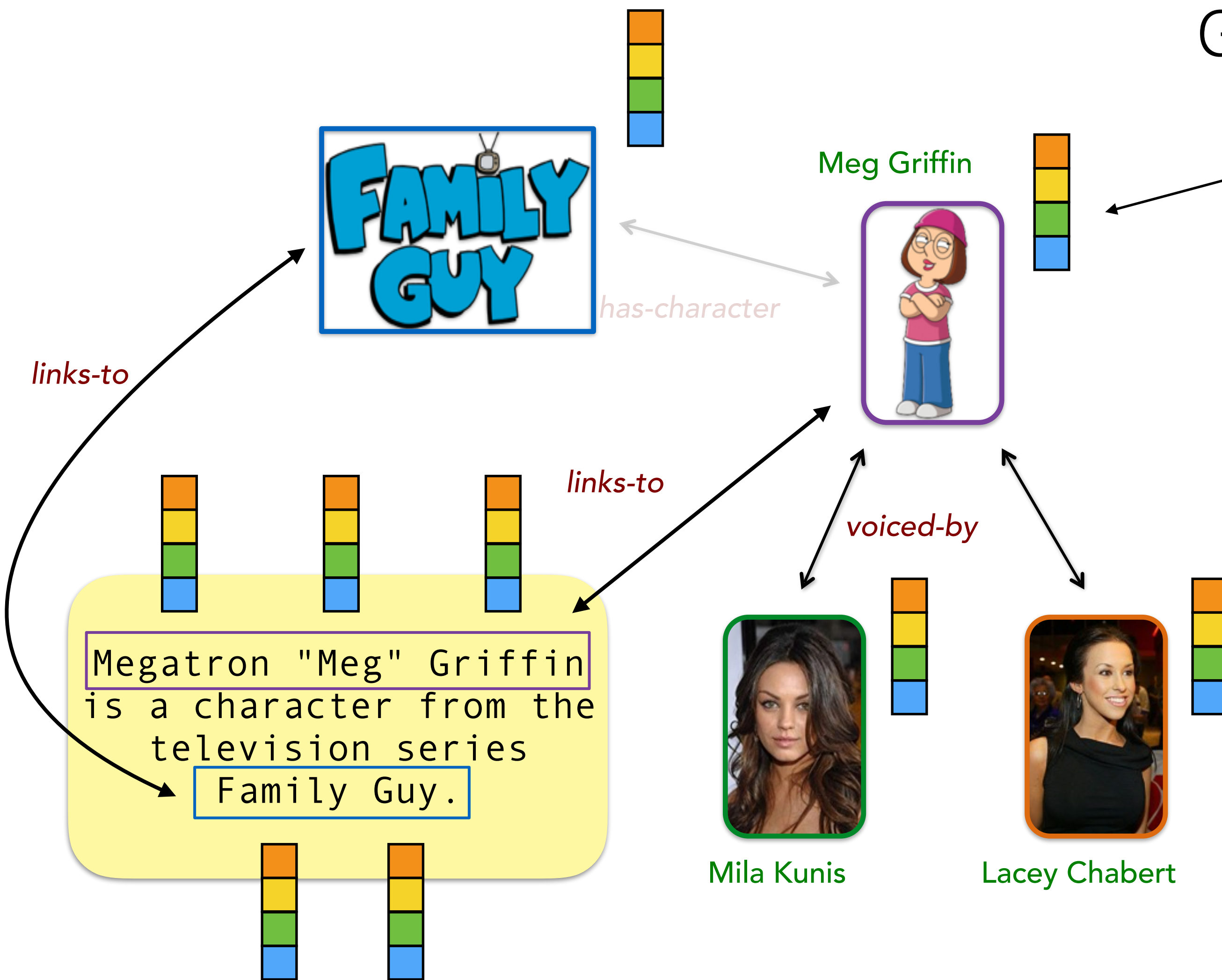
Entity Linking

Search via Representation Learning



Who voiced **Meg** in **Family Guy**?

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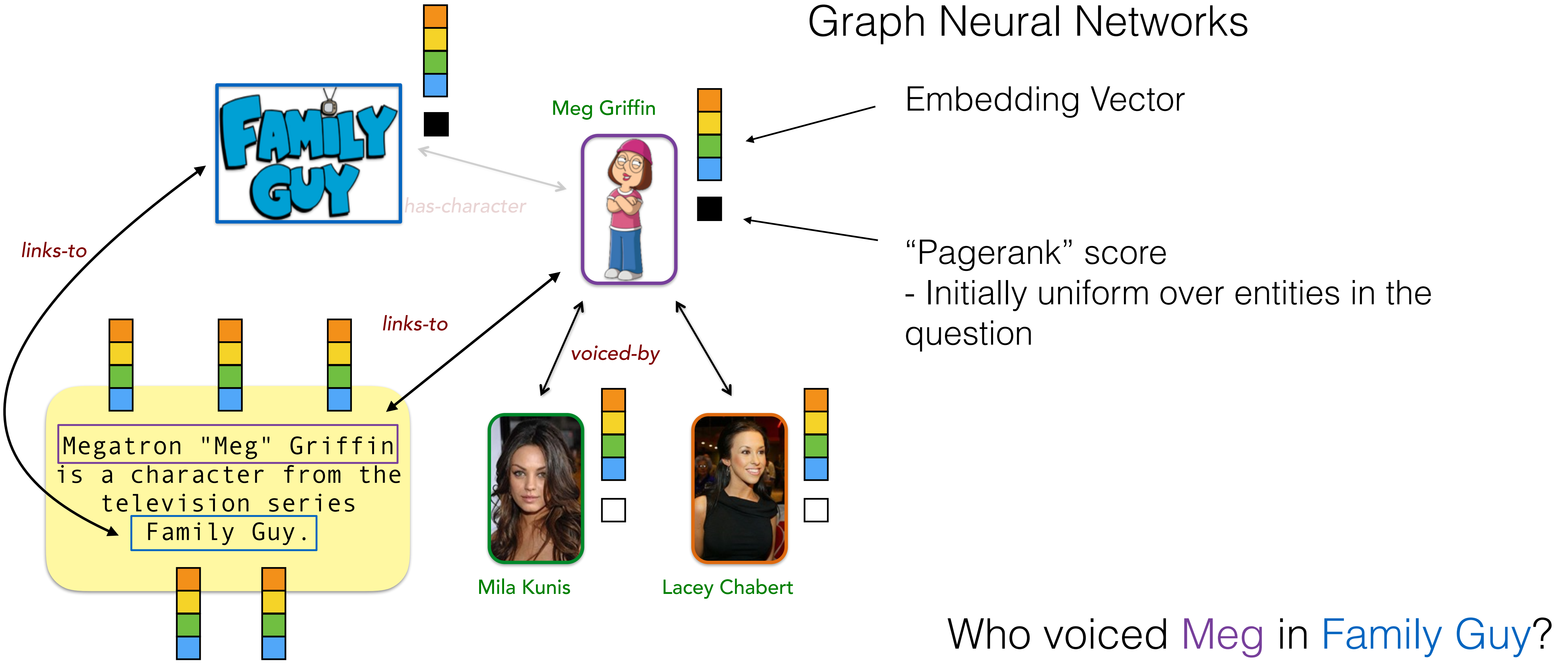


Graph Neural Networks

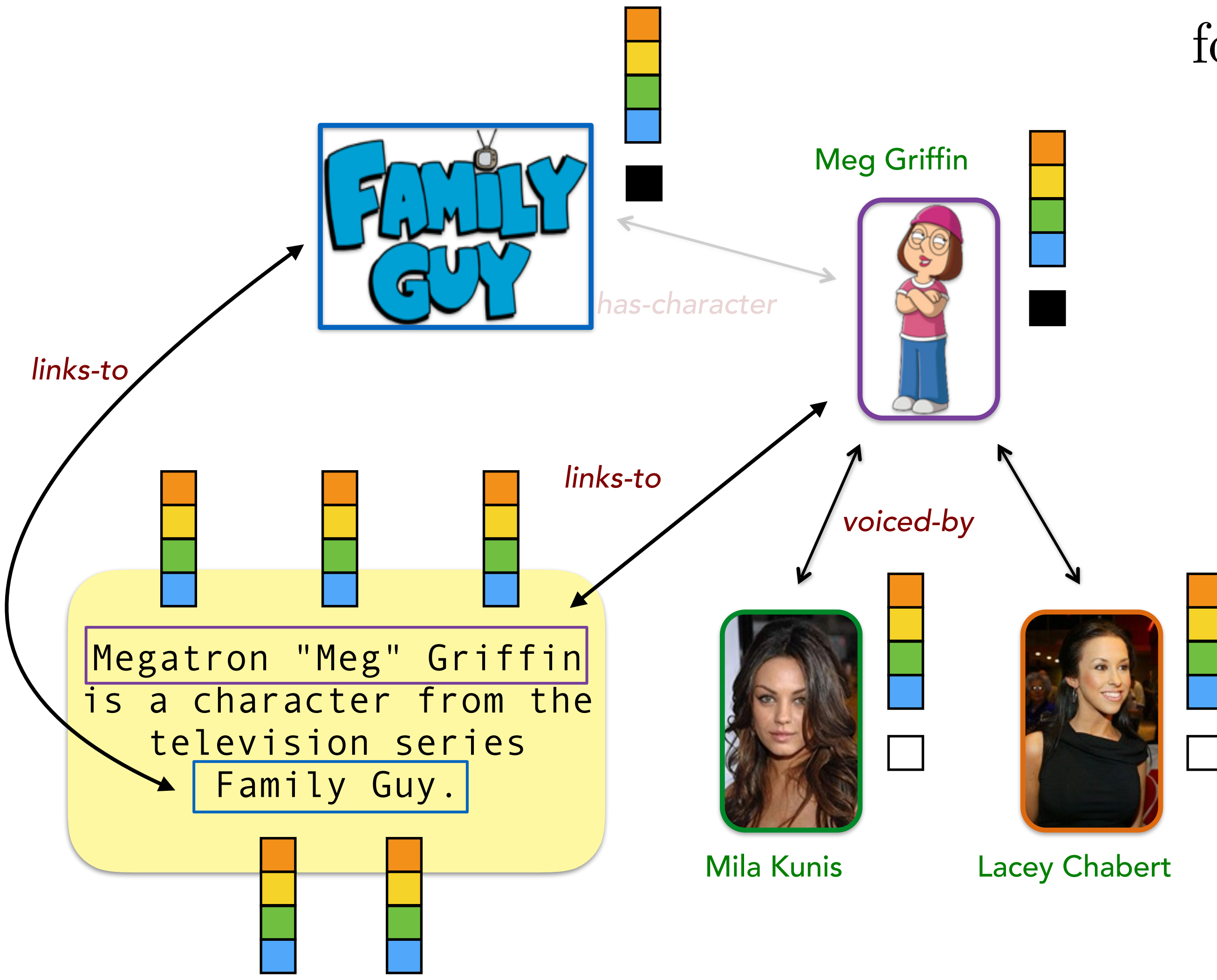
Embedding Vector

Who voiced **Meg** in **Family Guy**?

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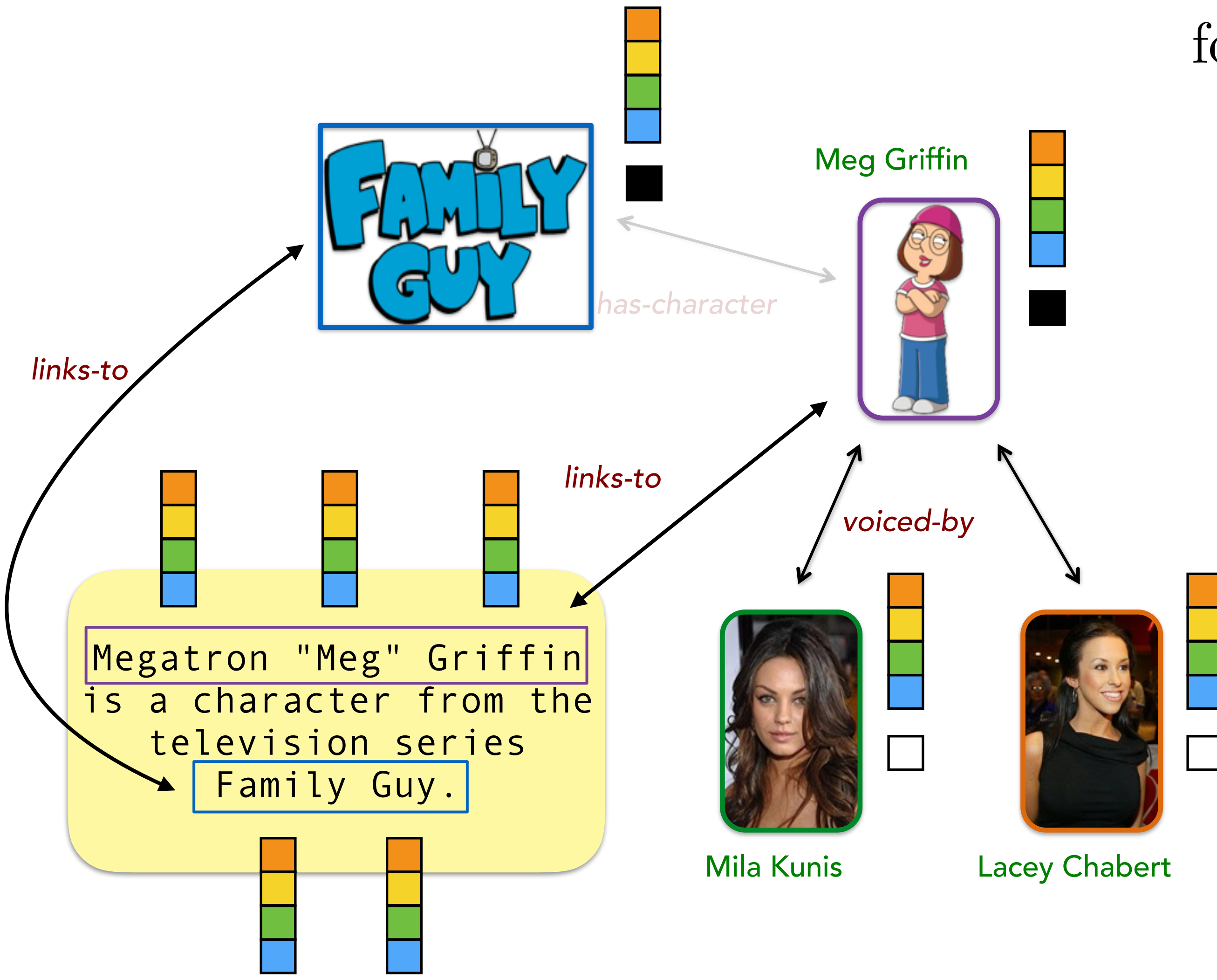


for $t = 1 \dots T$:

$$h_v^{(t)} = f\left(h_v^{(t-1)}, \sum_{v' \in N(v)} \alpha_{v'} h_{v'}^{(t-1)}, \sum_{d:v \in d} h_{d_w}^{(t-1)}\right)$$

Who voiced **Meg** in **Family Guy**?

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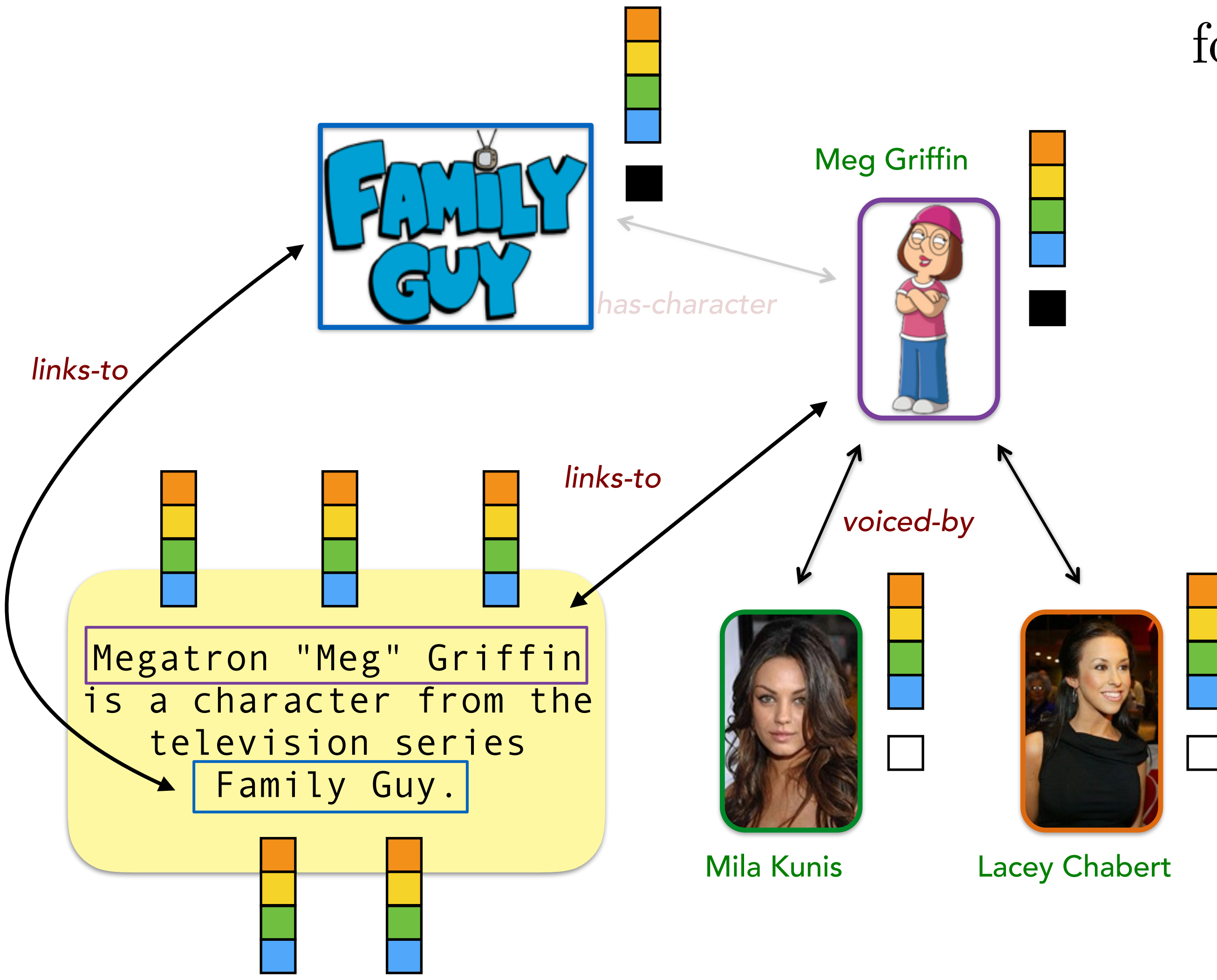
Self connection

Entity neighbors

Text mentions

Who voiced **Meg** in **Family Guy**?

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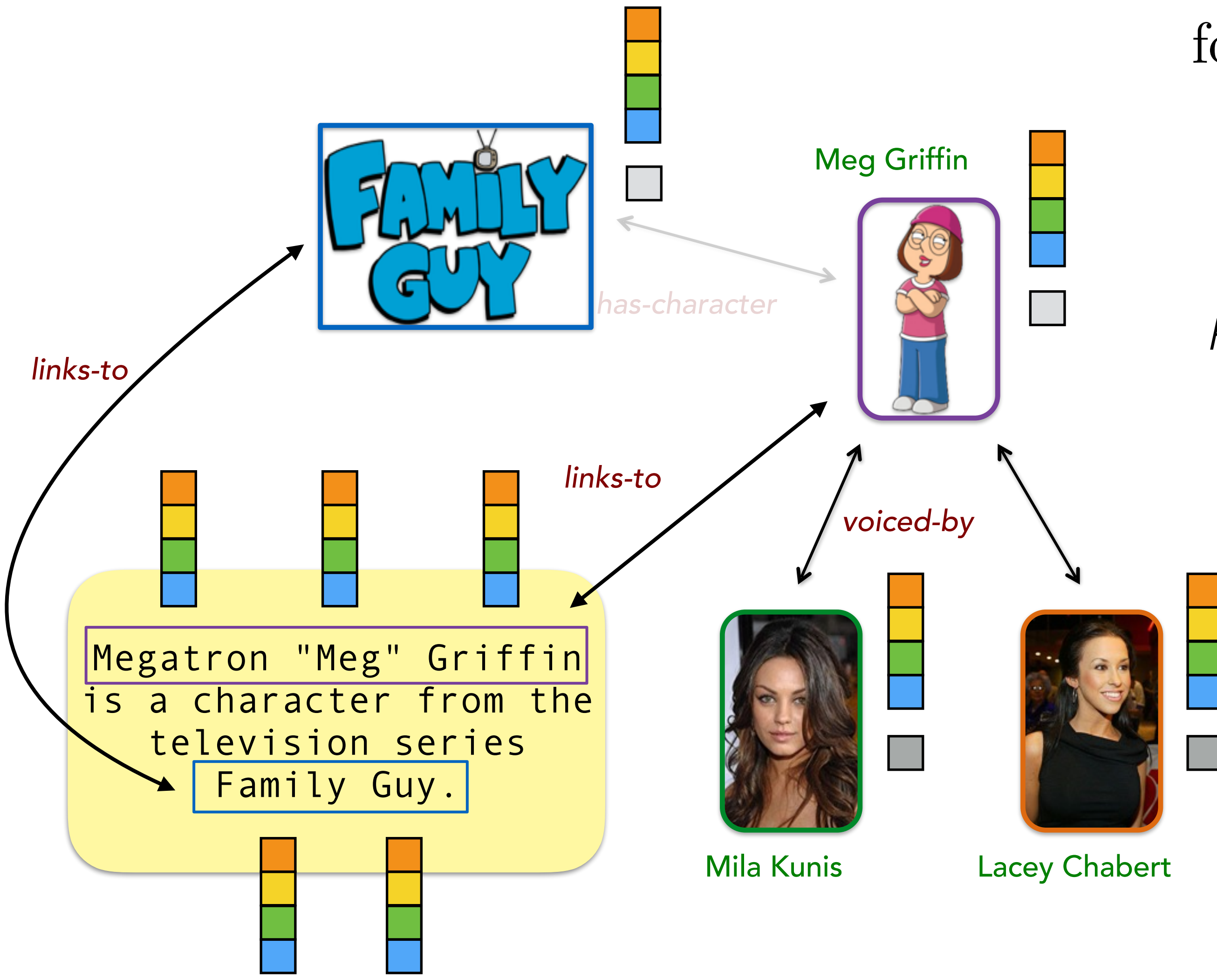
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\nearrow Self connection
 \nearrow Entity neighbors
 \nearrow Text mentions

- Only propagate embeddings from nodes with **non-zero pagerank score**
- This constrains learning along **valid paths** in the graph

Who voiced **Meg** in **Family Guy**?

Search via Representation Learning



for $t = 1 \dots T$:

$$pr_v^{(t)} = (1 - \lambda)pr_v^{(t-1)} + \lambda \sum_{v' \in N_r(v)} \alpha_{v'} pr_{v'}^{(t-1)}$$

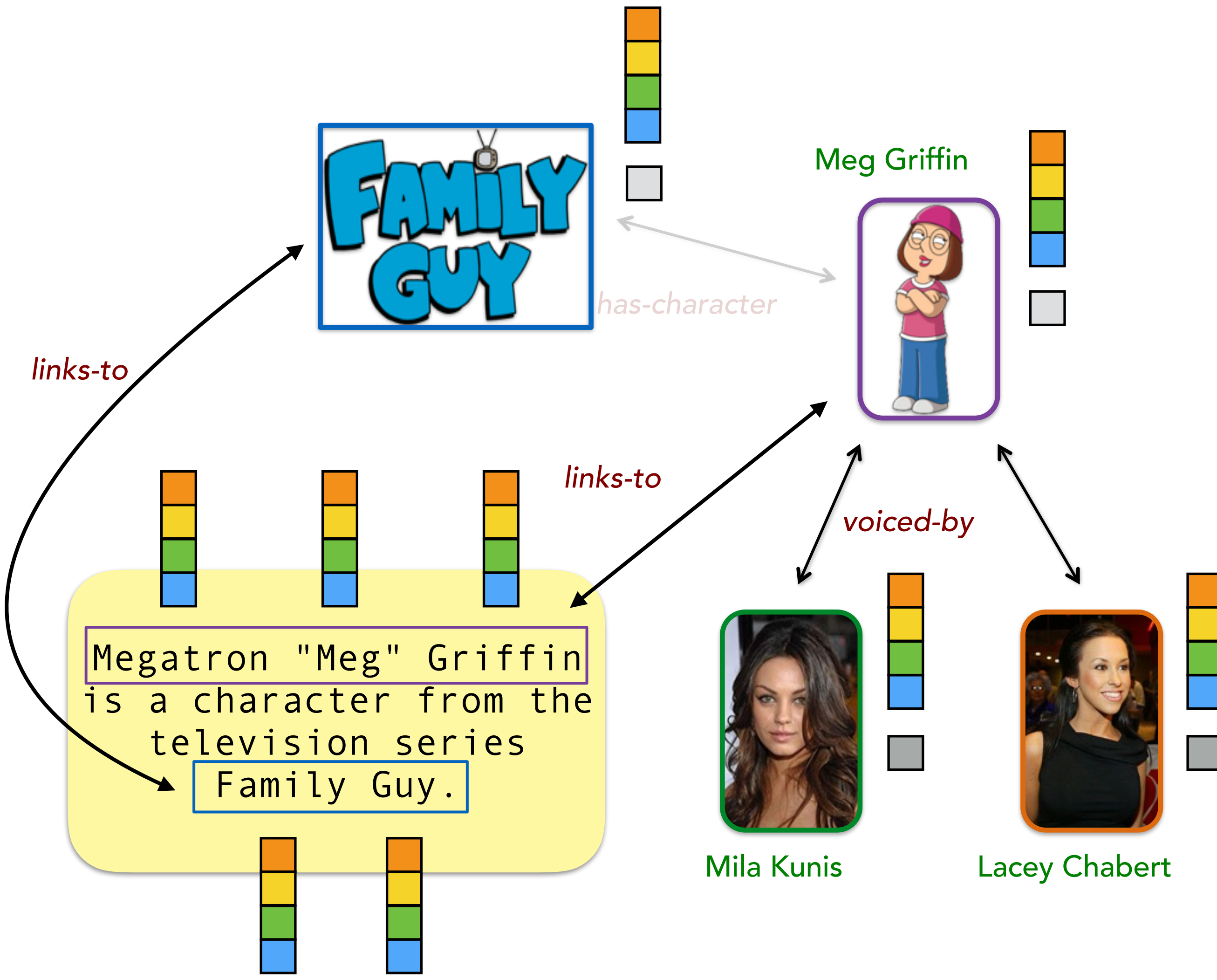
Pagerank update

Learned weights

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Search via Representation Learning

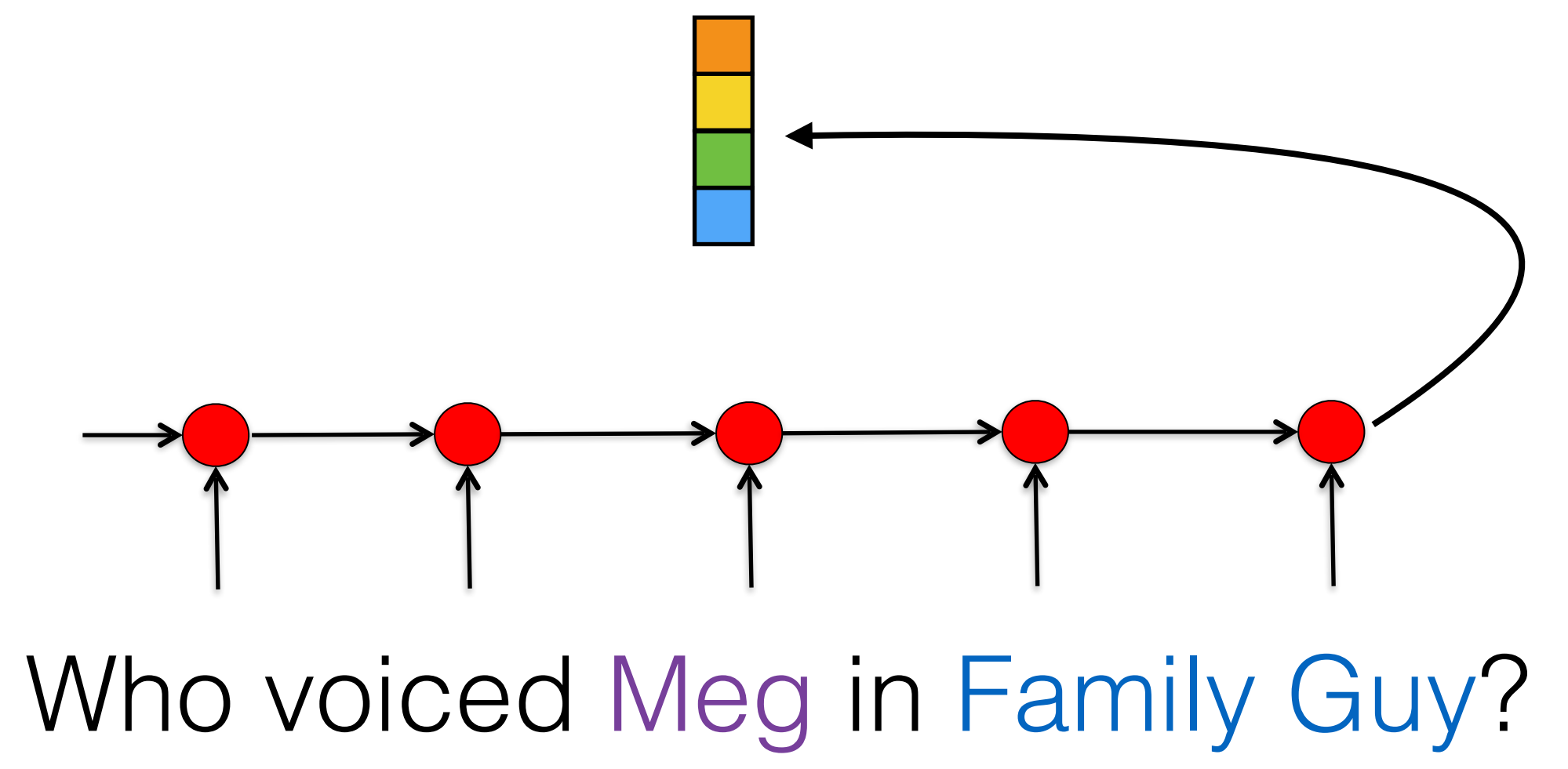


Classify each entity as Answer / Not-Answer:

$$\log Pr(v|q) \propto (h_q \cdot h_v^T)$$

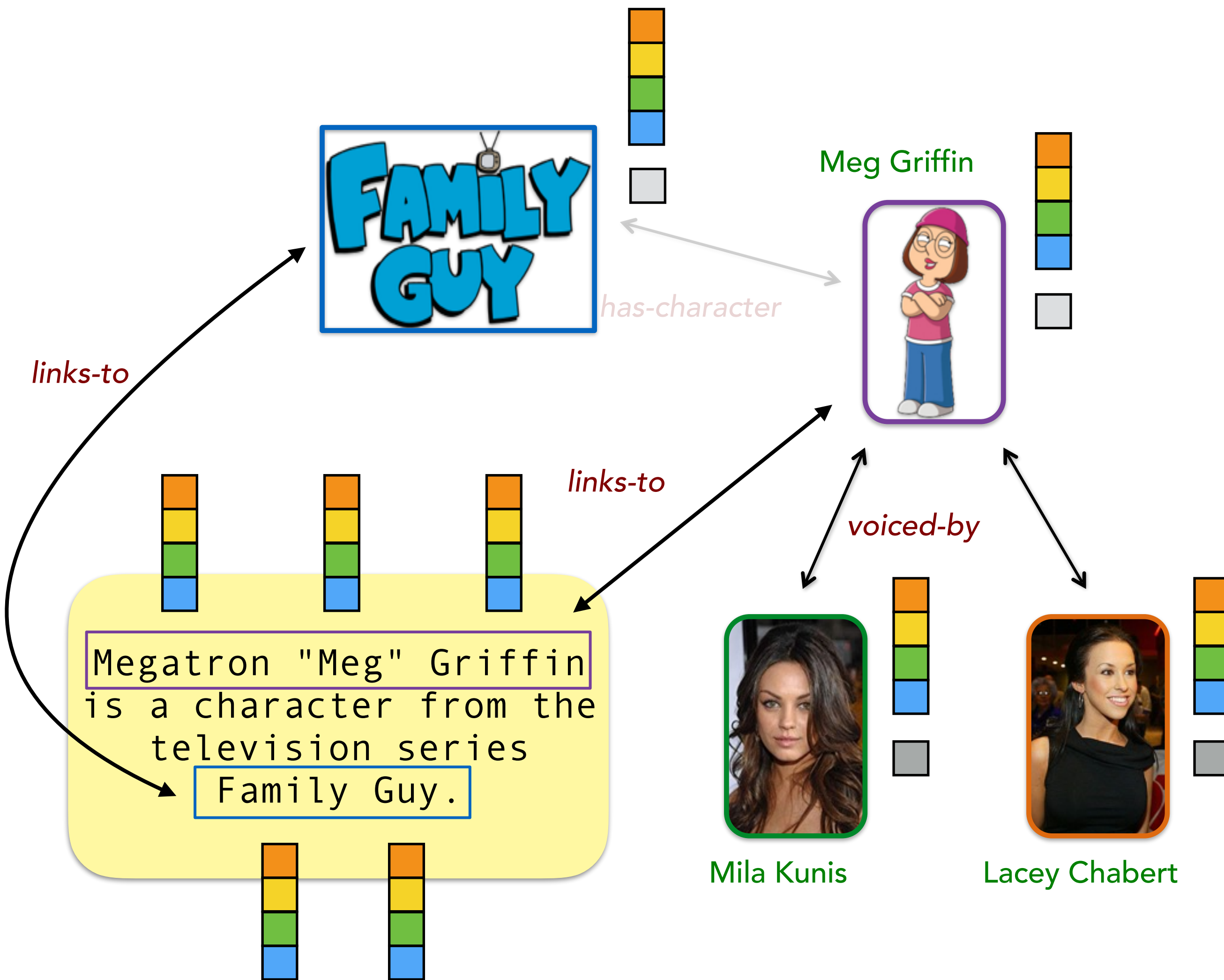
h_q : Question Representation

h_v^T : Entity Representation



Who voiced **Meg** in **Family Guy**?

Search via Representation Learning



Summary:

1. Inject text into KB using retrieval
2. Propagate entity embeddings along paths starting from question entities
3. Classify each entity as answer / no-answer

Who voiced **Meg** in **Family Guy**?

Evaluation — WebQuestionsSP & WikiMovies

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- WebQuestionsSP [Berant, 2013; Yih, 2016]:
E.g. *“What language do they speak in Afghanistan?” – Pashto language*
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 - KB - Subset of OMDb, Text - Subset of Wikipedia
 - 10K QA pairs for training
- Both datasets are answerable using KBs
 - But we simulate an incomplete KB setting

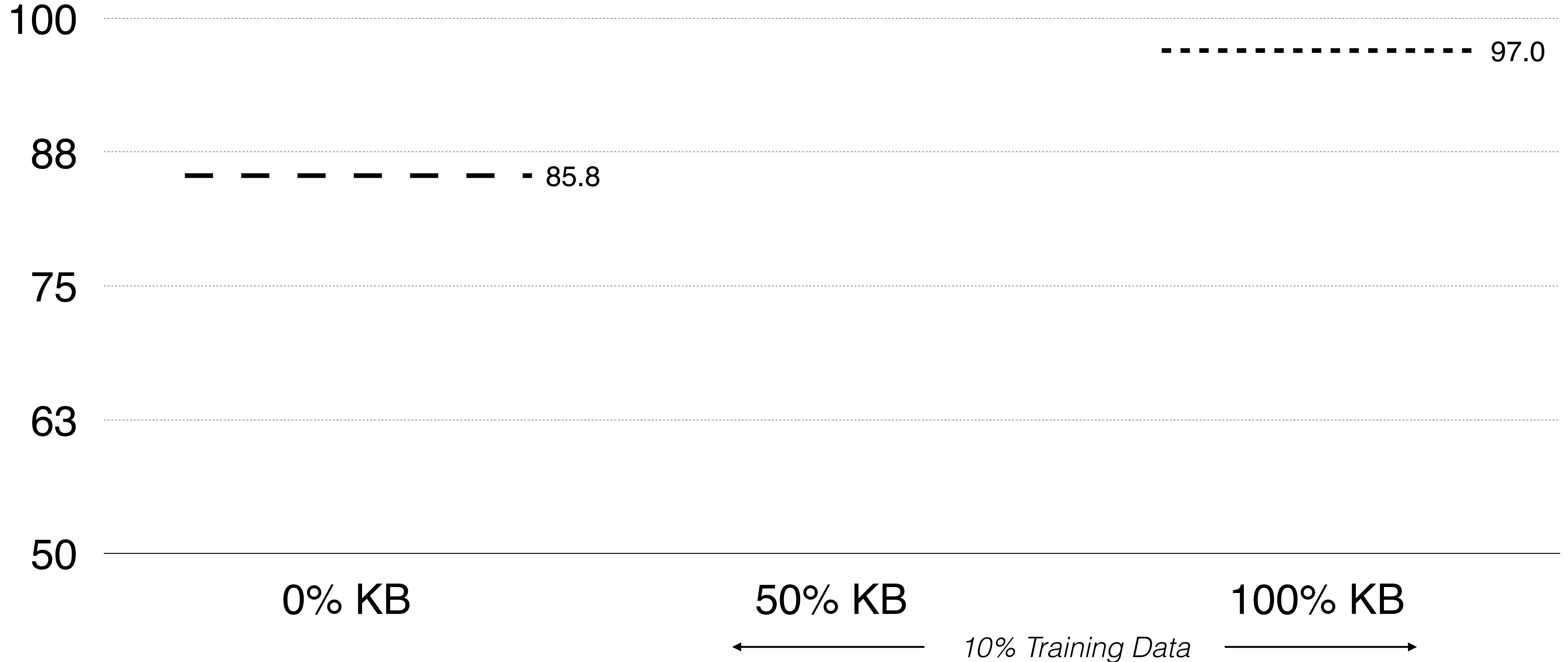
WikiMovies Results

Hits @1 Performance

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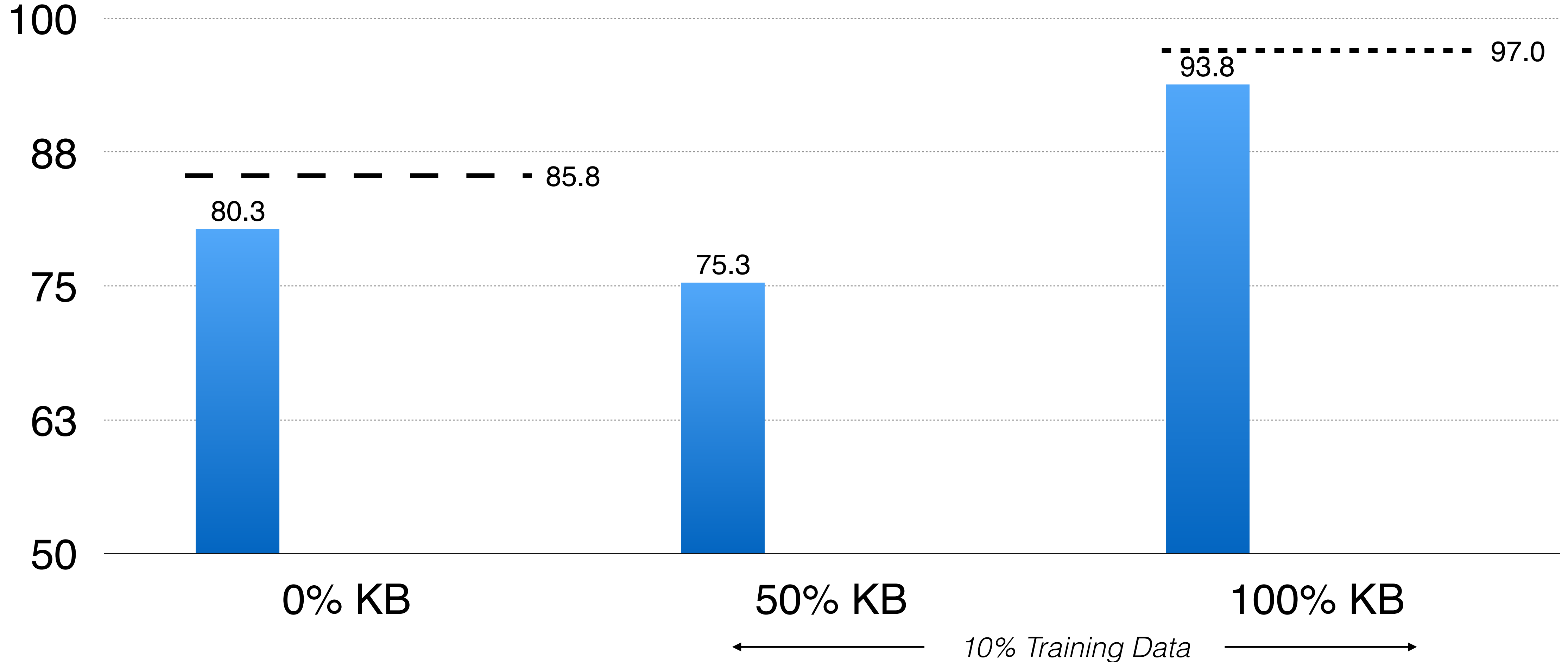
— — Text-SOTA (Watanabe et al (arxiv'17)) - - - - - KB-SOTA (Das et al (ICLR'18)) ■ Universal Schema ■ Ours (KB-only) ■ Ours (KB+Text)



WikiMovies Results

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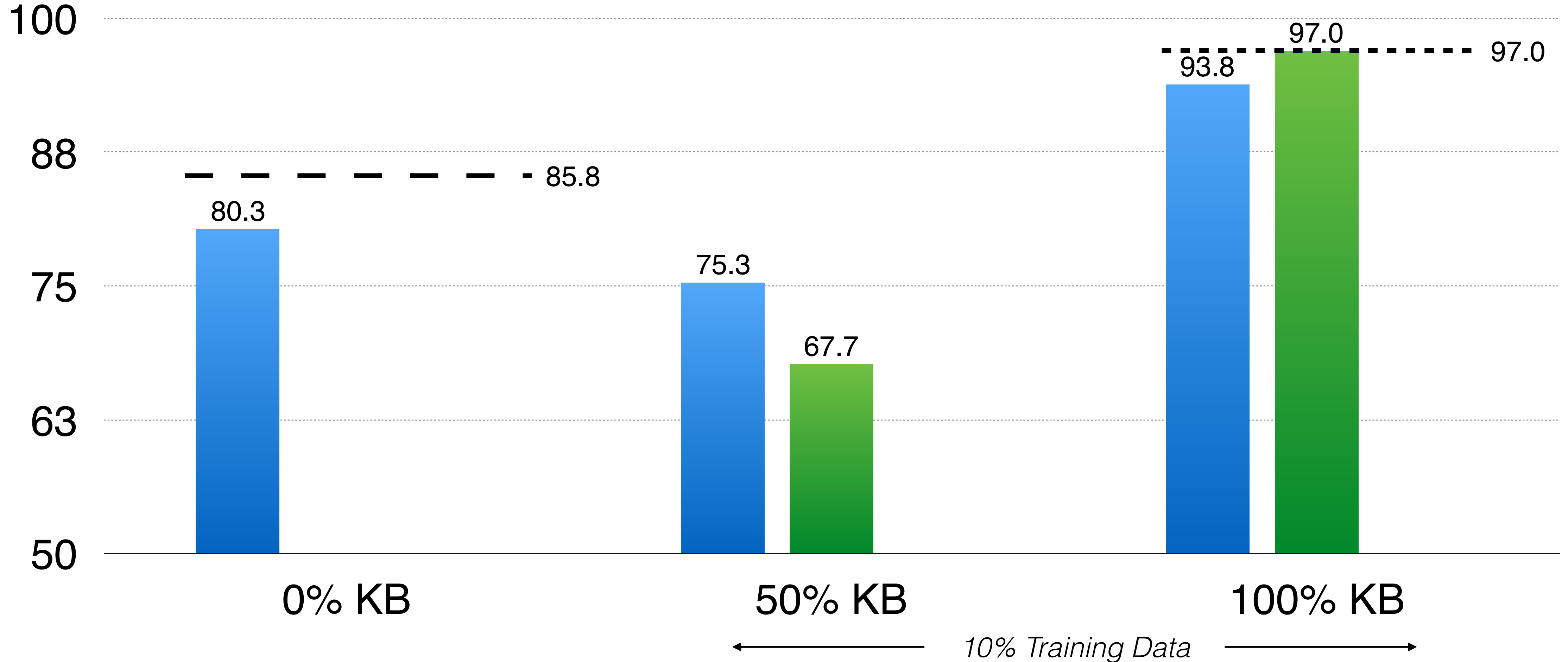
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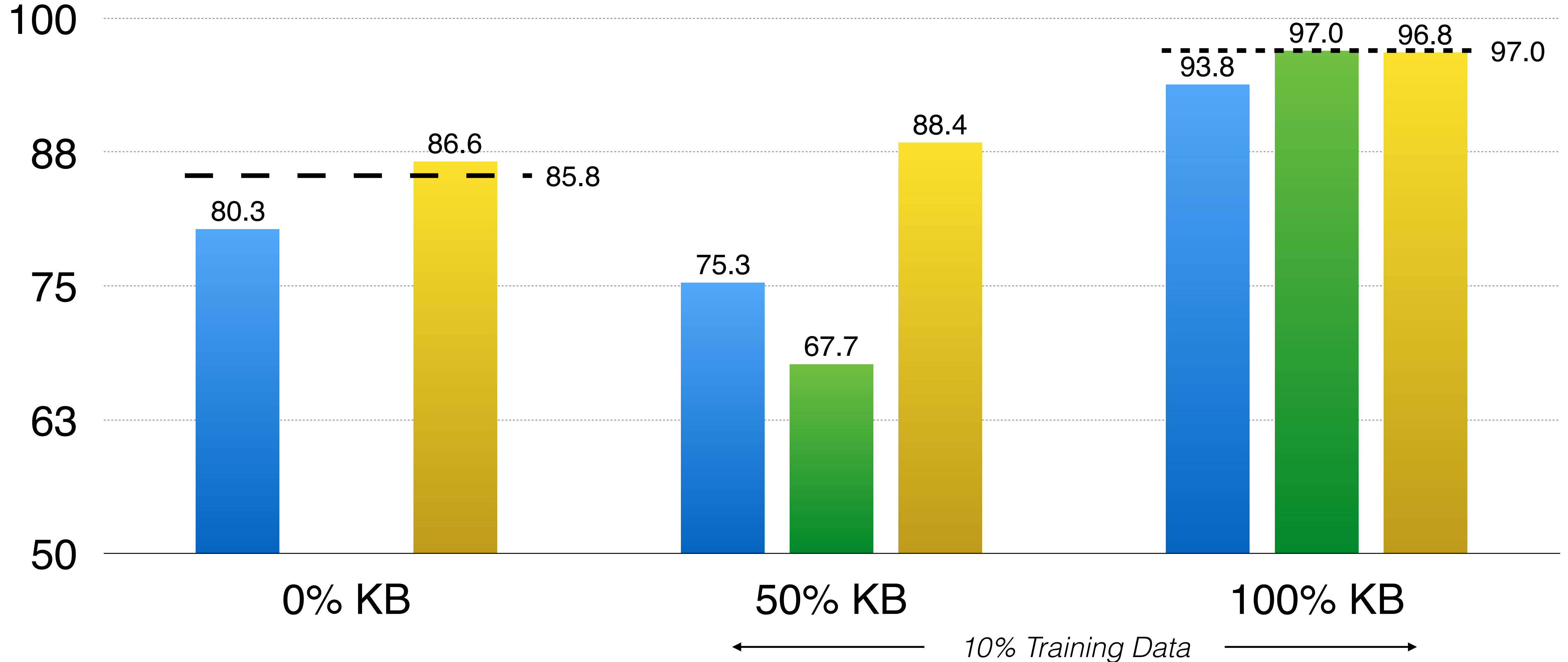
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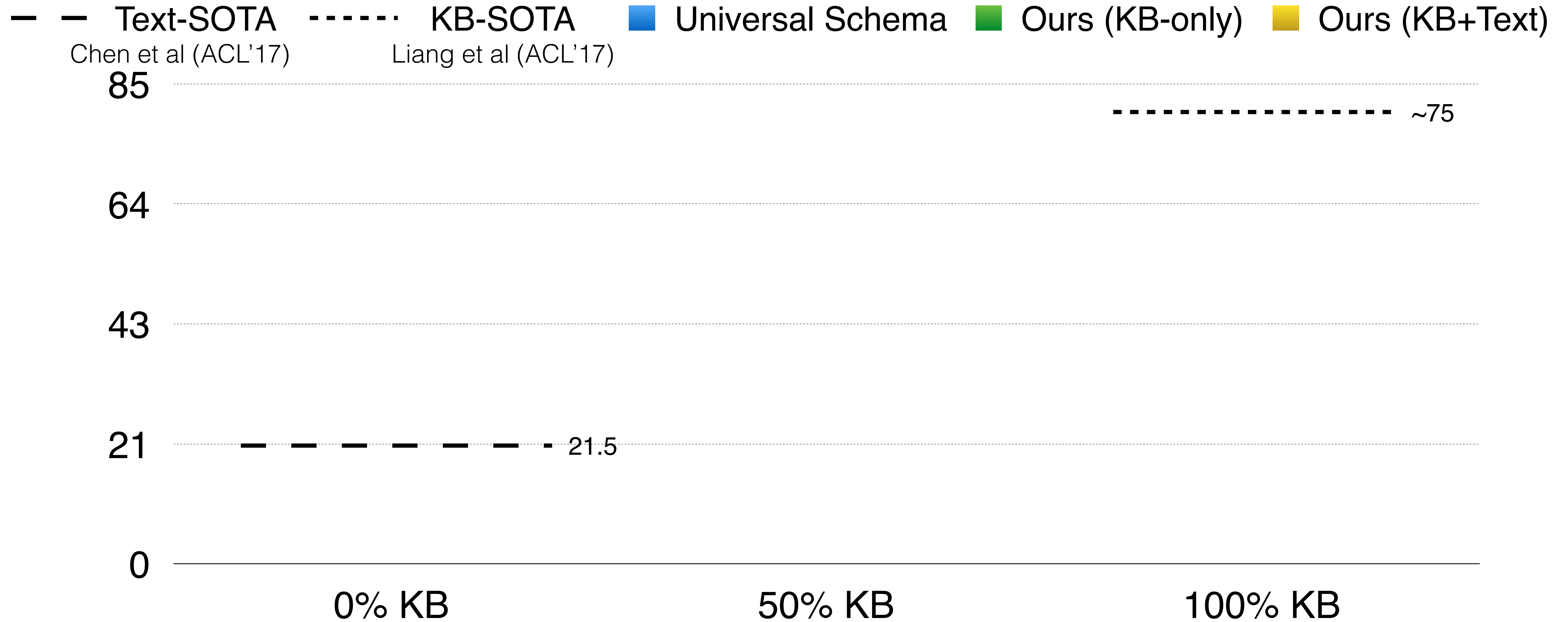


WebQuestionsSP Results

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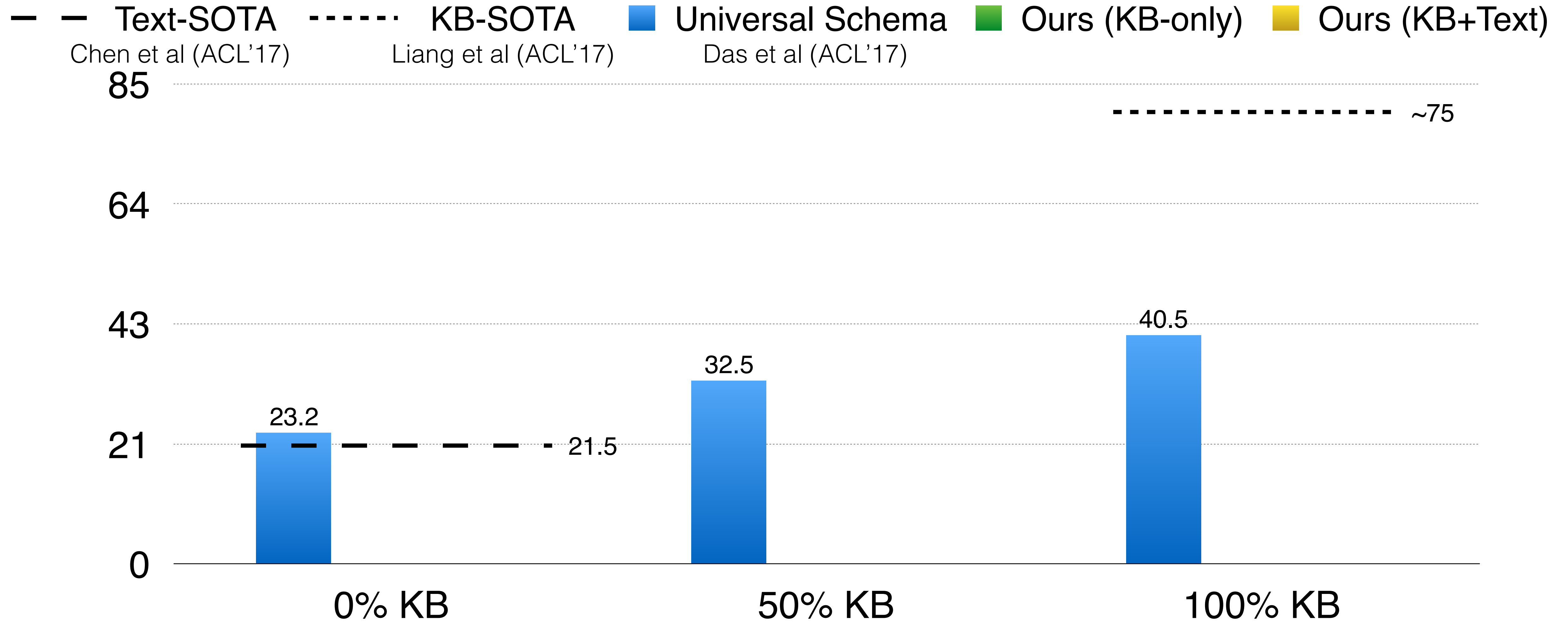
WebQuestionsSP Results

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WebQuestionsSP Results

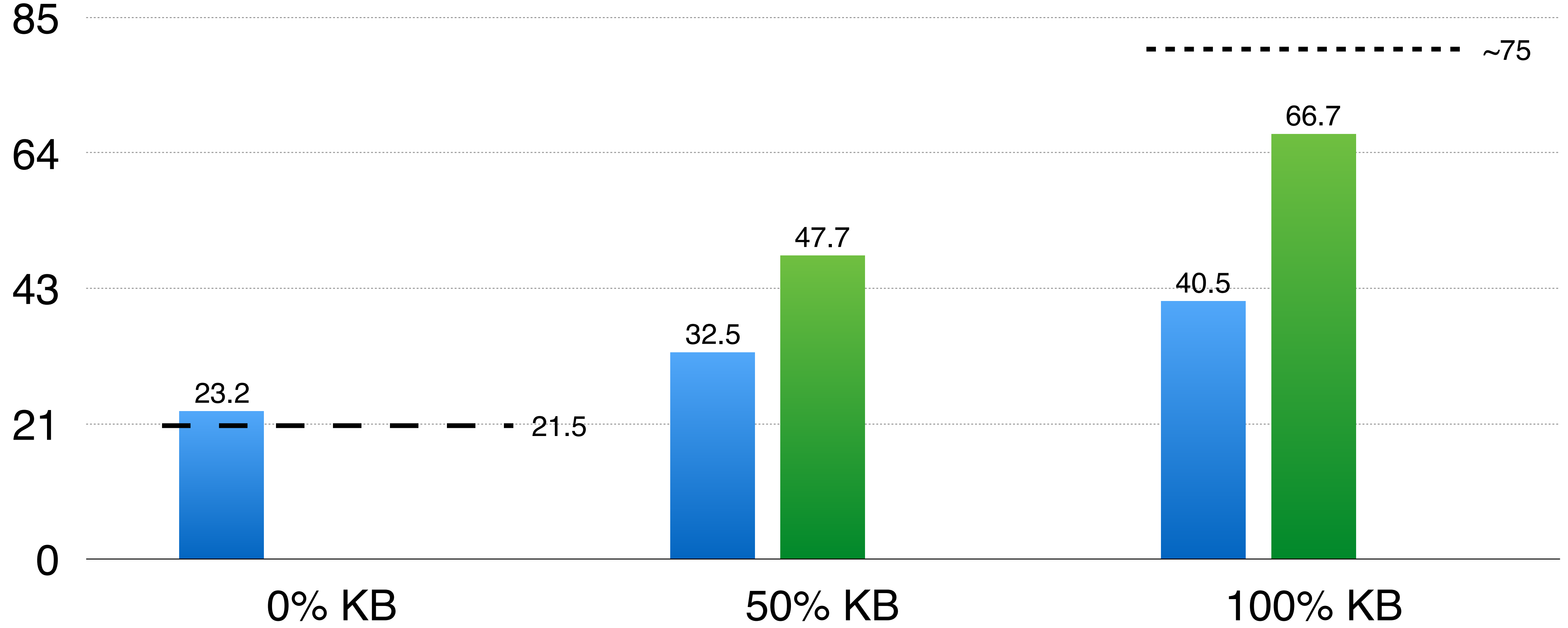
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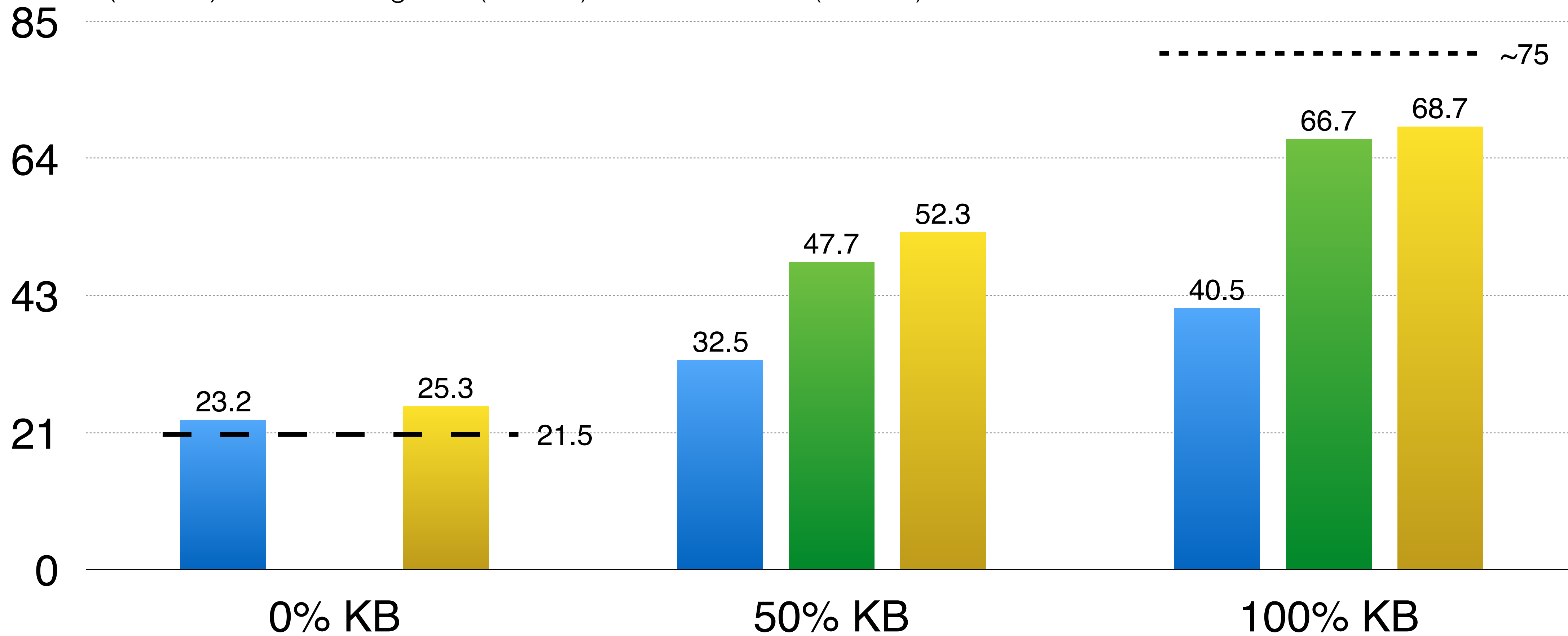
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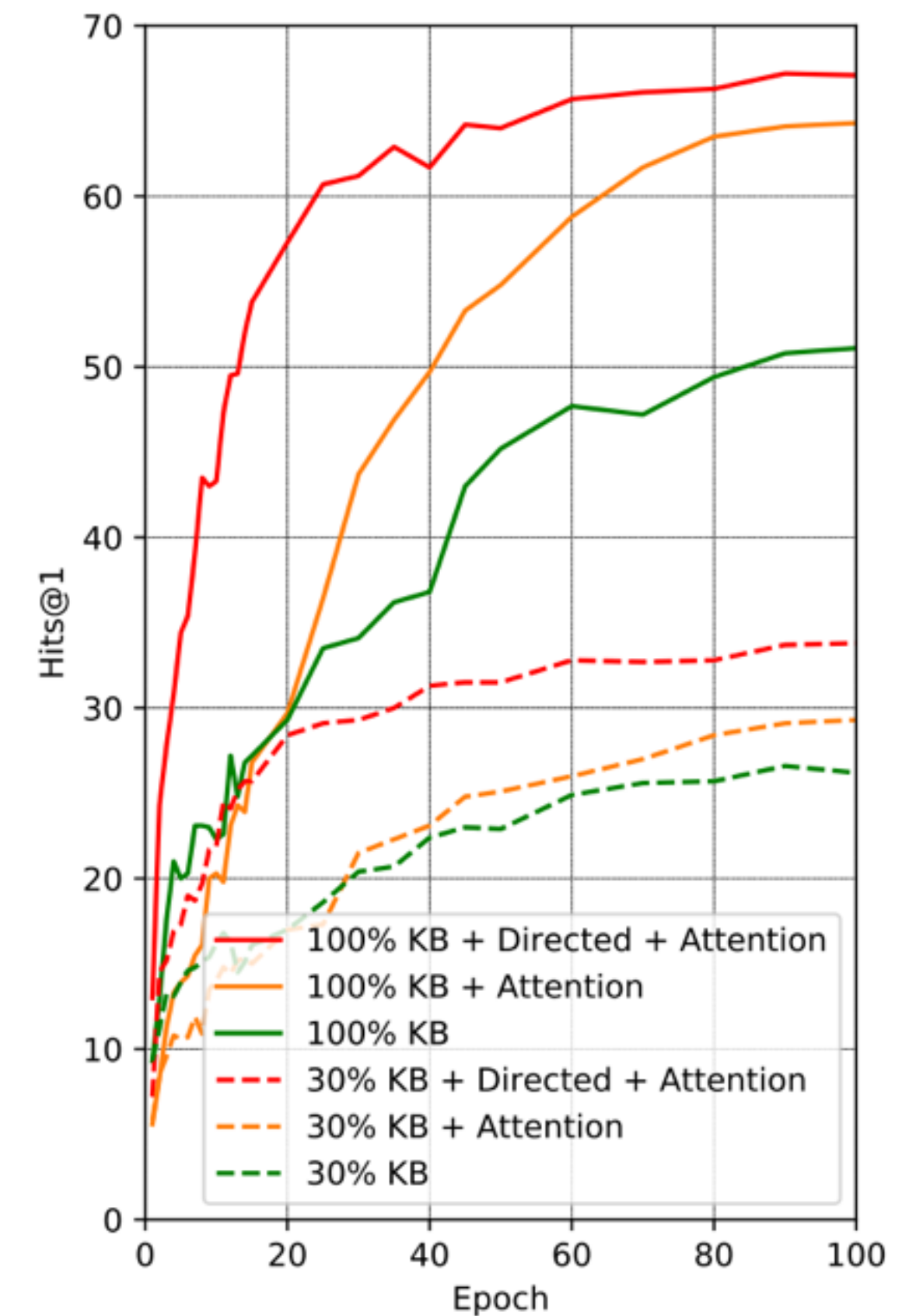


Analysis

- *Pagerank* propagation leads to ~10% improvement
- Errors:
 - Retrieval (both text + facts) has only 90% recall
 - Complex questions:

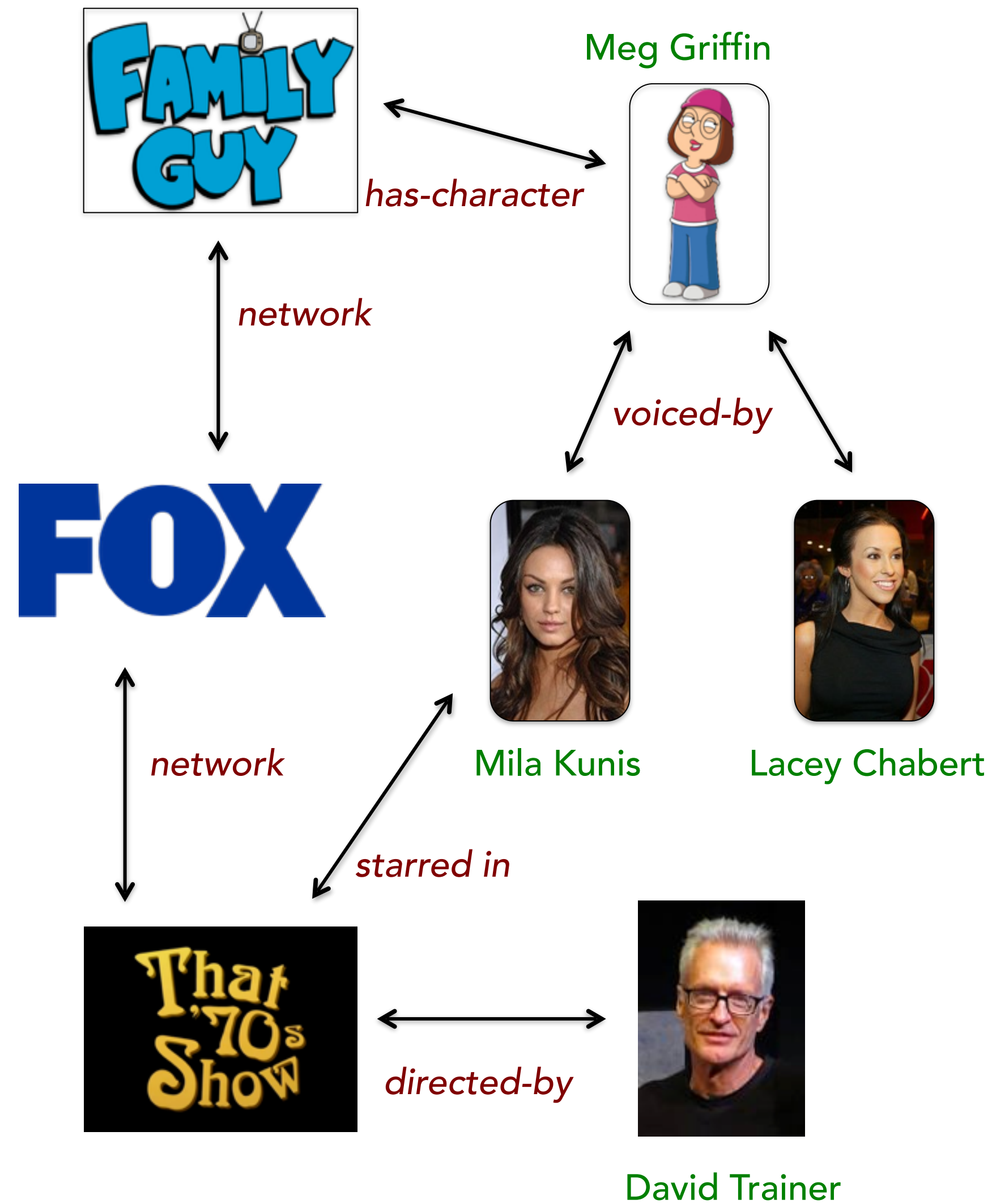
“Who *first* voiced Meg in Family Guy?”

“Which club did Cristiano Ronaldo play for *in 2007*?”



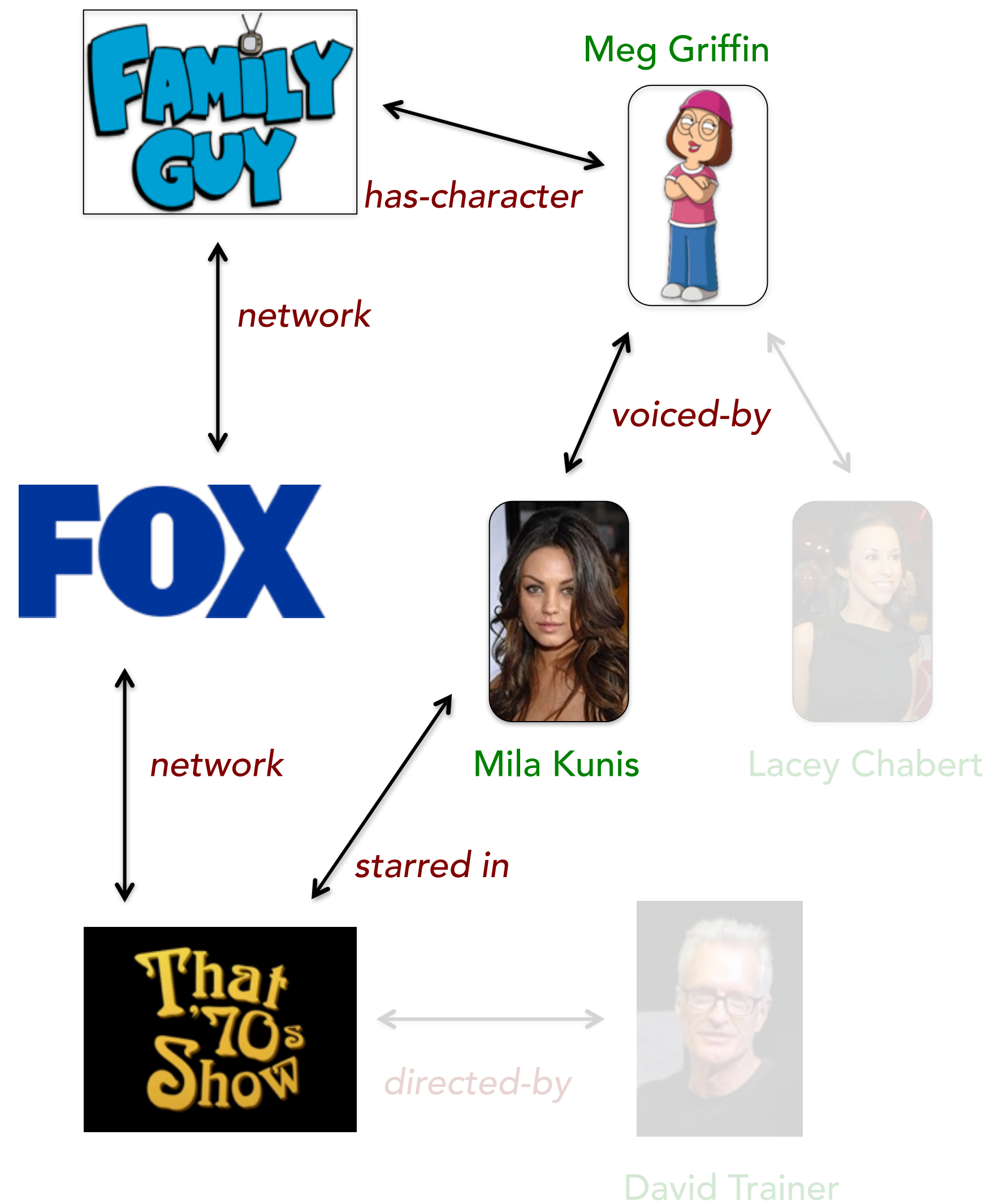
Title and authors removed for anonymity

Multi-Hop Question Answering



Q. Which TV Networks has *Mila Kunis* appeared on?

Multi-Hop Question Answering



Q. Which TV Networks has *Mila Kunis* appeared on?

```
Y1 = {Mila_Kunis}.follow(starred-in).follow(network)
```

```
Y2 = {Mila_Kunis}.follow(voiced)....follow(network)
```

```
Ans = Y1 UNION Y2
```

A. Fox

$$Y = X.\text{follow}(R) = \{x' : \exists x \in X \text{ s.t. } R(x, x') \text{ holds}\}$$

Can we do this with a Text Corpus?

This collage consists of overlapping snippets from Wikipedia articles. The visible text includes:

- Mila Kunis**: From Wikipedia, the free encyclopedia. Milena Markovna "Mila" Kunis (/ˈmɪlə ˈkʊnɪs/; Ukrainian: Мілена Маркіана Куніс; born August 14, 1983) is an American actress. In 1991, at the age of seven, she moved from Soviet Ukraine to the United States with her family. After being enrolled in acting classes as an after-school activity, she was soon discovered by an agent. She appeared in several television series and commercials, before landing her first significant role at age 14, playing Jackie Burkhart on the television series *That '70s Show* (1998–2006). Since 1999, she has voiced Meg Griffin on the animated series *Family Guy*. Kunis's breakout film role came in 2008,^[13] playing Rachel in the romantic comedy *Forgetting Sarah Marshall*. She gained further critical acclaim and accolades for her performance in the psychological thriller *Black Swan* (2010), for which she received the *Marcello Mastroianni Award* for Best Young Actor or Actress, and nominations for the SAG Award and the Golden Globe Award.
- Fox Broadcasting Company**: From Wikipedia, the free encyclopedia. *"FOX" and "Fox (TV channel)" redirect here. For "Fox" television channels outside the United States, see Fox (channel). For the film studio that the network was named after, see 20th Century Fox. For the 24-hour news channel, see Fox News. For other uses, see Fox (disambiguation).*
- Family Guy**: From Wikipedia, the free encyclopedia. *This article needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed.* Find sources: "Fox Broadcasting Company" – news · newspapers · books · scholar · JSTOR (August 2019) *Learn how and when to remove this template message.* *Not to be confused with Fox Film.* *Family Guy* is an American animated sitcom created by Seth MacFarlane for the Fox Broadcasting Company. The series centers on the Griffins, a family consisting of parents Peter and Lois; their children, Meg, Chris, and Stewie; and their anthropomorphic pet dog, Brian. The show is set in the fictional city of Quahog, Rhode Island, and exhibits much of its humor in the form of metafictional cutaway gags that often lampoon American culture. The family was conceived by MacFarlane after developing two animated films, *The Life of Larry and Larry & Steve*. MacFarlane redesigned the films' protagonist, Larry, and his dog, Steve, and renamed them Peter and Brian, respectively. MacFarlane pitched a seven-minute pilot to Fox in 1998, and the show was greenlit and began production. Shortly after the third season of *Family Guy* had aired in 2002, Fox canceled the series' original run. However, favorable DVD sales and high ratings for syndicated reruns on Adult Swim convinced the network to produce a fourth season, which began airing on May 1, 2005.
- That '70s Show**: From Wikipedia, the free encyclopedia. *That '70s Show* is an American television period sitcom that originally aired on Fox from August 23, 1998 to May 18, 2006. The series focuses on the lives of a group of six teenage friends living in fictional Point Place, Wisconsin, from May 17, 1976 to December 31, 1979.^[1] The main teenage cast members were Tophér Grace, Mila Kunis, Ashton Kutcher, Danny Masterson, Laura Prepon and Wilmer Valderrama. The main adult cast members were Debra Jo Rupp, Kurtwood Smith, Don Stark, Tommy Chong and Tanya Roberts.

The collage also features several images: a portrait of Mila Kunis, the *Family Guy* title logo, the Fox Broadcasting Company logo, and the *That '70s Show* title logo. A large empty rectangular box is positioned to the right of the collage.



Can we do this with a Text Corpus?

Q. Which TV Networks has *Mila Kunis* appeared on?

The image displays a collage of four Wikipedia article snippets. At the top left is the article for **Mila Kunis**, describing her as an American actress. To its right is a small portrait of her. Below that is the article for **Fox Broadcasting Company**, including a note about redirects. On the left side, overlapping the other articles, is the article for **Family Guy**, which mentions it is an animated sitcom on Fox. At the bottom left is the article for **That '70s Show**, listing its cast and production details. A large, empty rectangular box is positioned on the right side of the collage.

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Since 1999, she has voiced Meg Griffin on the animated series *Family Guy*.

The image shows a collage of Wikipedia article snippets. An arrow points from the Mila Kunis article to the question. The snippets include:

- Mila Kunis**: From Wikipedia, the free encyclopedia. Milena Markovna "Mila" Kunis (/ˈmɪlə ˈkʊnz/; Ukrainian: Мілена Маркіана Куніс; born August 14, 1983) is an American actress. In 1991, at the age of seven, she moved from Soviet Ukraine to the United States with her family. After being enrolled in acting classes as an after-school activity, she was soon discovered by an agent. She appeared in several television series and commercials, before landing her first significant role at age 14, playing Jackie Burkhart on the television series *That '70s Show* (1998–2006). Since 1999, she has voiced Meg Griffin on the animated series *Family Guy*. Kunis's breakout film role came in 2008,^[13] playing Rachel in the romantic comedy *Forgetting Sarah Marshall*. She gained further critical acclaim and accolades for her performance in the psychological thriller *Black Swan* (2010), for which she received the *Marcello Mastroianni Award* for Best Young Actor or Actress, and nominations for the *SAG Award* and the *Golden Globe Award*.
- Fox Broadcasting Company**: From Wikipedia, the free encyclopedia. "FOX" and "Fox (TV channel)" redirect here. For "Fox" television channels outside the United States, see *Fox (channel)*. For the film studio that the network was named after, see *20th Century Fox*. For the 24-hour news channel, see *Fox News*. For other uses, see *Fox (disambiguation)*.
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- That '70s Show**: From Wikipedia, the free encyclopedia. *That '70s Show* is an American television period sitcom that originally aired on Fox from August 23, 1998 to May 18, 2006. The series focuses on the lives of a group of six teenage friends living in fictional Point Place, Wisconsin, from May 17, 1976 to December 31, 1979.^[1] The main teenage cast members were Tophér Grace, Mila Kunis, Ashton Kutcher, Danny Masterson, Laura Prepon and Wilmer Valderrama. The main adult cast members were Debra Jo Rupp, Kurtwood Smith, Don Stark, Tommy Chong and Tanya Roberts.

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The image shows a collage of Wikipedia article snippets. The top-left snippet is for Mila Kunis, mentioning her role as Meg Griffin on Family Guy. The top-right snippet is for Fox Broadcasting Company. The middle-left snippet is for Family Guy, mentioning it was created by Seth MacFarlane for the Fox Broadcasting Company. The middle-right snippet is for Fox, a terrestrial television network. The bottom-left snippet is for That '70s Show, mentioning it was created by Bonnie Turner, Terry Turner, and Mark Brazill. Arrows point from the snippets to the text boxes on the right.

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Arrows from the snippets point to the answer boxes on the right. One arrow points from the *Family Guy* snippet to the first answer box, and another points from the *Fox Broadcasting Company* snippet to the second answer box.

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Information can be spread out across the corpus

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MetaQA Benchmark

MetaQA Benchmark

- Expands Wikimovies dataset to 2-hop and 3-hop questions

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What movies did Quentin Tarantino direct?

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MetaQA Benchmark

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- 2-hop:
Which movies have the same director as that of Pulp Fiction?
- 3-hop:
Who acted in the movies which have the same director as Pulp Fiction?

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- 1-hop:
What movies did Quentin Tarantino direct?
- 2-hop:
Which movies have the same director as that of Pulp Fiction?
- 3-hop:
Who acted in the movies which have the same director as Pulp Fiction?
- Text corpus:
17K first paragraphs from Wikipedia articles about the movies

Pulp Fiction is a 1994 American crime film written and directed by Quentin Tarantino, who conceived it with Roger Avary. Starring John Travolta, Samuel L. Jackson, Bruce Willis, Tim Roth, Ving Rhames, and Uma Thurman, it tells several stories of criminal Los Angeles. The title refers to the pulp magazines and hardboiled crime novels popular during the mid-20th century, known for their graphic violence and punchy dialogue.

Graph Networks on MetaQA

Hits @1 Performance

Graph Networks on MetaQA

Hits @1 Performance

■ Using KB

■ Using Text

100

75

50

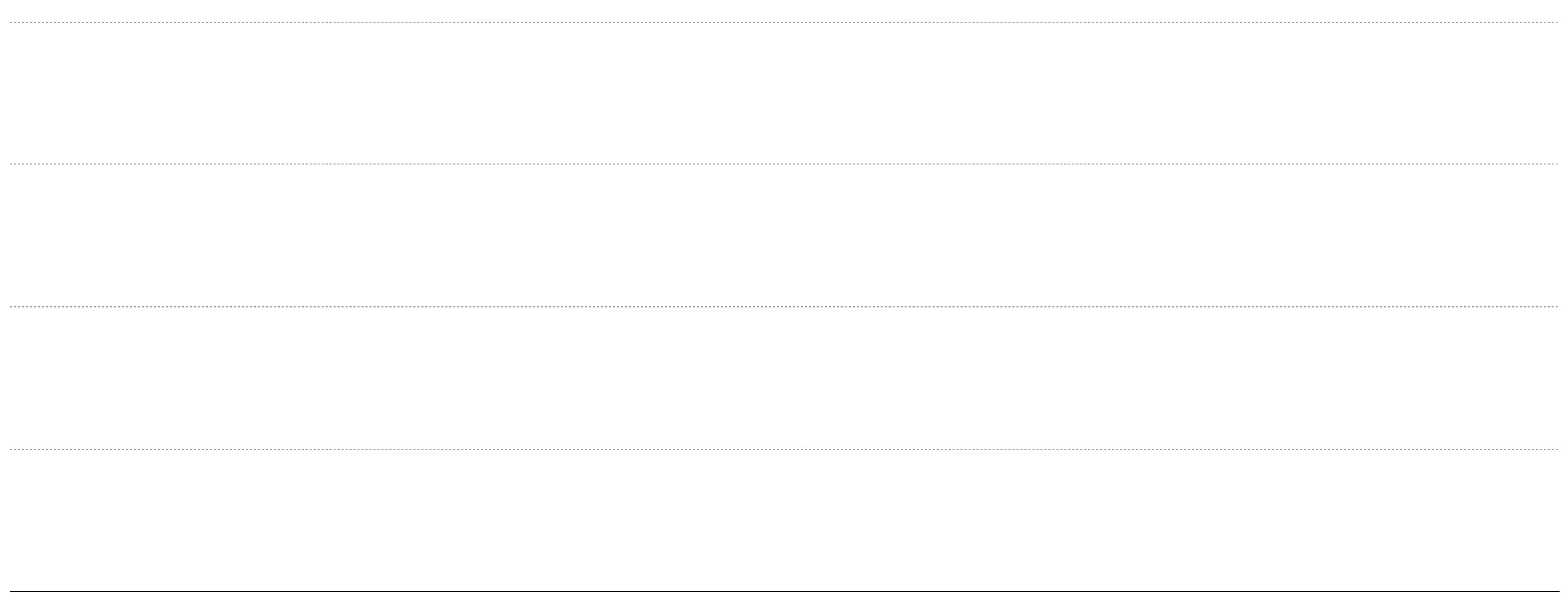
25

0

1-hop

2-hop

3-hop

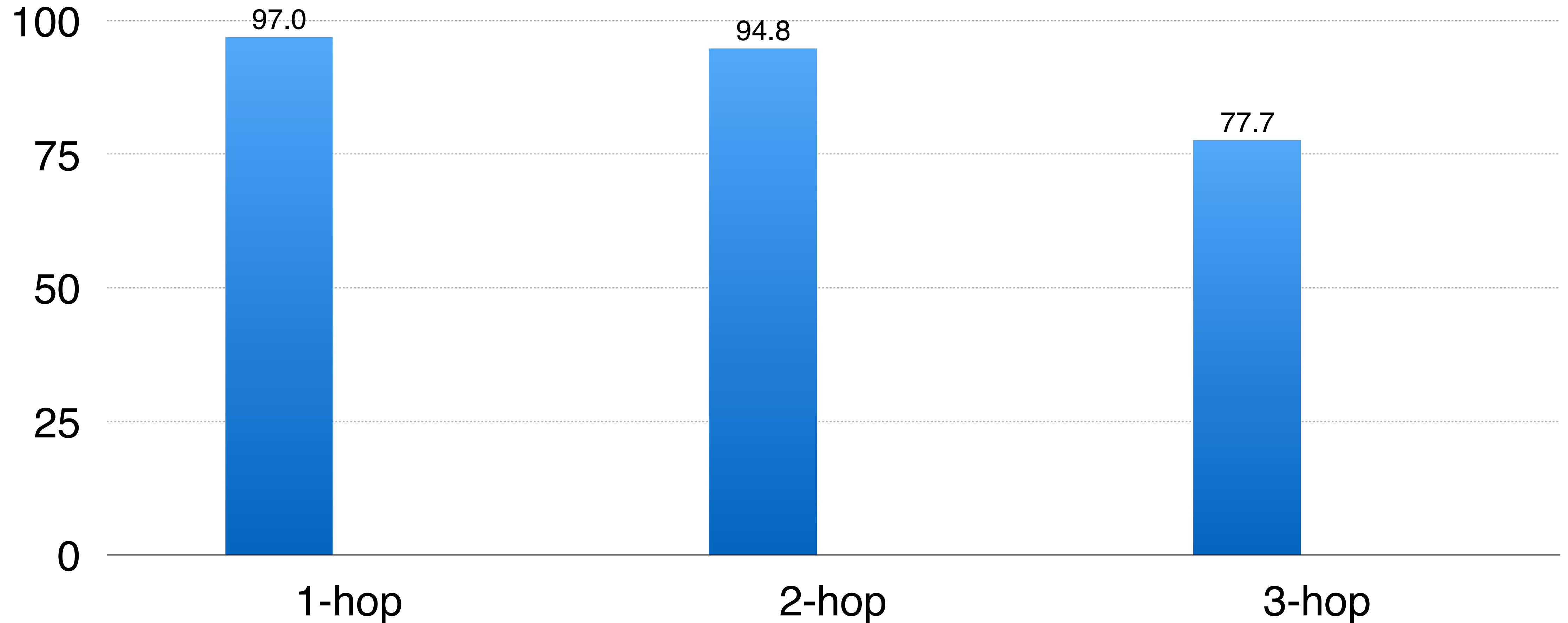


Graph Networks on MetaQA

Hits @1 Performance

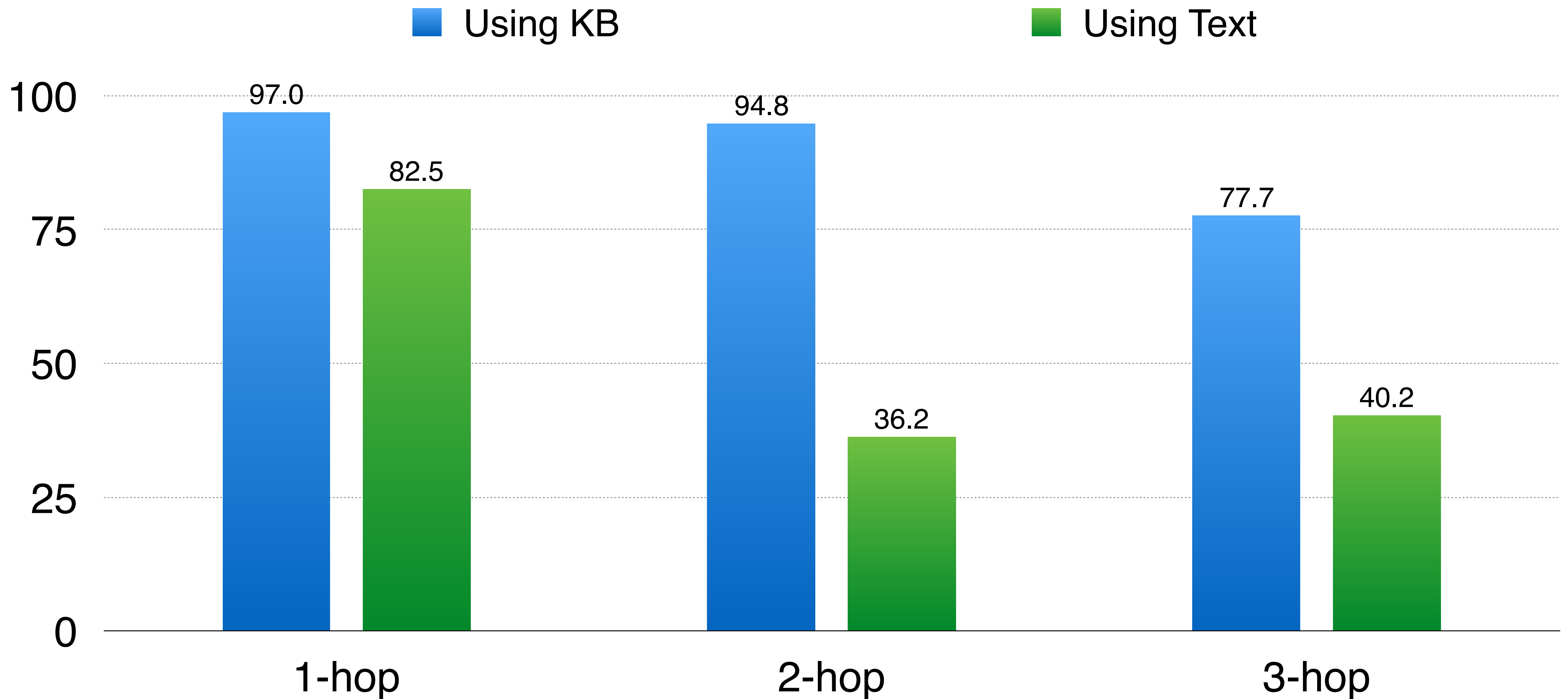
Using KB

Using Text



Graph Networks on MetaQA

Hits @1 Performance



Problem: Retrieval

Q. Which TV Networks has *Mila Kunis* appeared on?

Since 1999, she has voiced Meg Griffin on the animated series *Family Guy*.

Family Guy is an American animated sitcom created by Seth MacFarlane for the *Fox* Broadcasting Company.

A. *Fox*

Information can be spread out across the corpus

The image shows a collage of Wikipedia article snippets. The top-left snippet is for Mila Kunis, mentioning her role as Meg Griffin on Family Guy. The top-middle snippet is for Fox Broadcasting Company, with a note that 'FOX' and 'Fox (TV channel)' redirect here. The middle-left snippet is for Family Guy, stating it is an animated sitcom created by Seth MacFarlane for the Fox Broadcasting Company. The middle-right snippet is for Fox, identifying it as a terrestrial television network. The bottom-left snippet is for That '70s Show, mentioning it is an American television period sitcom that originally aired on Fox from August 23, 1998 to May 18, 2006. The bottom-right snippet is for That '70s Show, listing its genre as 'Period sitcom', created by Bonnie Turner, Terry Turner, and Mark Brazil, and directed by David Trainer and Terry Hughes (pilot).

Problem: Retrieval

The collage consists of four overlapping Wikipedia snippets. The top-left snippet is for Mila Kunis, mentioning her role as Meg Griffin on Family Guy. The top-right snippet is for Fox Broadcasting Company, mentioning Family Guy. The middle-left snippet is for Family Guy, mentioning it is created by Seth MacFarlane for Fox. The bottom-left snippet is for That '70s Show, mentioning Mila Kunis as a cast member. Arrows from the snippets point towards the answer box on the right.

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A. Fox **Information can be spread out across the corpus**

- Shallow information retrieval does not work
- Can expand retrieval using e.g. pseudo-relevance-feedback
 - But “reading” large number of documents is expensive

Our Approach: Read offline, Reason online

Our Approach: Read offline, Reason online

Reading

Pre-train contextual
representations into an index

ELMo [Peters, 2018], BERT
[Devlin, 2018], Phrase-Indexed
QA [Seo, 2018]

Offline and slow

Our Approach: Read offline, Reason online

Reading

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Offline and slow

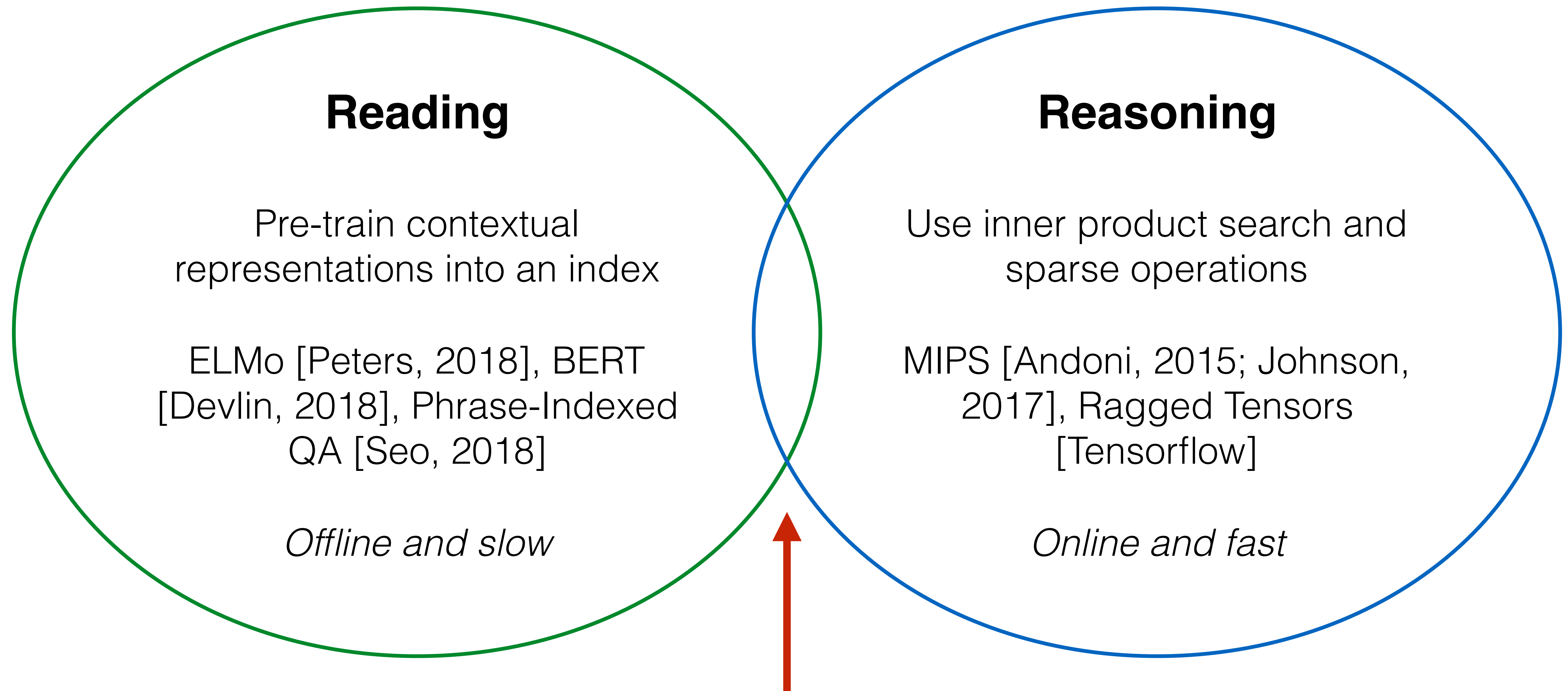
Reasoning

Use inner product search and sparse operations

MIPS [Andoni, 2015; Johnson, 2017], Ragged Tensors [Tensorflow]

Online and fast

Our Approach: Read offline, Reason online



Differentiable Reasoning over a KB of Indexed Text

Reading: Offline Index of Entity Mentions

The image shows four overlapping Wikipedia article snippets. The top-left snippet is for **Mila Kunis**, an American actress. The top-right snippet is for **Fox Broadcasting Company**, a television network. The middle-left snippet is for **Family Guy**, an animated sitcom. The bottom snippet is for **That '70s Show**, a television period sitcom. Each snippet includes a title, a brief description, and a small image related to the article.

Mila Kunis
From Wikipedia, the free encyclopedia

Milena Markovna "Mila" Kunis (/ˈmiːlə kuːnɪs/; Ukrainian: Мілена Маркієвна Куніс; born August 14, 1983) is an American actress. In 1991, at the age of seven, she moved from Soviet Ukraine to the United States with her family. After being enrolled in acting classes as an after-school activity, she was soon discovered by an agent. She appeared in several television series and commercials, before landing her first significant role at age 14, playing Jackie Burkhardt on the television series *That '70s Show* (1998–2006). Since 1999, she has voiced Meg Griffin on the animated series *Family Guy*.

Kunis's breakout film role came in 2008,^{[1][2]} playing Rachel in the romantic comedy *Forgetting Sarah Marshall*. She gained further critical acclaim and accolades for her performance in the psychological thriller *Black Swan* (2010), for which she received the *Marcello Mastroianni Award* for Best Young Actor or Actress, and nominations for the SAG Award and the Golden Globe Award. She also starred in *Book of Eli* (2010), *The Wicked Witch of the West* (2010), and *The Way, Way Back* (2013).

Fox Broadcasting Company
From Wikipedia, the free encyclopedia

"FOX" and "Fox (TV channel)" redirect here. For "Fox" television channels outside the United States, see Fox (channel). For the film studio that the network was named after, see 20th Century Fox. For the 24-hour news channel, see Fox News. For other uses, see Fox (disambiguation). Not to be confused with Fox Film.

Family Guy
From Wikipedia, the free encyclopedia

Family Guy is an American animated sitcom created by Seth MacFarlane for the Fox Broadcasting Company. The series centers on the Griffins, a family consisting of parents Peter and Lois; their children, Meg, Chris, and Stewie; and their anthropomorphic pet dog, Brian. The show is set in the fictional city of Quahog, Rhode Island, and exhibits much of its humor in the form of metafictional cutaway gags that often lampoon American culture.

The family was conceived by MacFarlane after developing two animated films, *The Life of Larry and Larry & Steve*. MacFarlane redesigned the films' protagonist, Larry, and his dog, Steve, and renamed them Peter and Brian, respectively. MacFarlane pitched a seven-minute pilot to Fox in 1998, and the show was greenlit and began production. Shortly after the third season of *Family Guy* had aired in 2002, Fox canceled the series' original run. In 2005, Fox convinced the original creators to return to the network. Since its debut season began in 2005, it has been nominated for several awards, including the Peabody Award in 2009, and it was ranked as the most popular animated series in 2009.

That '70s Show
From Wikipedia, the free encyclopedia

That '70s Show is an American television period sitcom that originally aired on Fox from August 23, 1998 to May 18, 2006. The series focuses on the lives of a group of six teenage friends living in fictional Point Place, Wisconsin, from May 17, 1976 to December 31, 1979.^[1] The main teenage cast members were Topher Grace, Mila Kunis, Ashton Kutcher, Danny Masterson, Laura Prepon and Wilmer Valderrama. The main adult cast members were Debra Jo Rupp, Kurtwood Smith, Don Stark, Tommy Chong and Tanya Roberts.

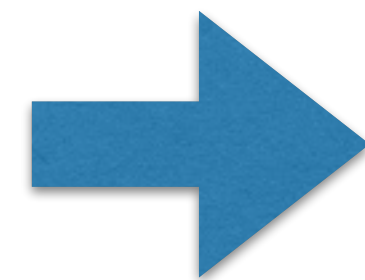
Contents [hide]

- Cast
 - Teens
 - Adults
- Episodes
 - Timeline
 - Eighth season and series finale
- Production
 - Title
 - Development

Genre Period sitcom
Created by Bonnie Turner
Terry Turner
Mark Brazill
Directed by David Trainer
Terry Hughes (pilot)

Based on Phrase-Indexed QA (Seo et al, EMNLP'18, ACL'19)

Reading: Offline Index of Entity Mentions



Entity
Linking

Entity Mentions

... **Family Guy** is an American ...

... their children, **Meg**, Chris, Stewie ...

... In 1999, **Kunis** replaced Lacey Chabert ...

... created by **Seth MacFarlane** for Fox ...

... cast members were **Topher Grace**, Mile Kunis ...

... originally aired on Fox from **August 23** ...

... wanted the show to have a **1970s** feel ...

Based on Phrase-Indexed QA (Seo et al, EMNLP'18, ACL'19)

Reading: Offline Index of Entity Mentions

Contextual Representations

The image shows four overlapping Wikipedia article snippets. The top-left snippet is for Mila Kunis, an American actress. The top-right snippet is for Fox Broadcasting Company, a television network. The middle-left snippet is for Family Guy, an animated sitcom. The middle-right snippet is for That '70s Show, a television sitcom. A large blue arrow points from these snippets towards the right side of the slide.

Entity Mentions

... **Family Guy** is an American ...

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... In 1999, **Kunis** replaced Lacey Chabert ...

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... cast members were **Topher Grace**, Mile Kunis ...

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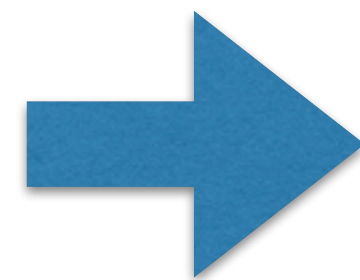
Entity
Linking

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Contextual Representations

The image shows four overlapping Wikipedia article snippets. From top to bottom: Mila Kunis (American actress), Fox Broadcasting Company (TV network), Family Guy (animated sitcom), and That '70s Show (television series). Each snippet includes a title, a small image, and a brief description of the entity.



Entity Linking

Entity Mentions

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... In 1999, **Kunis** replaced Lacey Chabert ...

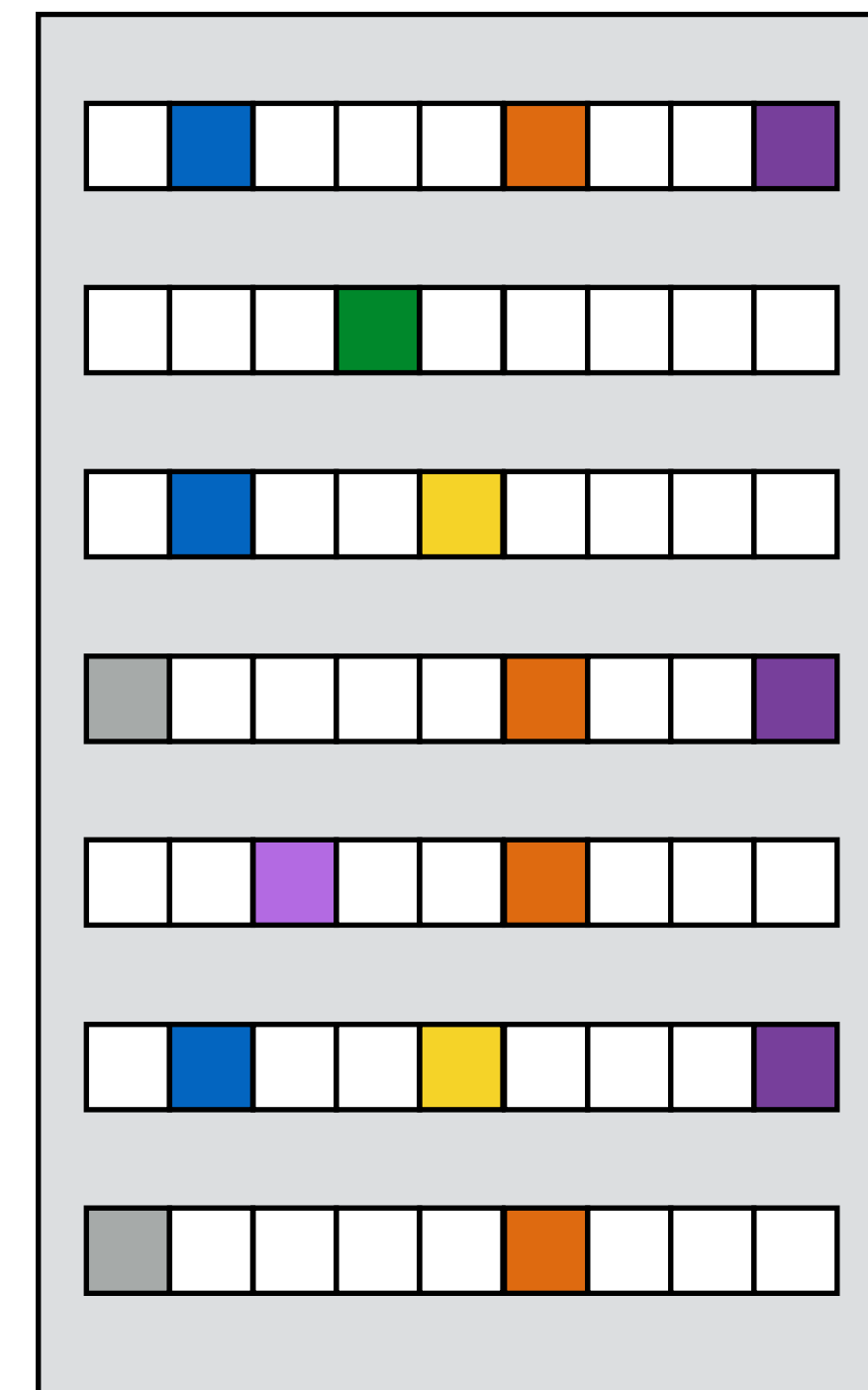
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... wanted the show to have a **1970s** feel ...

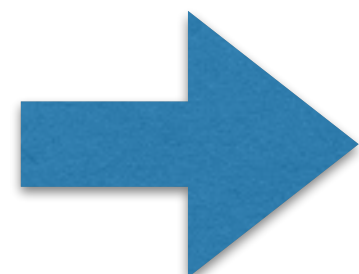
Sparse



(Fixed)

Based on Phrase-Indexed QA (Seo et al, EMNLP'18, ACL'19)

Reading: Offline Index of Entity Mentions



Entity Linking

Entity Mentions

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... created by **Seth MacFarlane** for Fox ...

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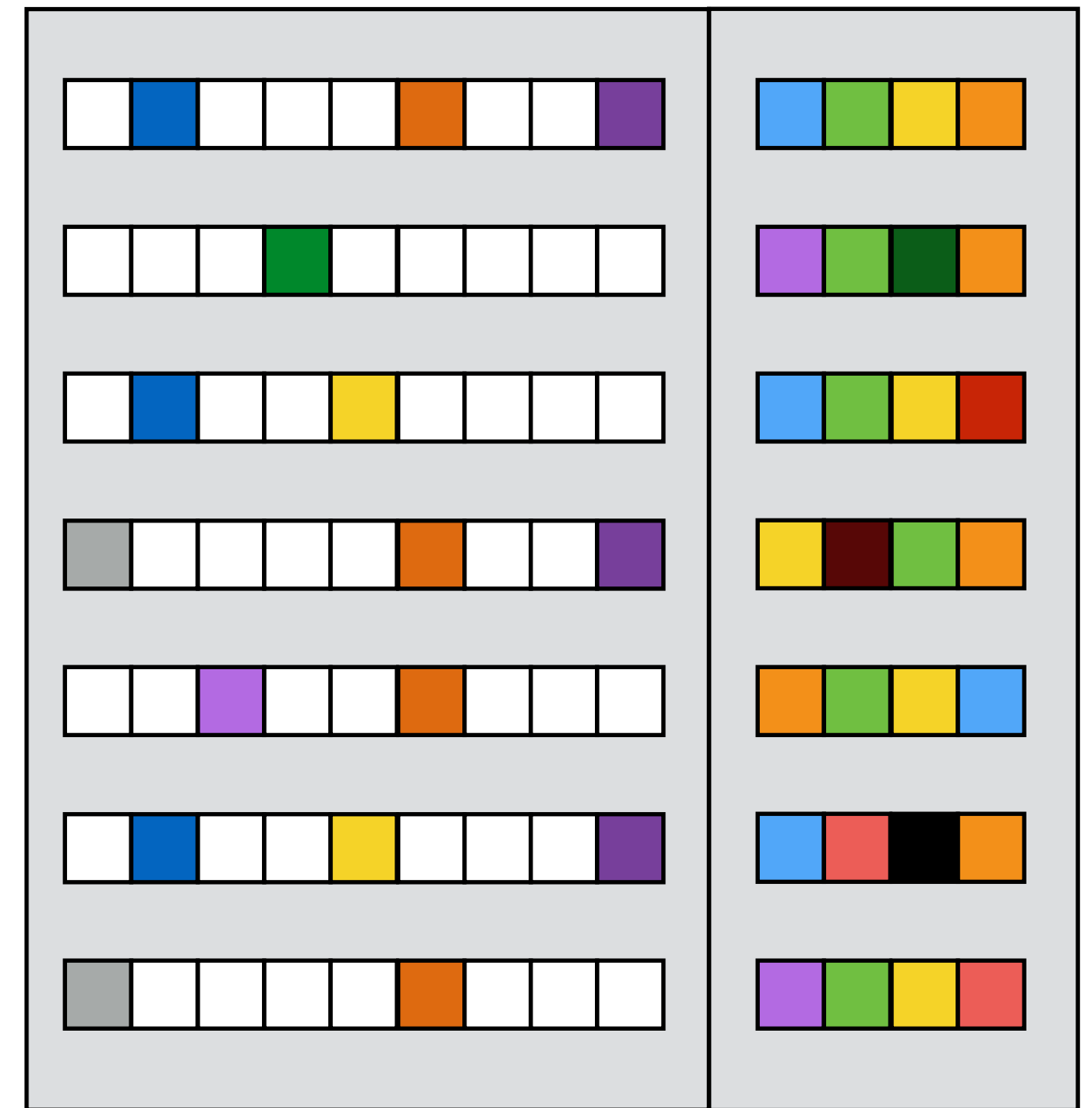
... originally aired on Fox from **August 23** ...

... wanted the show to have a **1970s** feel ...

Contextual Representations

Sparse

Dense

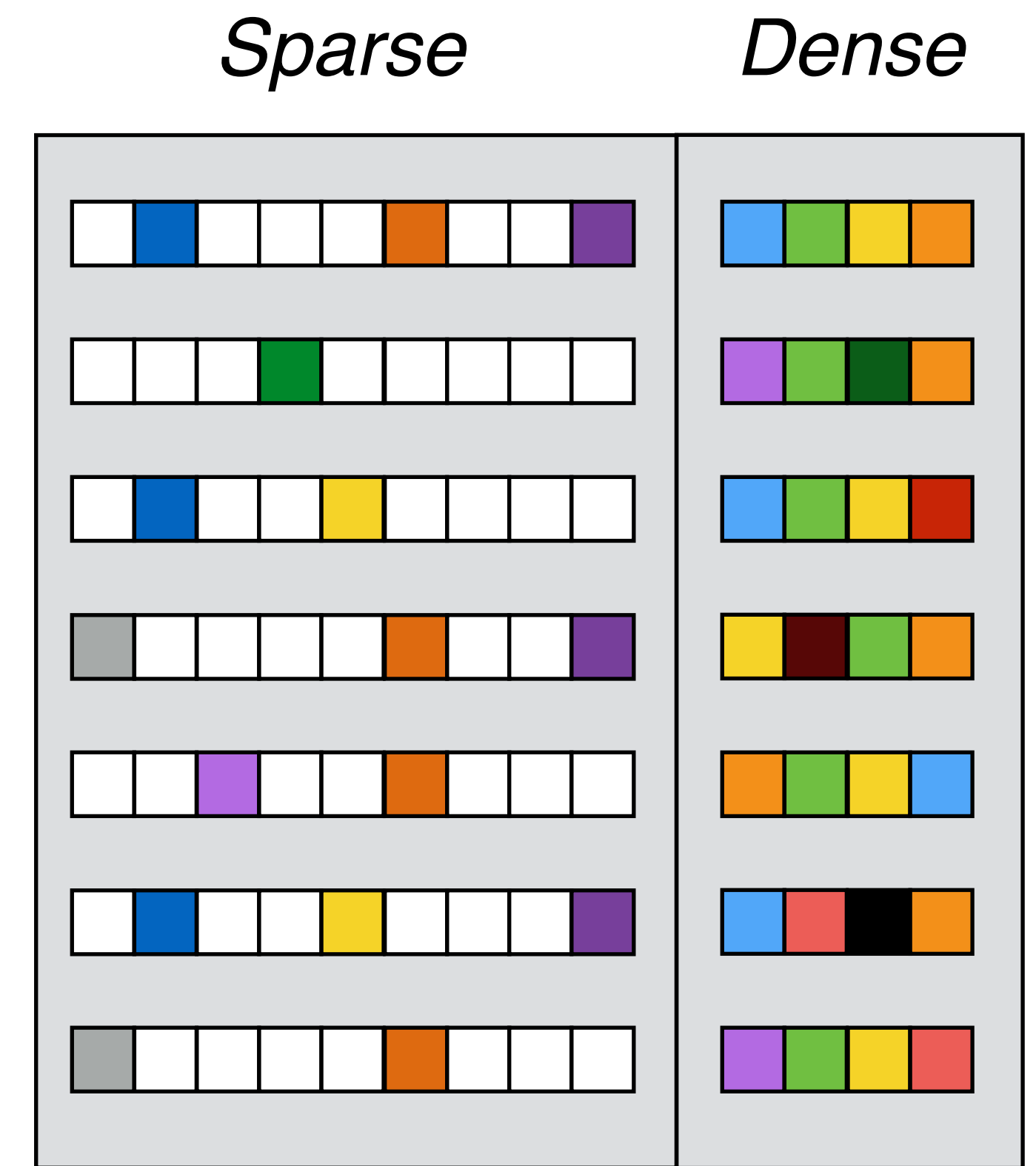


(Fixed)

(Pre-trained)

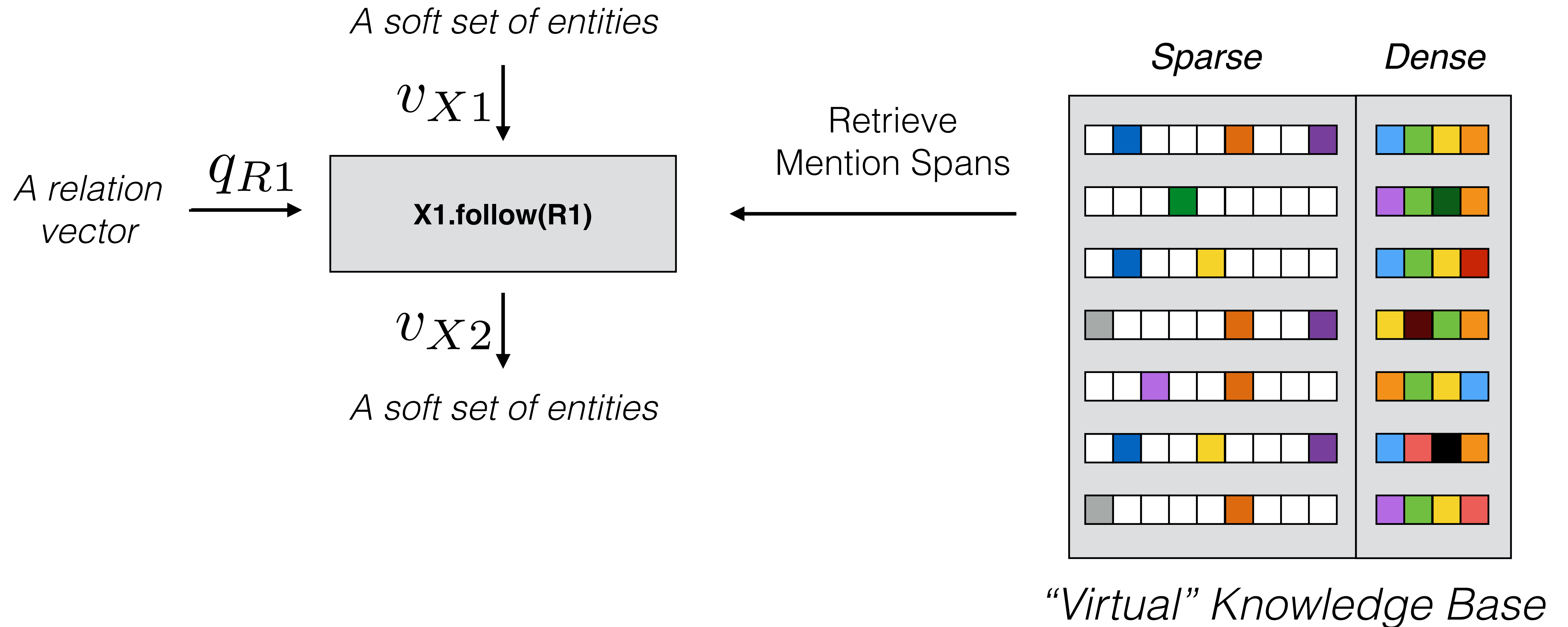
Based on Phrase-Indexed QA (Seo et al, EMNLP'18, ACL'19)

Reasoning: A “Soft” Textual Follow Op



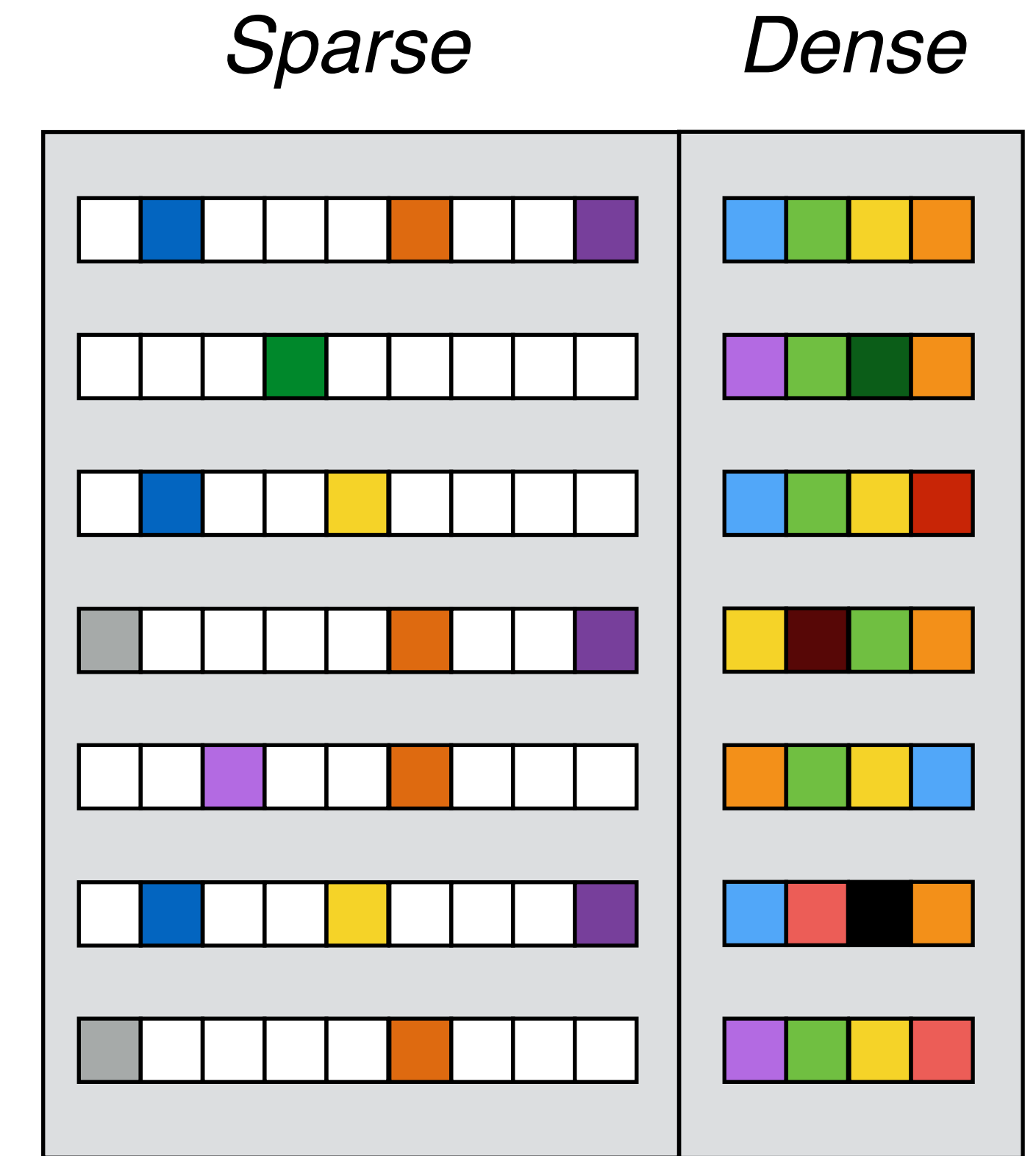
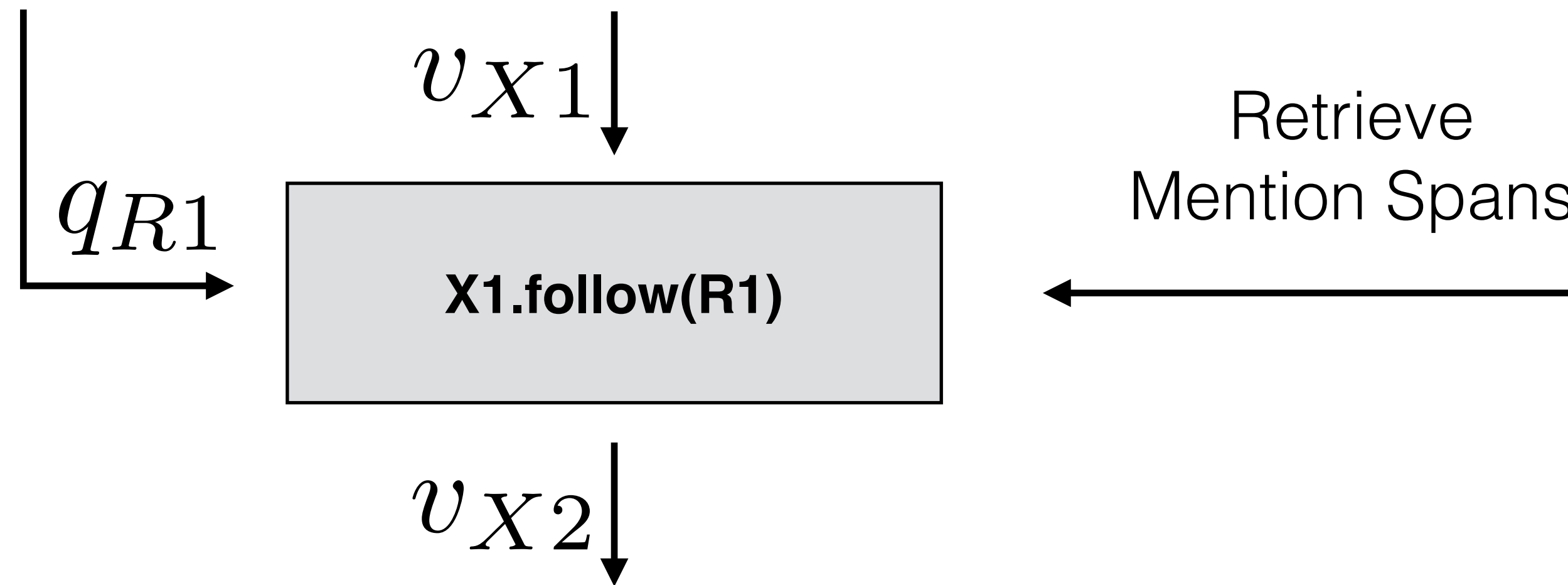
“Virtual” Knowledge Base

Reasoning: A “Soft” Textual Follow Op



Reasoning: A “Soft” Textual Follow Op

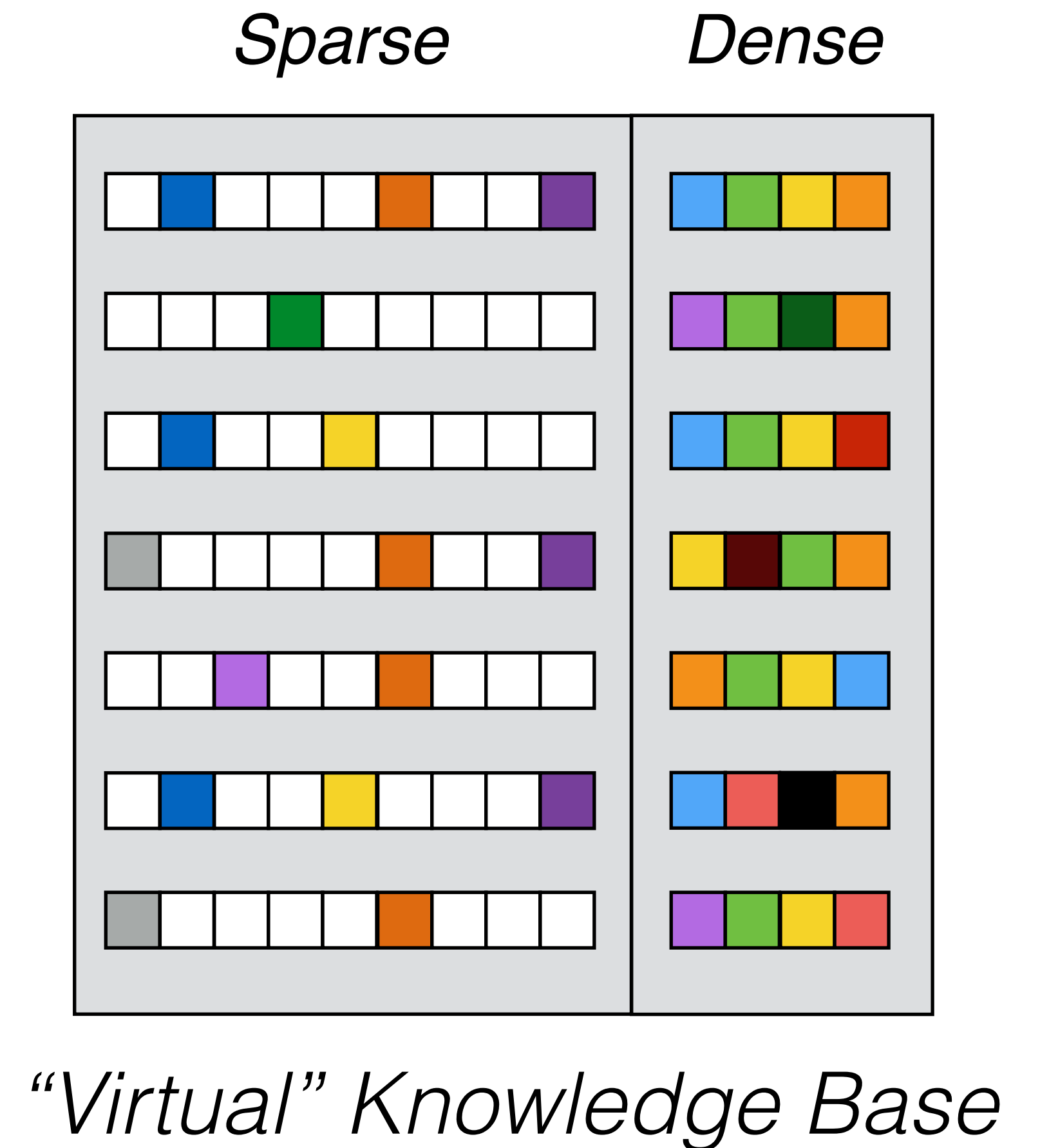
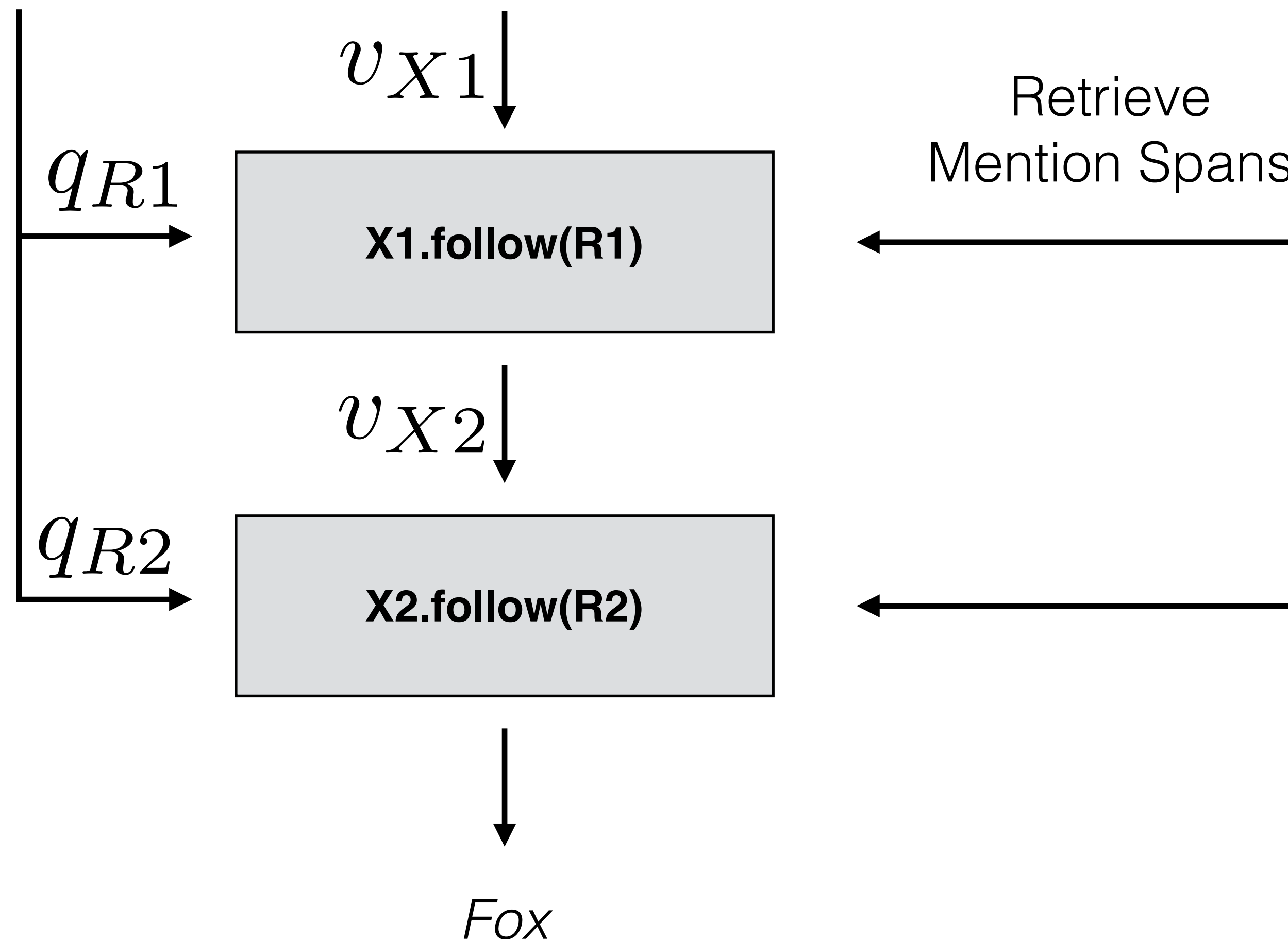
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“Virtual” Knowledge Base

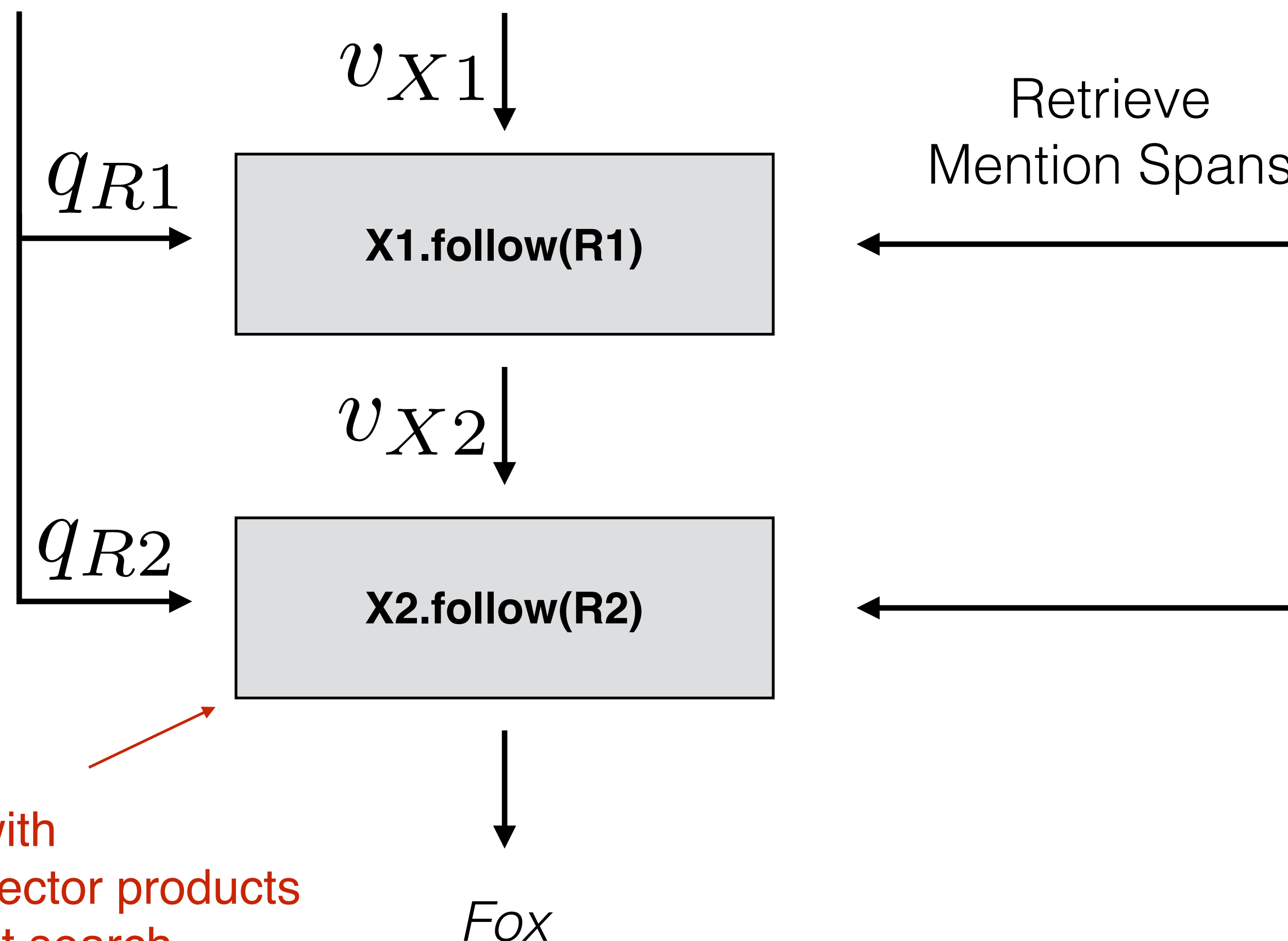
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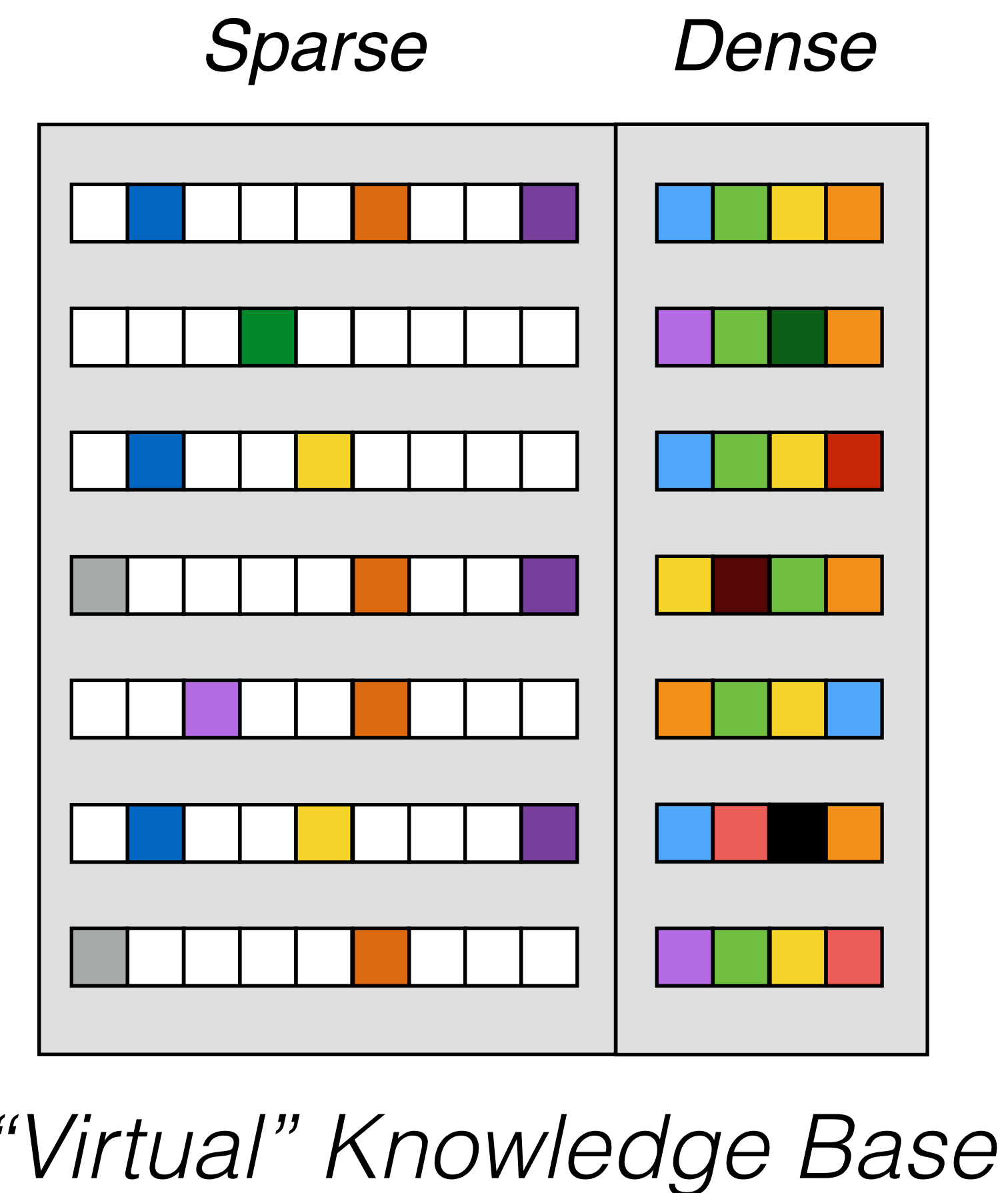


Reasoning: A “Soft” Textual Follow Op

Which TV Networks has *Mila Kunis* appeared on?



Key Idea:
We can do this with
sparse matrix - vector products
and inner product search

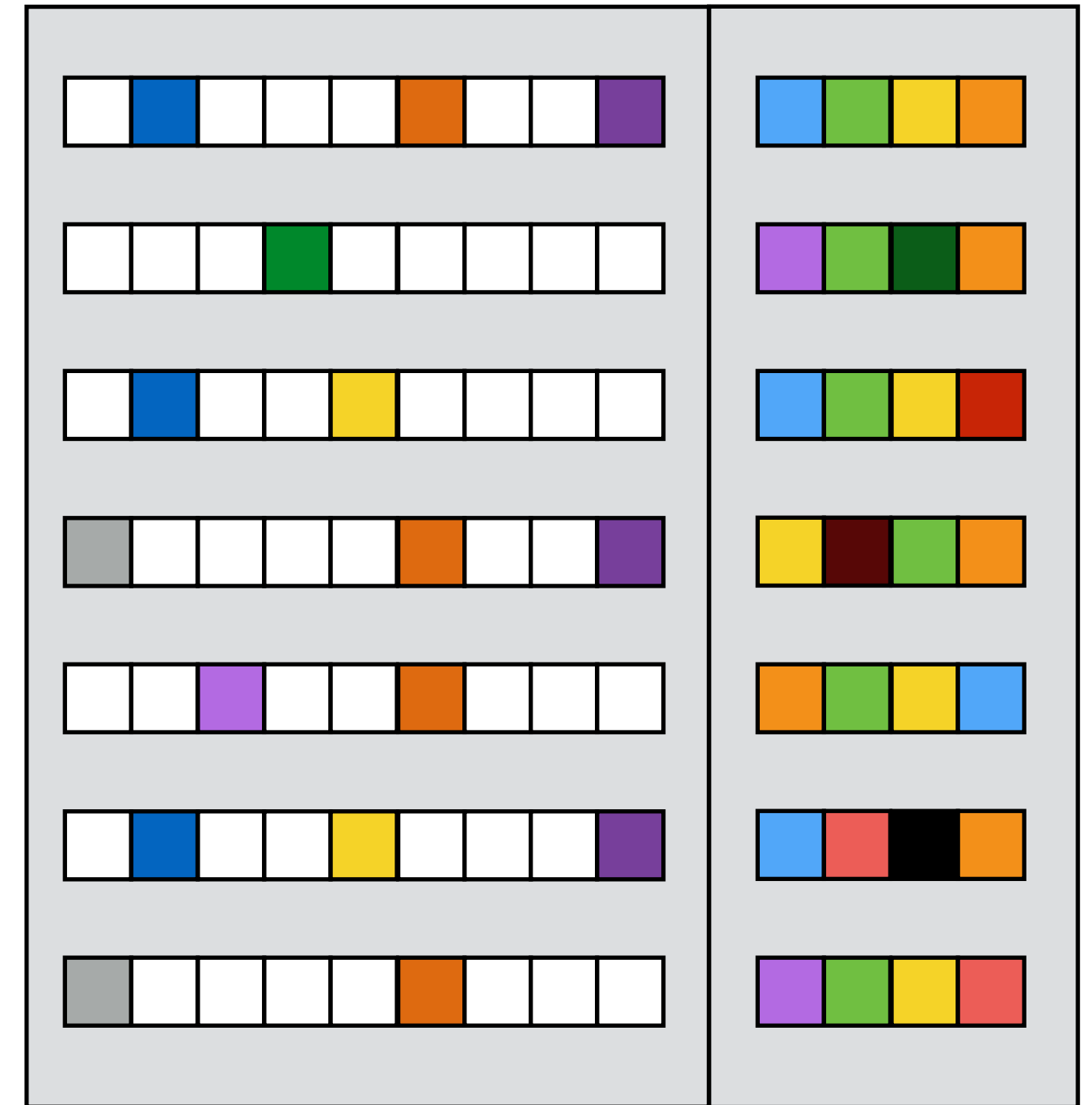


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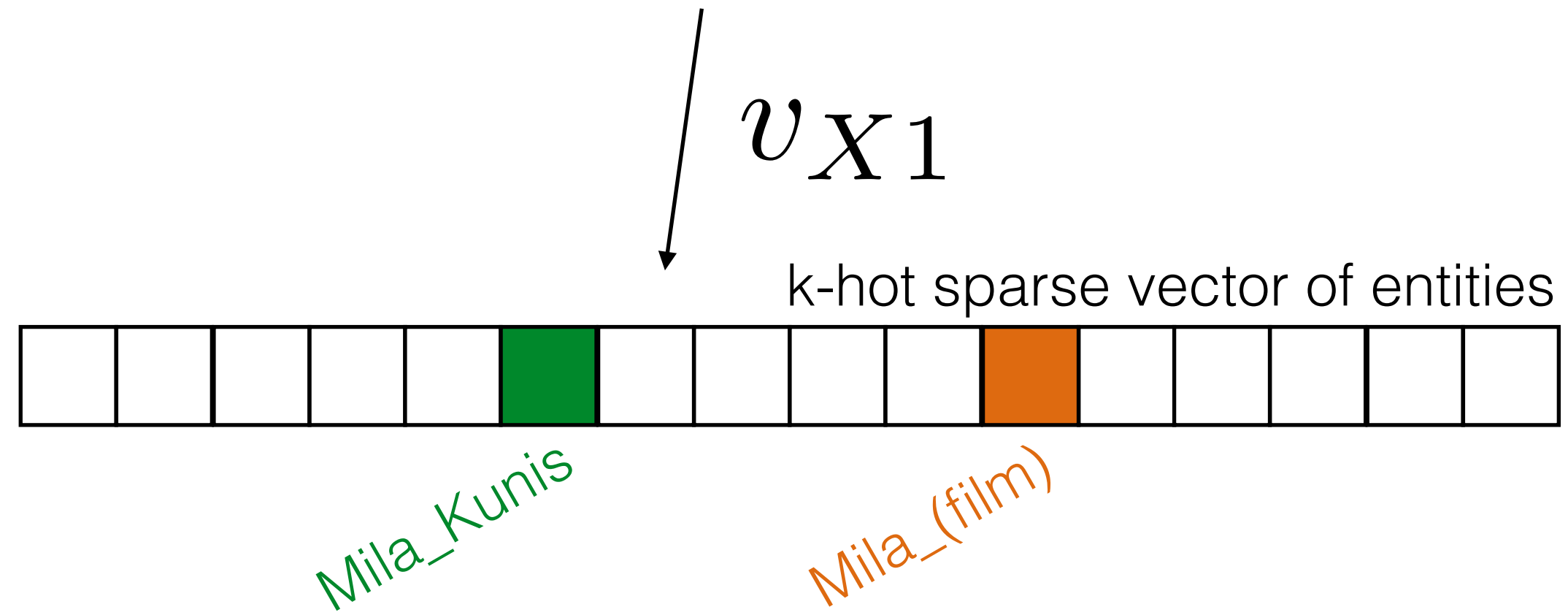
X1.follow(R1)

Sparse

Dense



Which TV Networks has *Mila Kunis* appeared on?



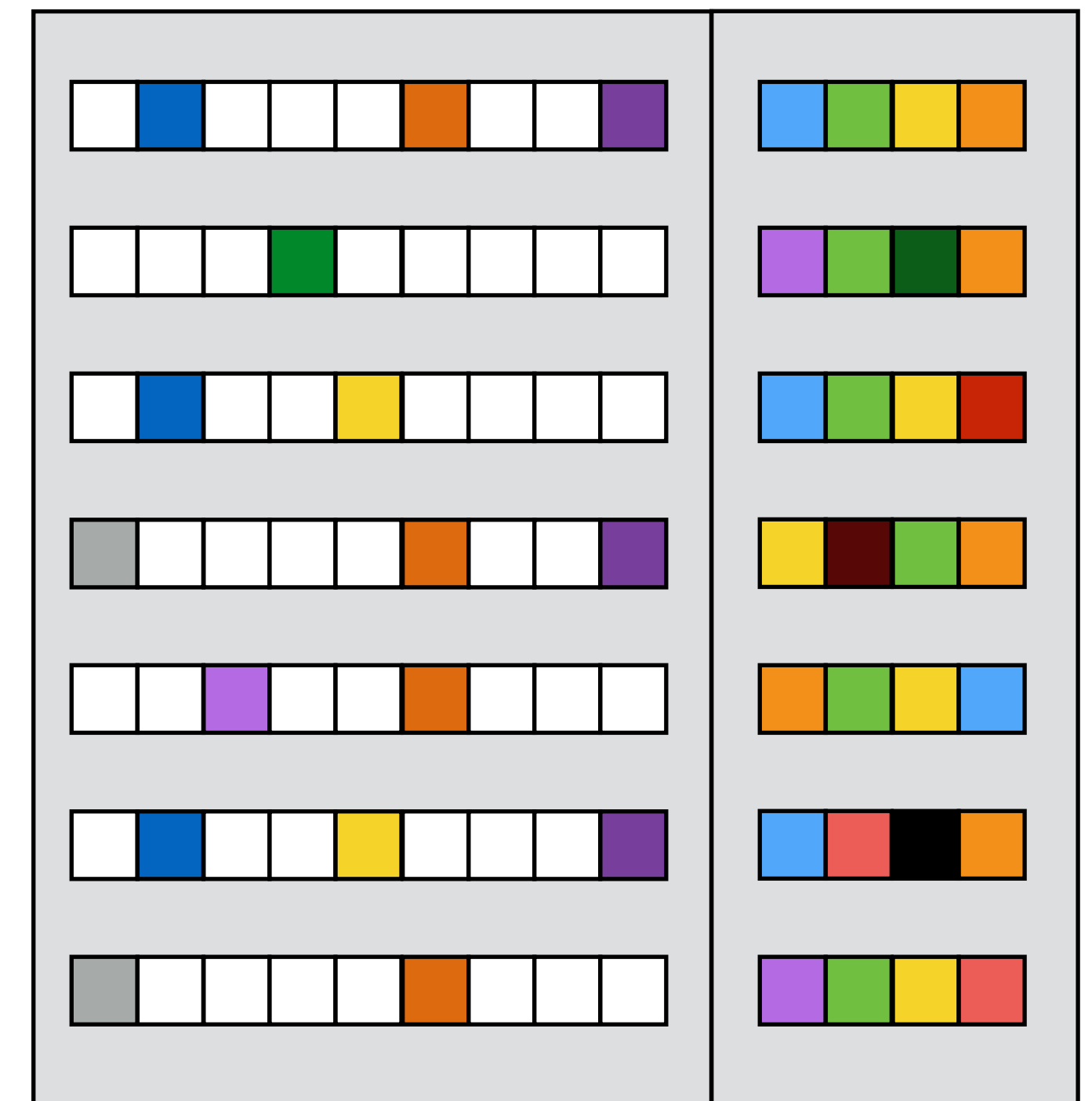
Entities are represented as a sparse vector

- Size = # entities in the corpus
- Non-zero values are confidence scores
- E.g. from an entity linking model

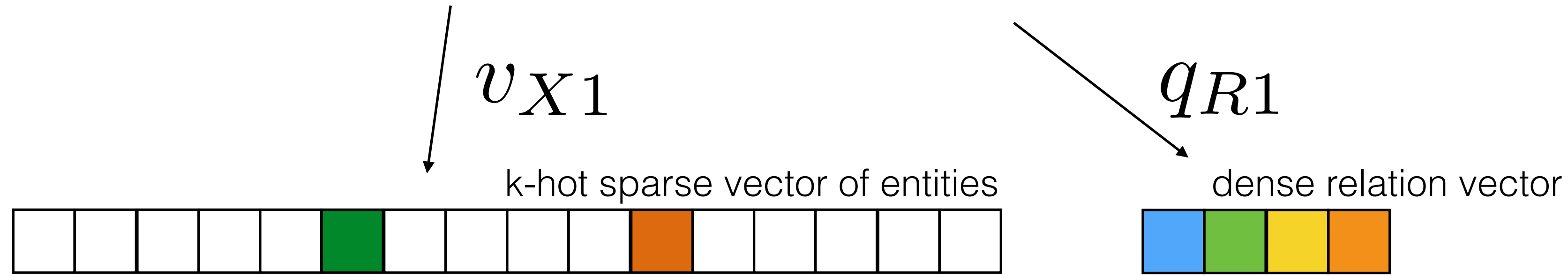
X1.follow(R1)

Sparse

Dense

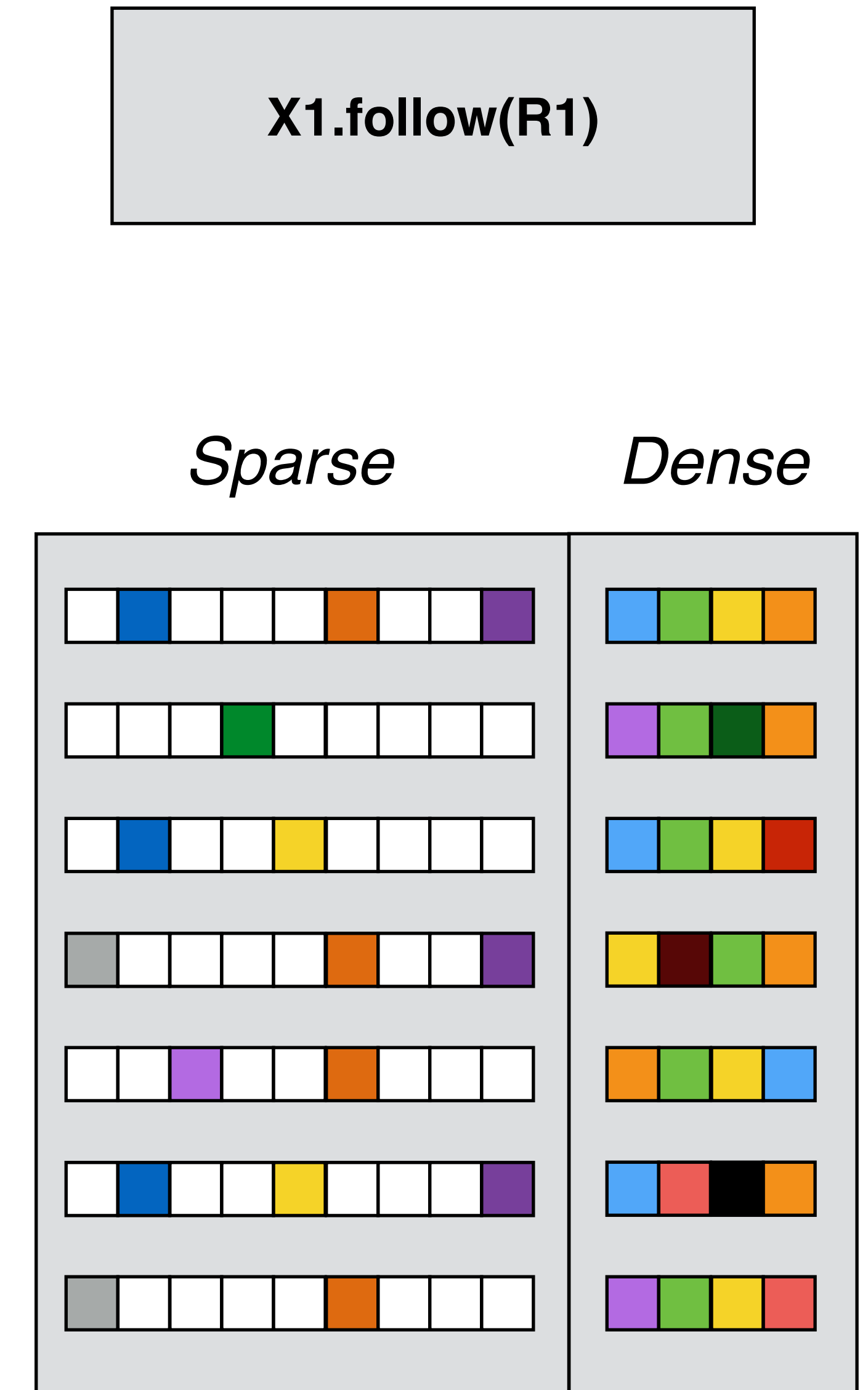


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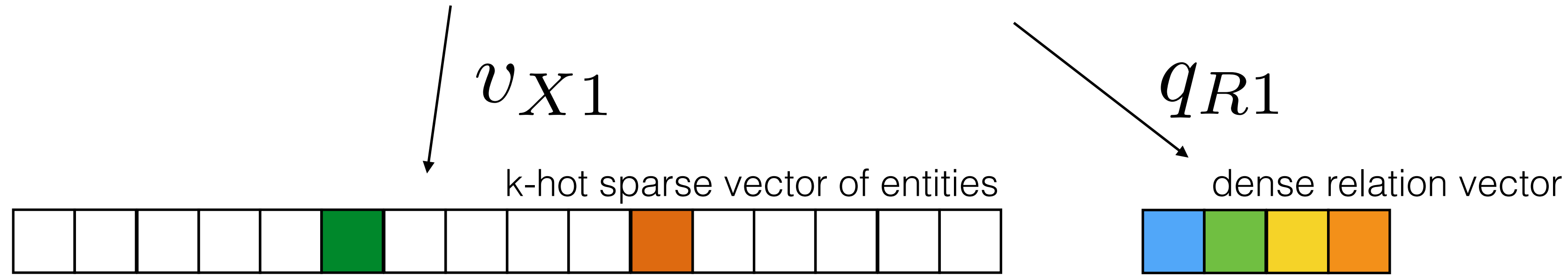


Relations are represented as a dense feature vector

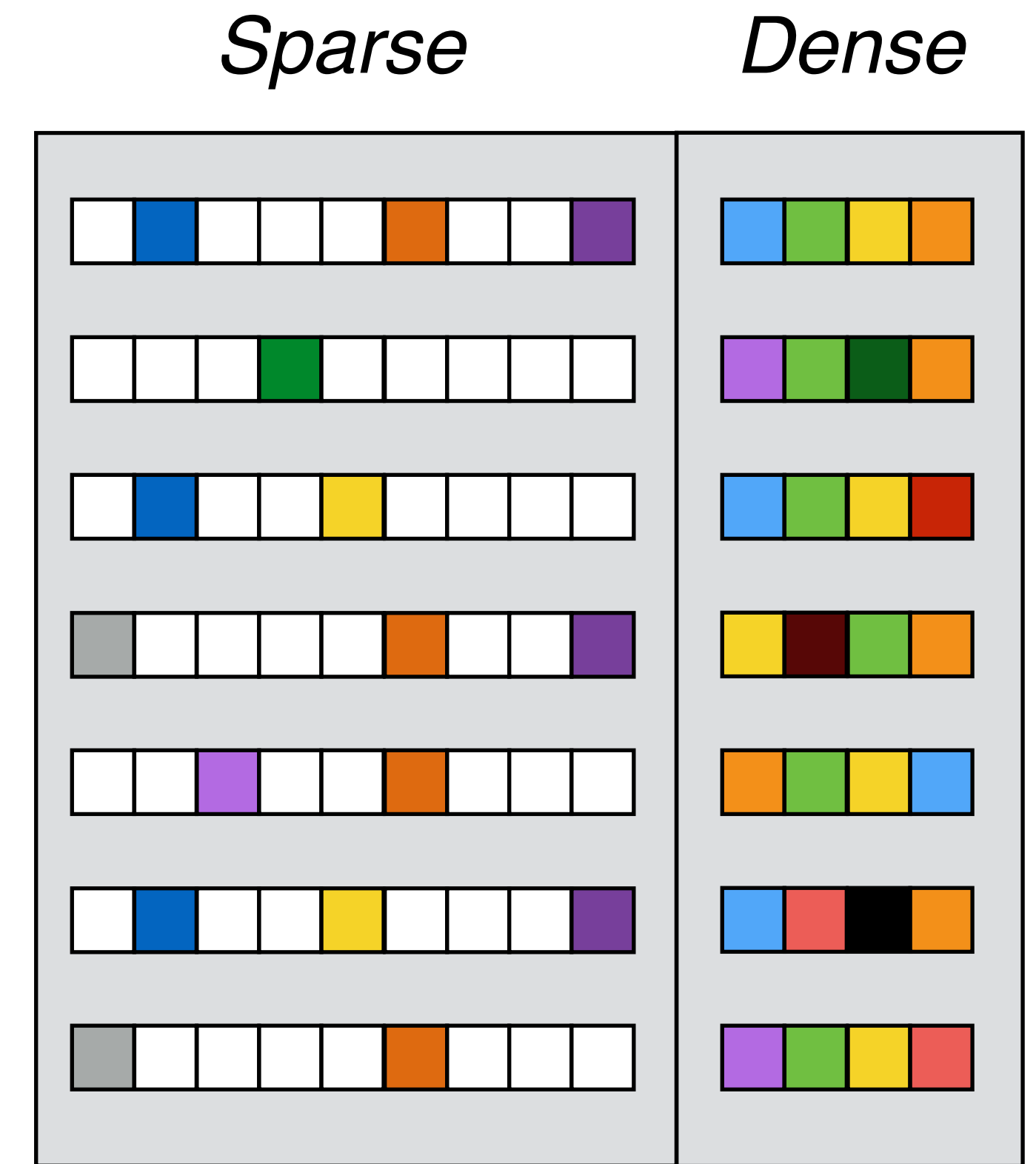
- We use a 5-layer Transformer Network over the question



Which TV Networks has *Mila Kunis* appeared on?



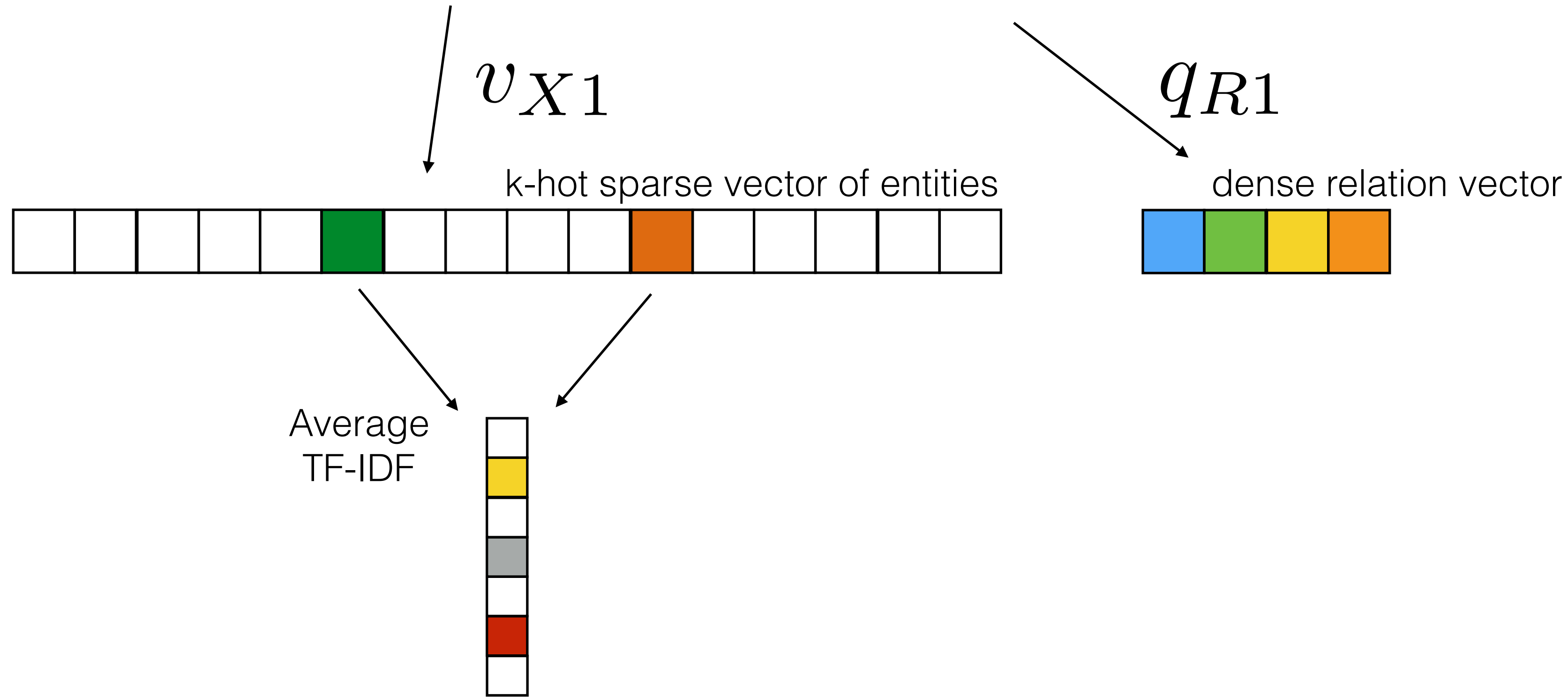
X1.follow(R1)



Mentions are retrieved in two steps:

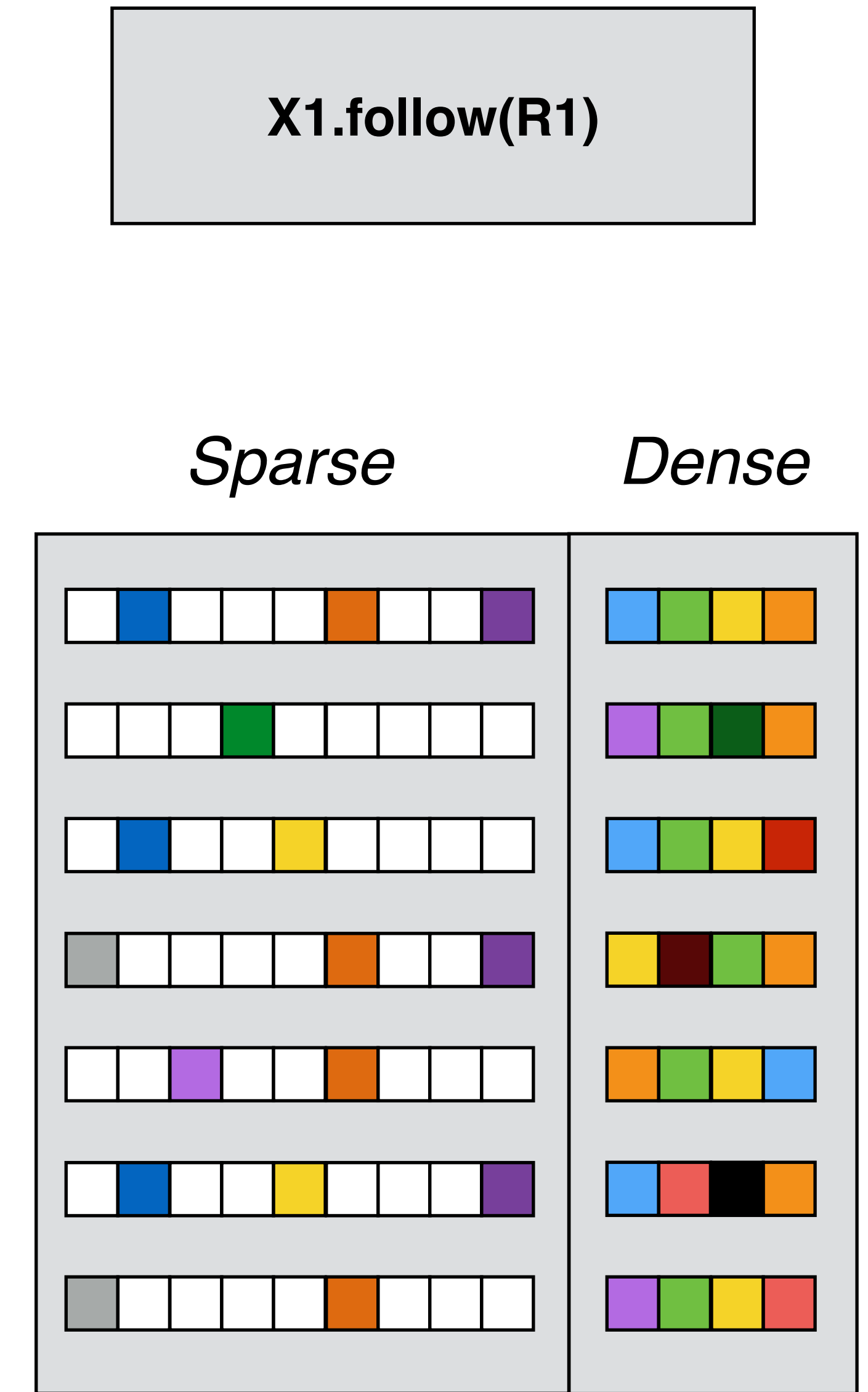
1. TF-IDF against the surface form of entities

Which TV Networks has *Mila Kunis* appeared on?

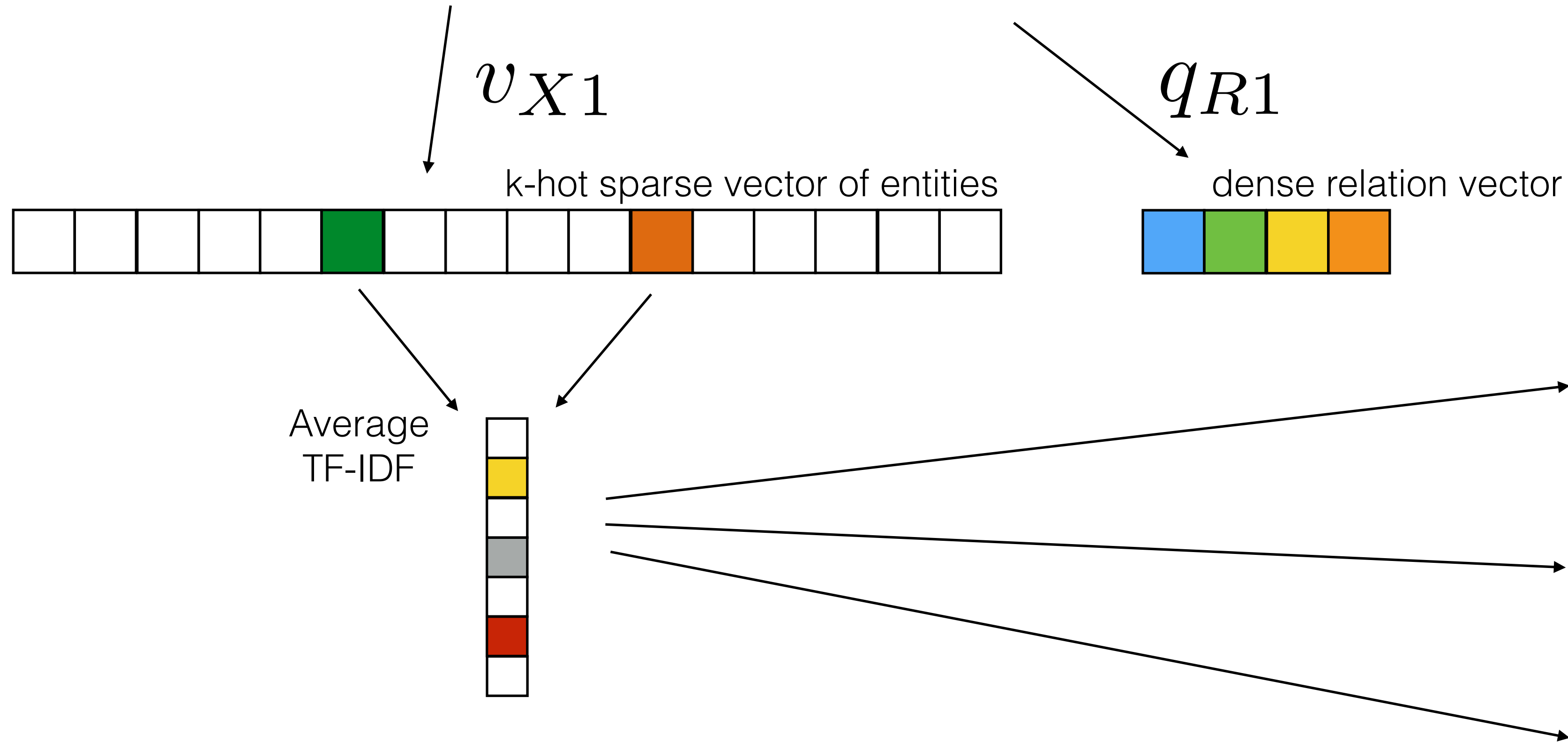


Mentions are retrieved in two steps:

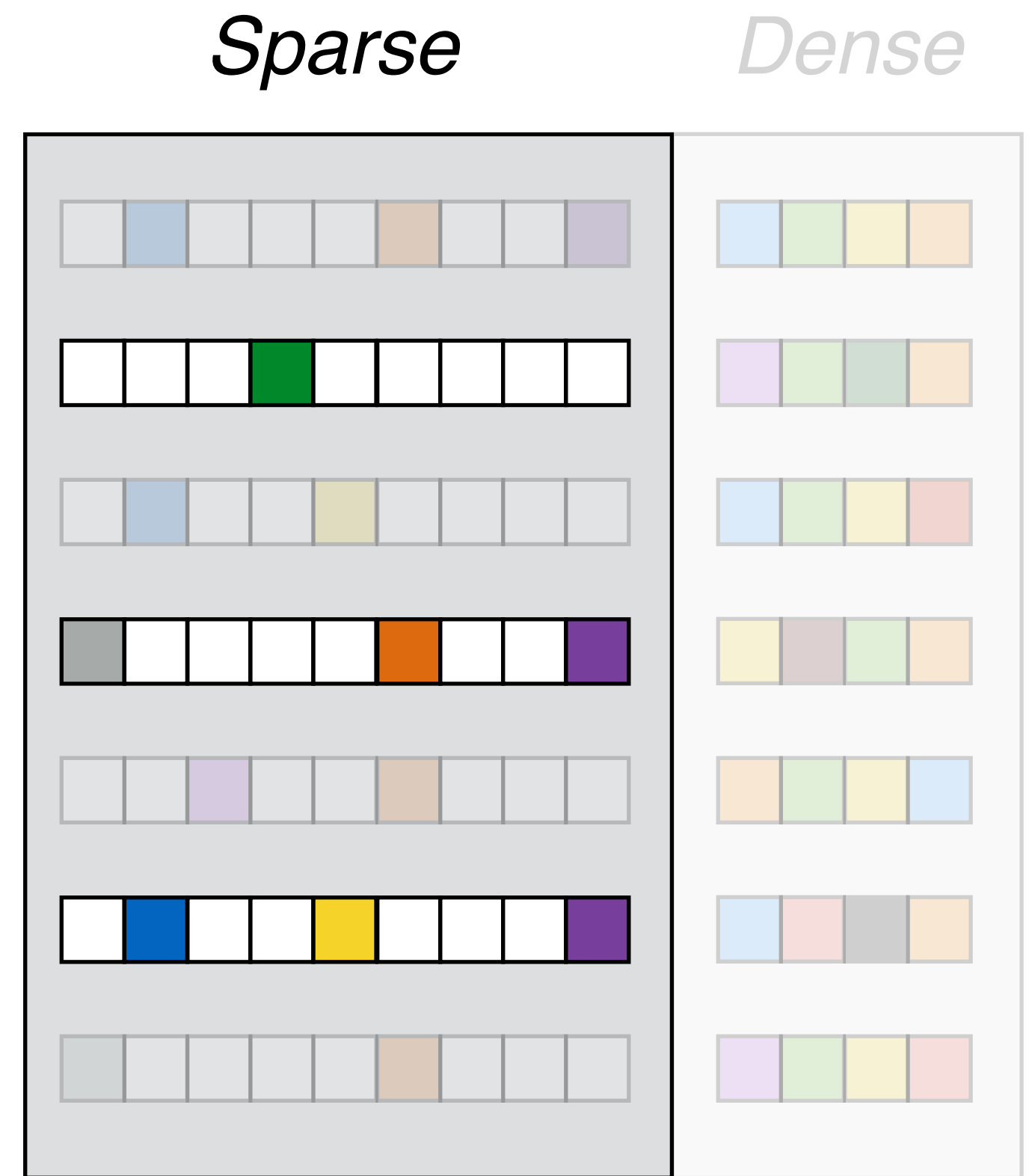
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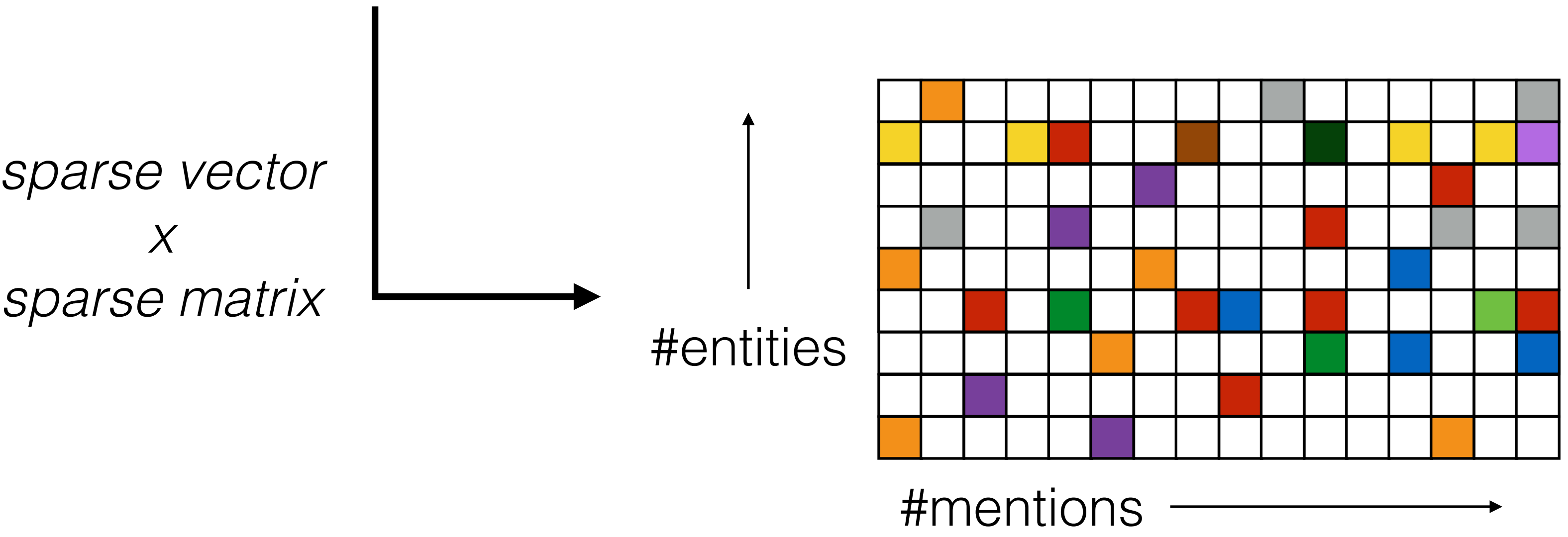
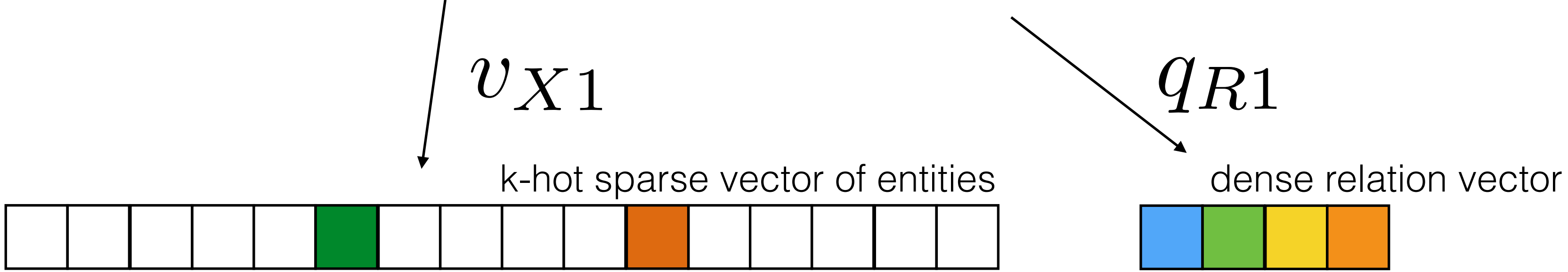


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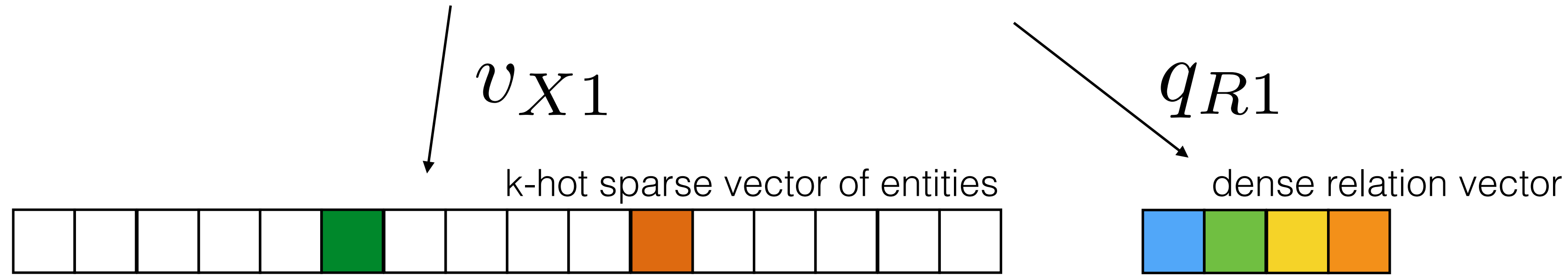
$A_{E \rightarrow M}$
 This can be pre-computed



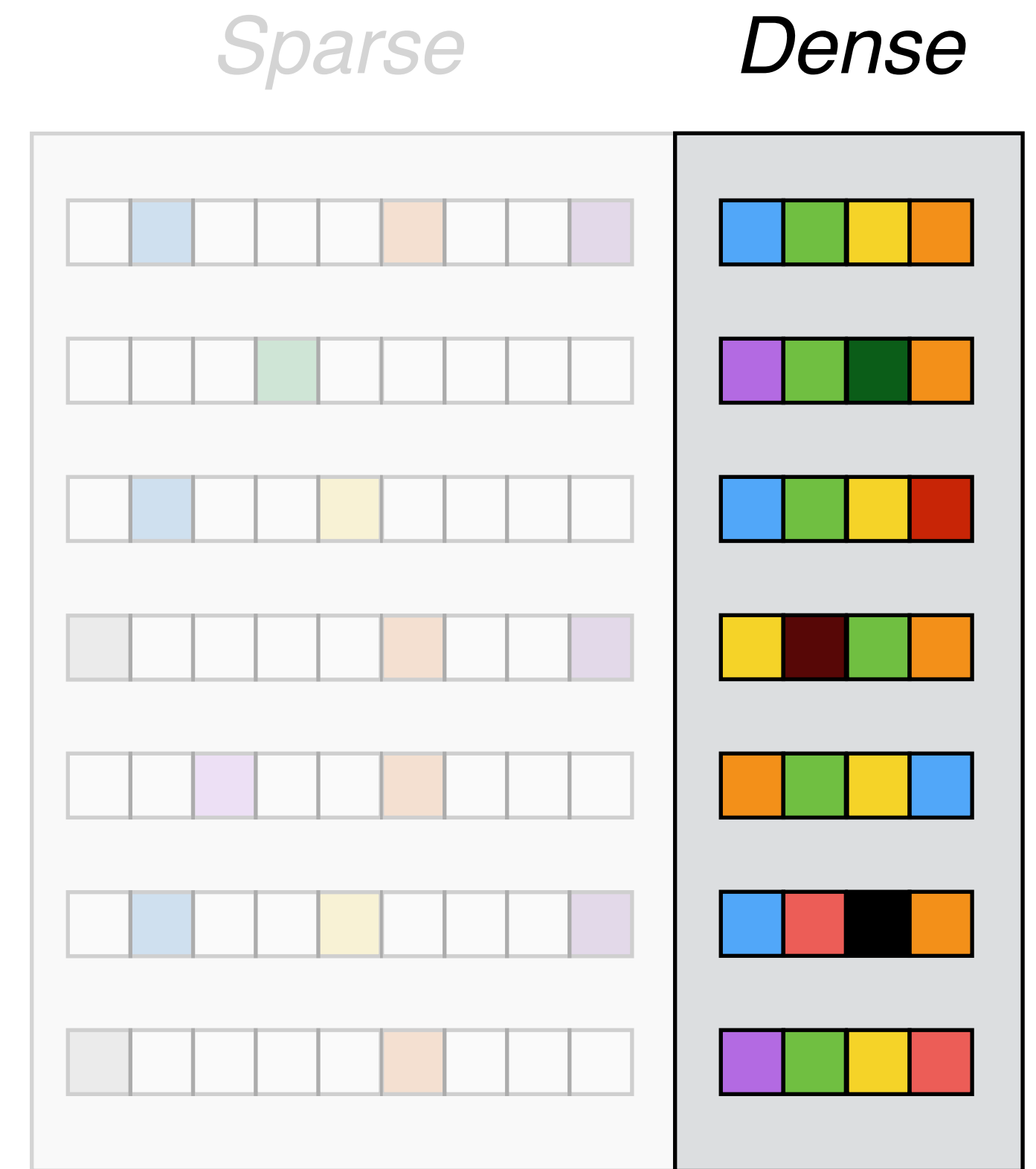
If max non-zero entries in each row is bounded (n) we can implement this efficiently using Ragged Tensors[1] — $O(k \max(k, n))$

[1] (https://www.tensorflow.org/guide/ragged_tensors)

Which TV Networks has *Mila Kunis* appeared on?



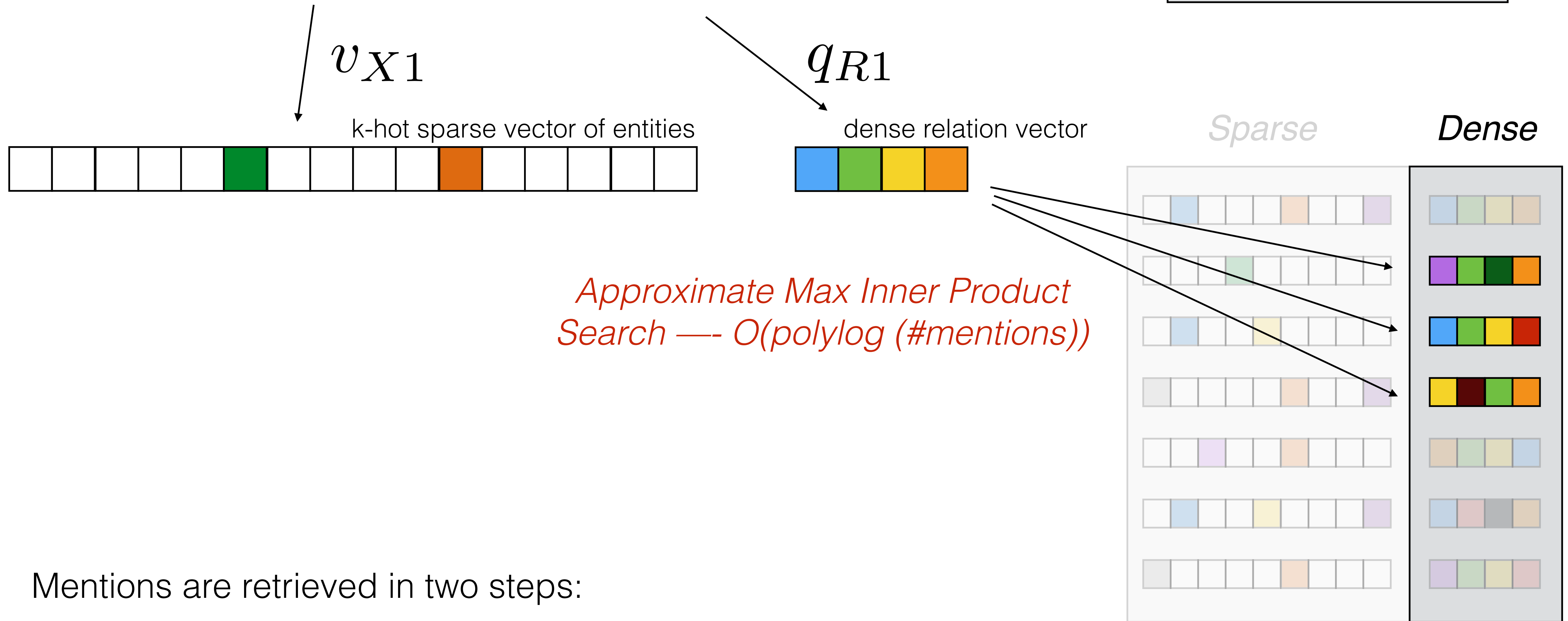
X1.follow(R1)



Mentions are retrieved in two steps:

1. TF-IDF against the surface form of entities
2. Dot product against relation vector

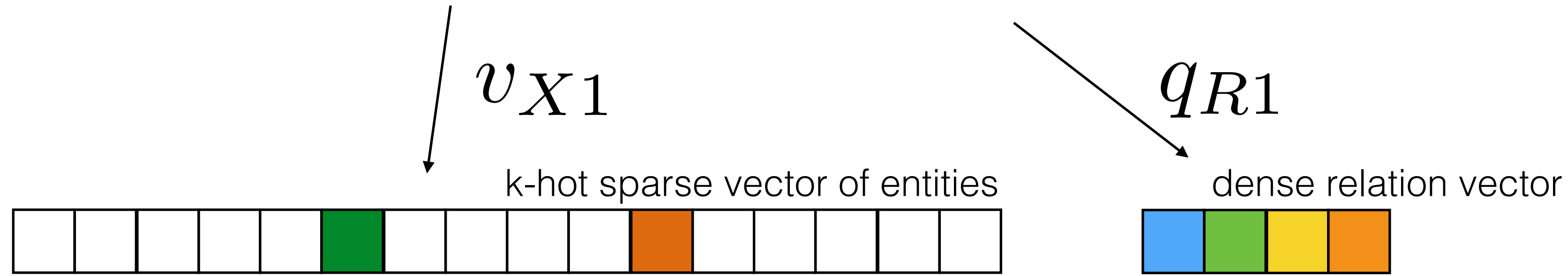
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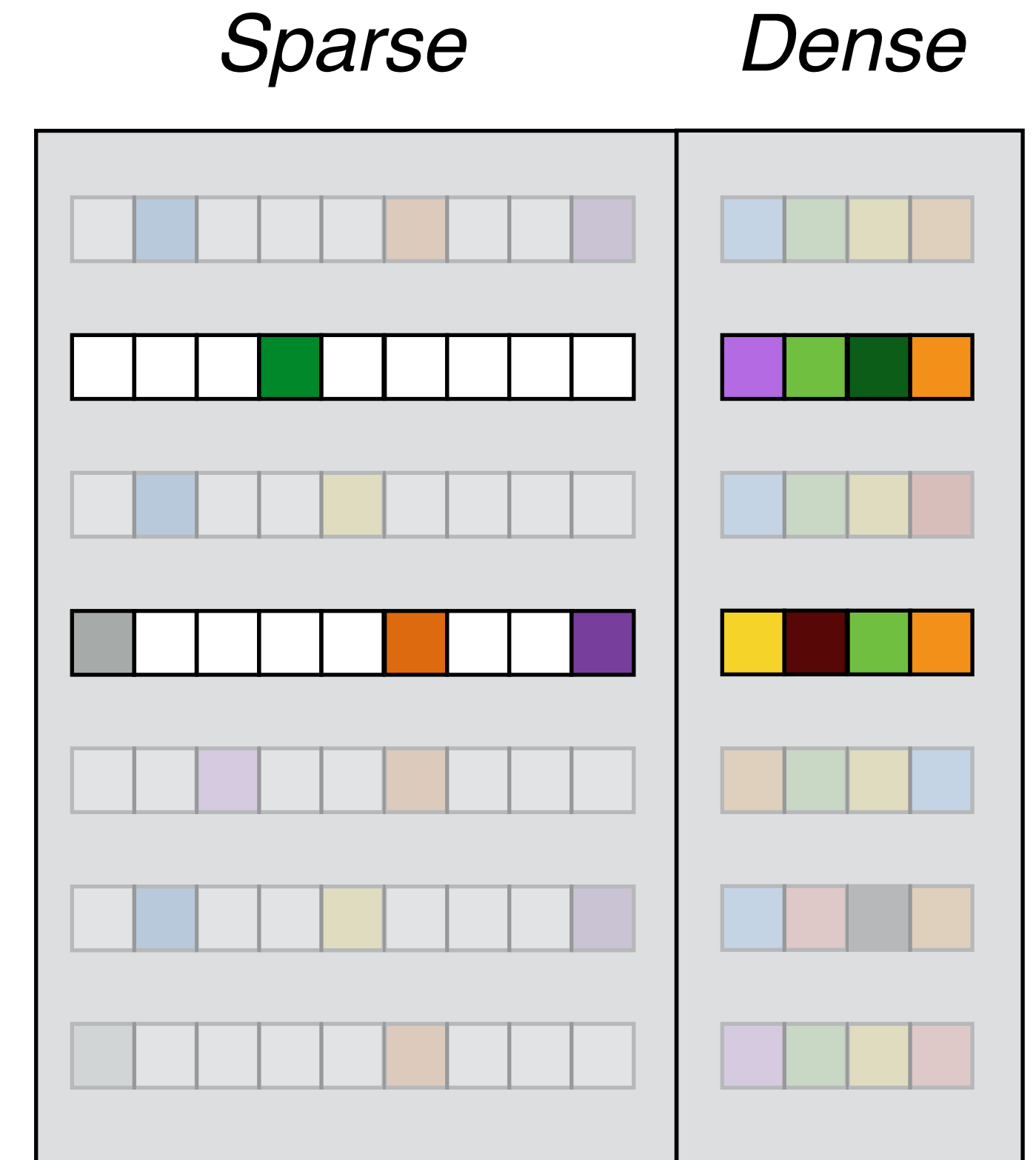
Mentions are retrieved in two steps:

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Which TV Networks has *Mila Kunis* appeared on?



X1.follow(R1)



Retrieve mentions which score high using both components

- Dense part checks whether *type is correct*
- Sparse part checks whether it *co-occurs with an input entity*

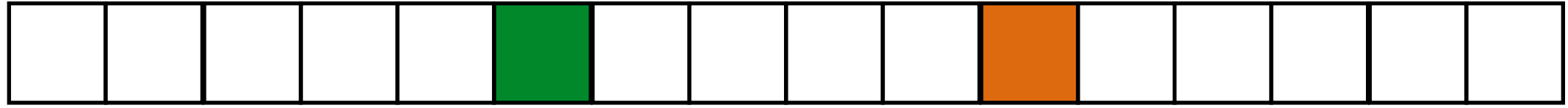
Which TV Networks has *Mila Kunis* appeared on?

v_{X1}

q_{R1}

k-hot sparse vector of entities

dense relation vector

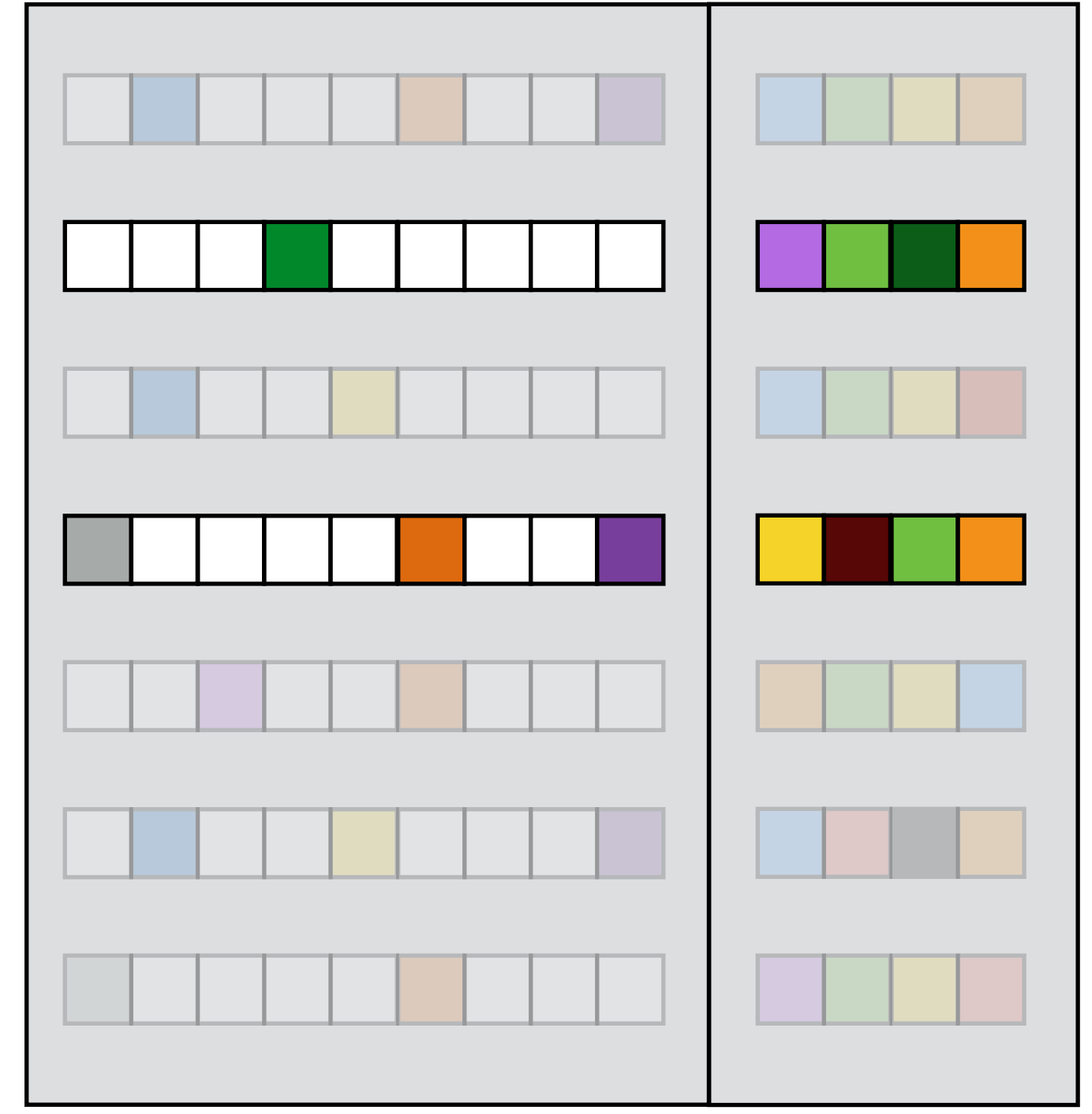


Aggregate mentions to entities
(take maximum score of all coreferent mentions)

X1.follow(R1)

Sparse

Dense



Which TV Networks has *Mila Kunis* appeared on?

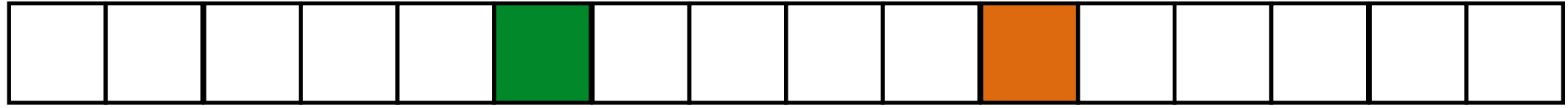
X1.follow(R1)

v_{X1}

q_{R1}

k-hot sparse vector of entities

dense relation vector



Sparse

Dense

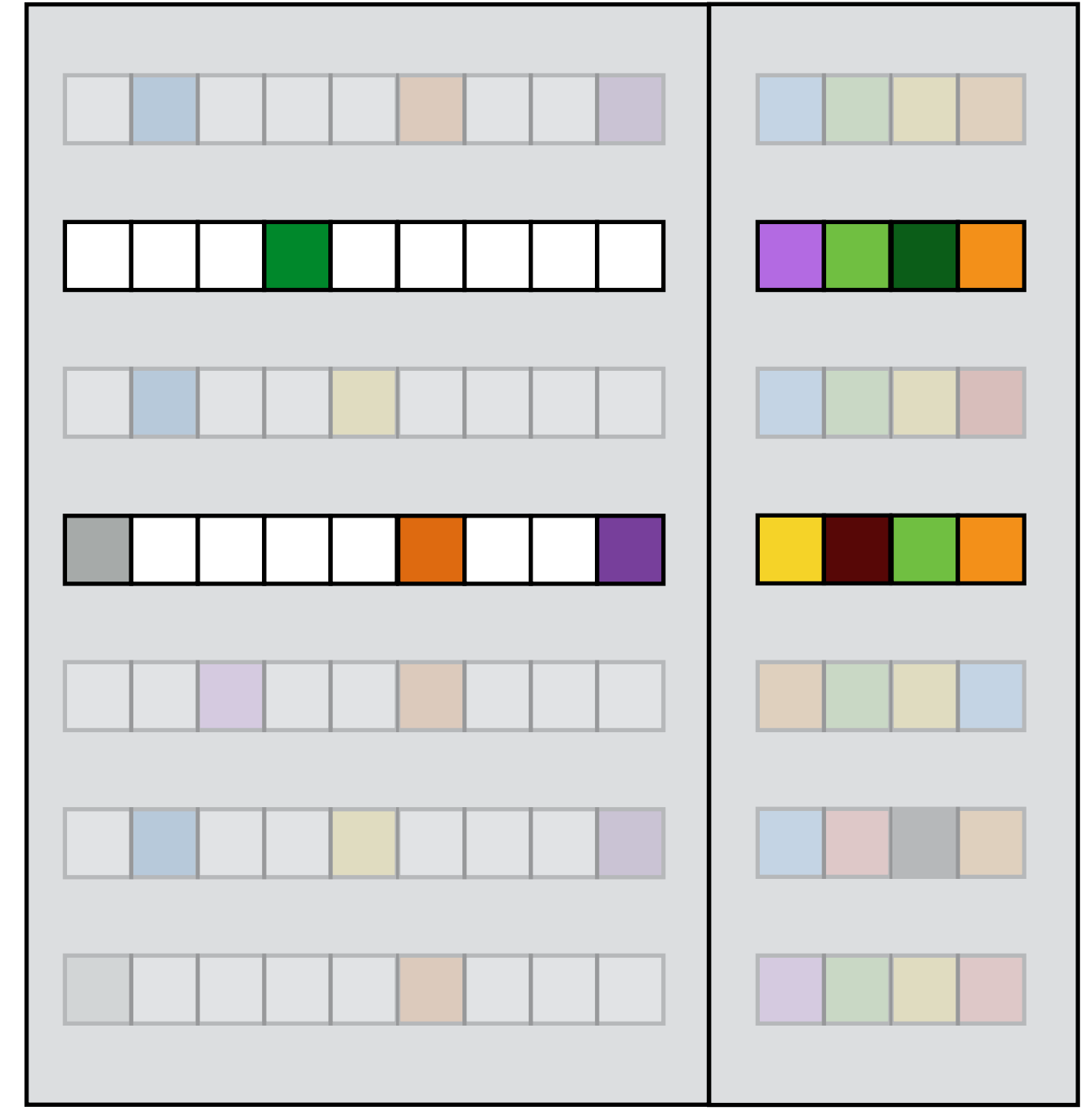
Aggregate mentions to entities
(take maximum score of all coreferent mentions)

v_{X2}

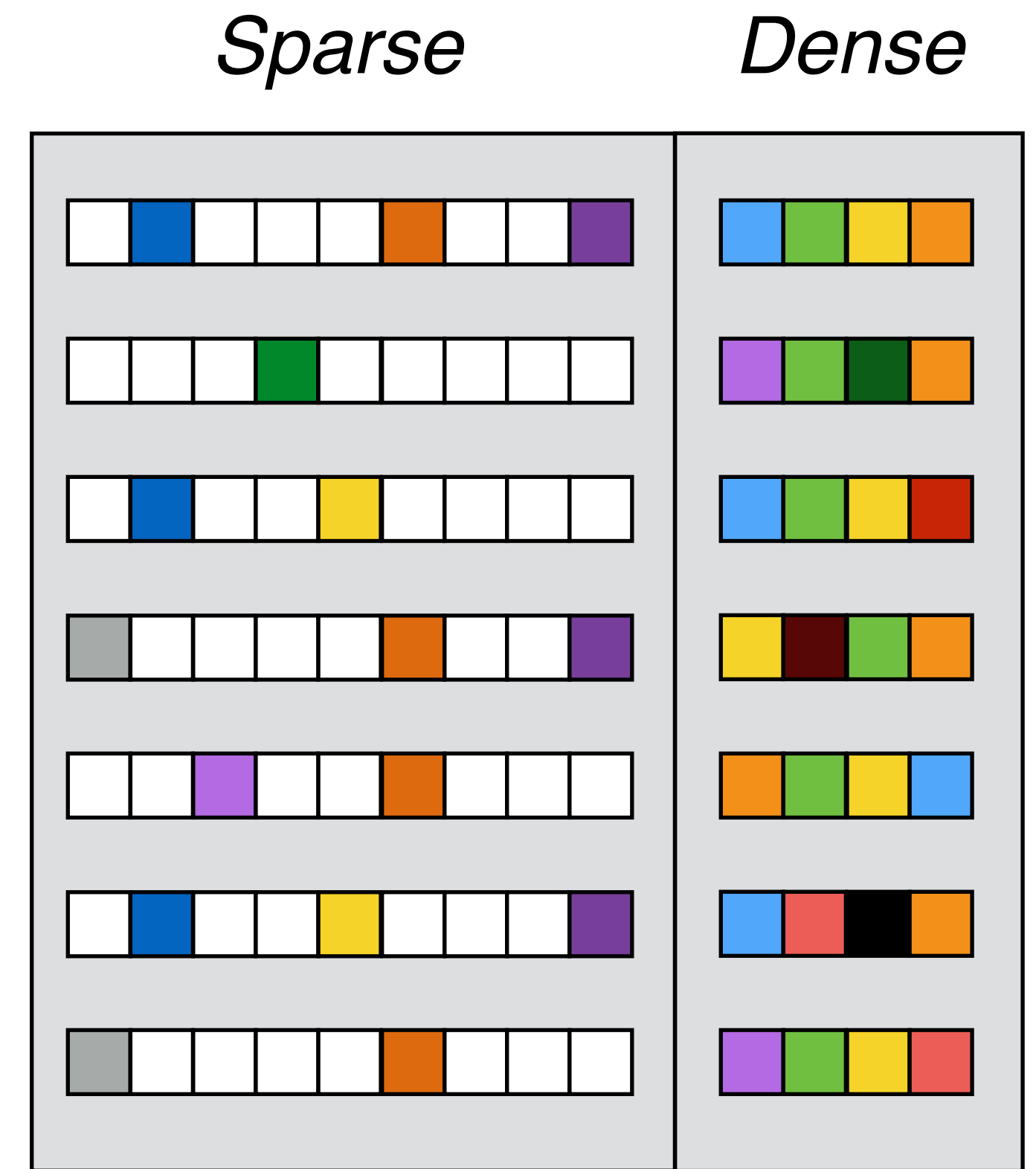
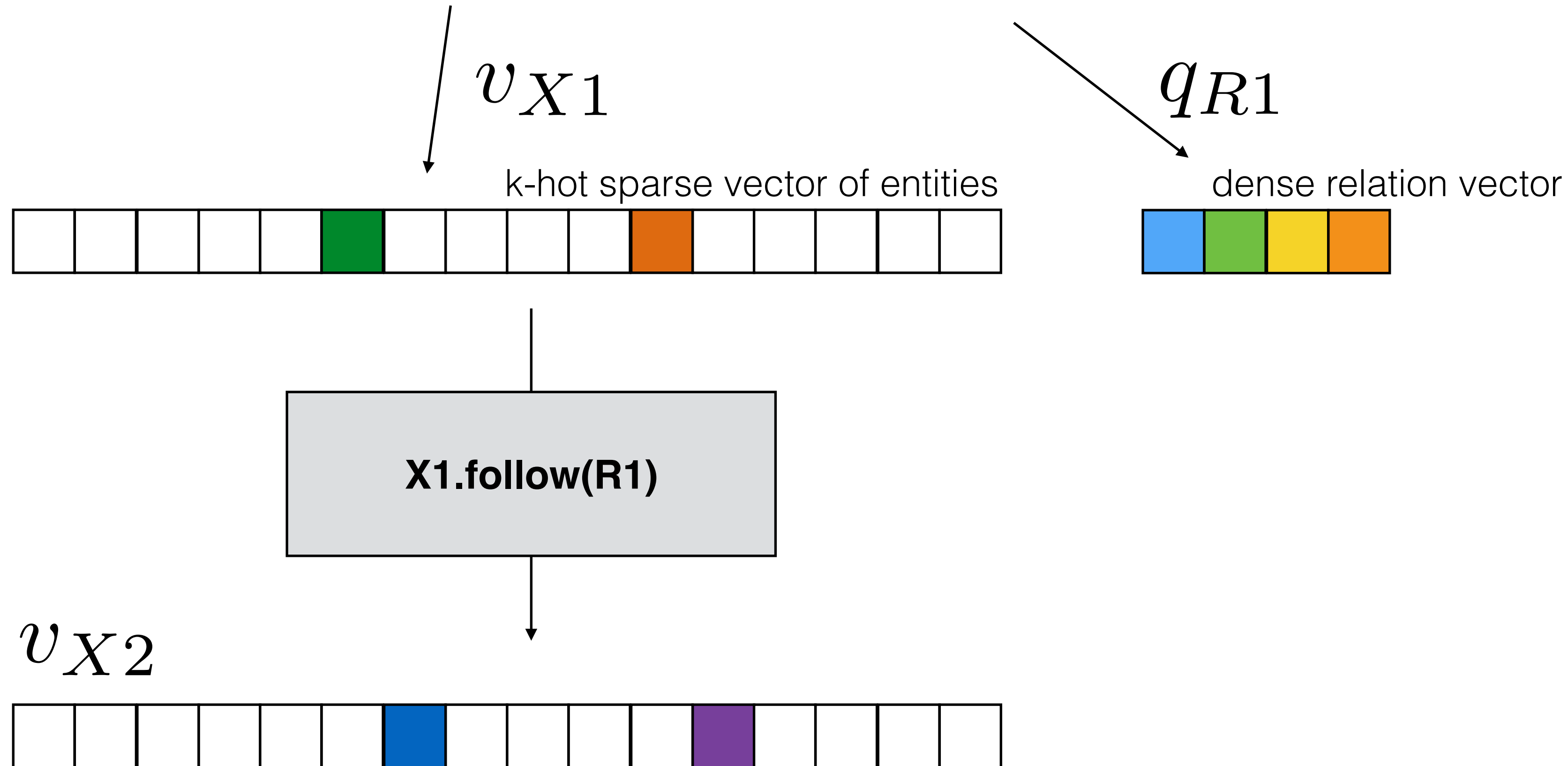


Family_Guy

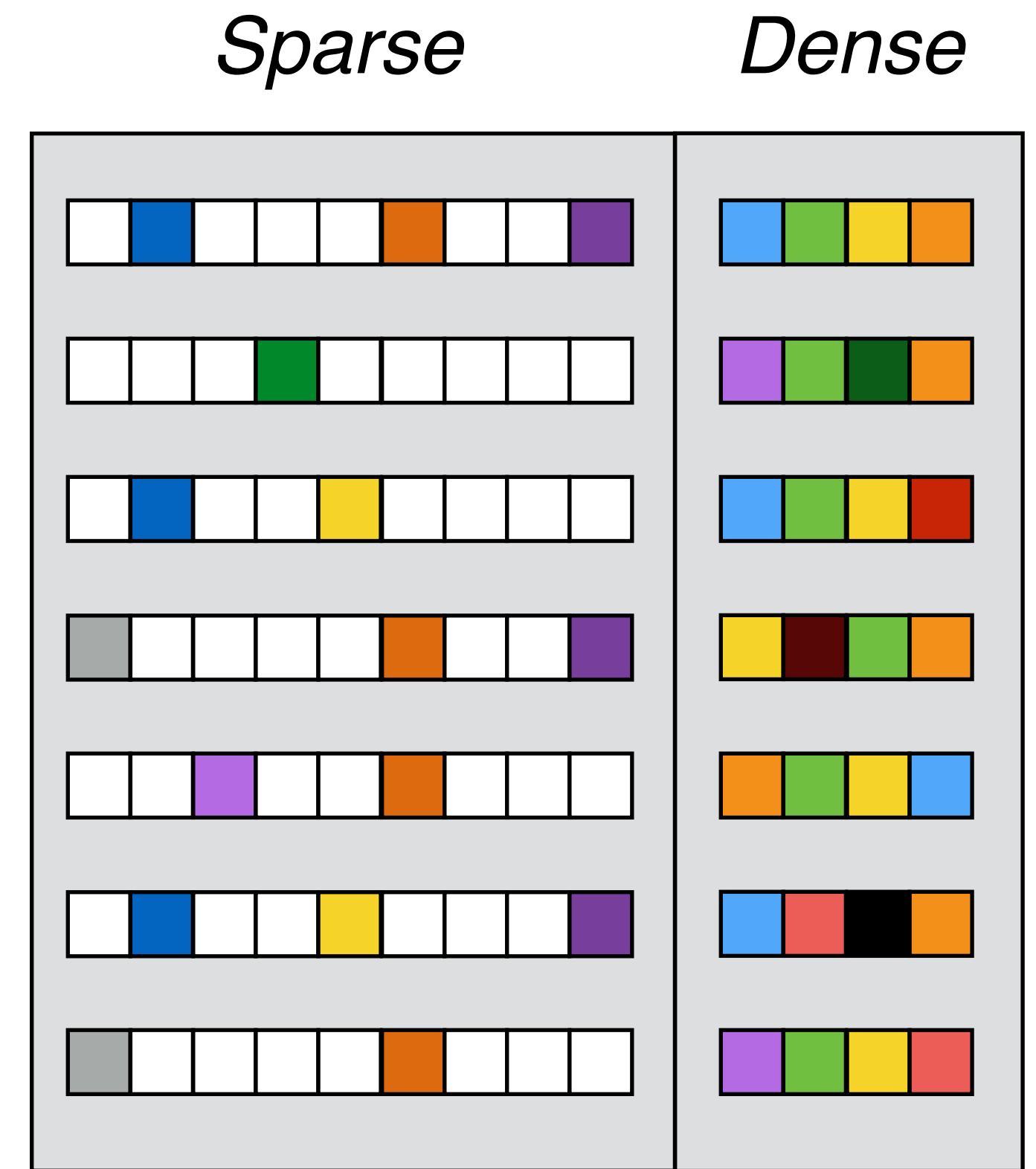
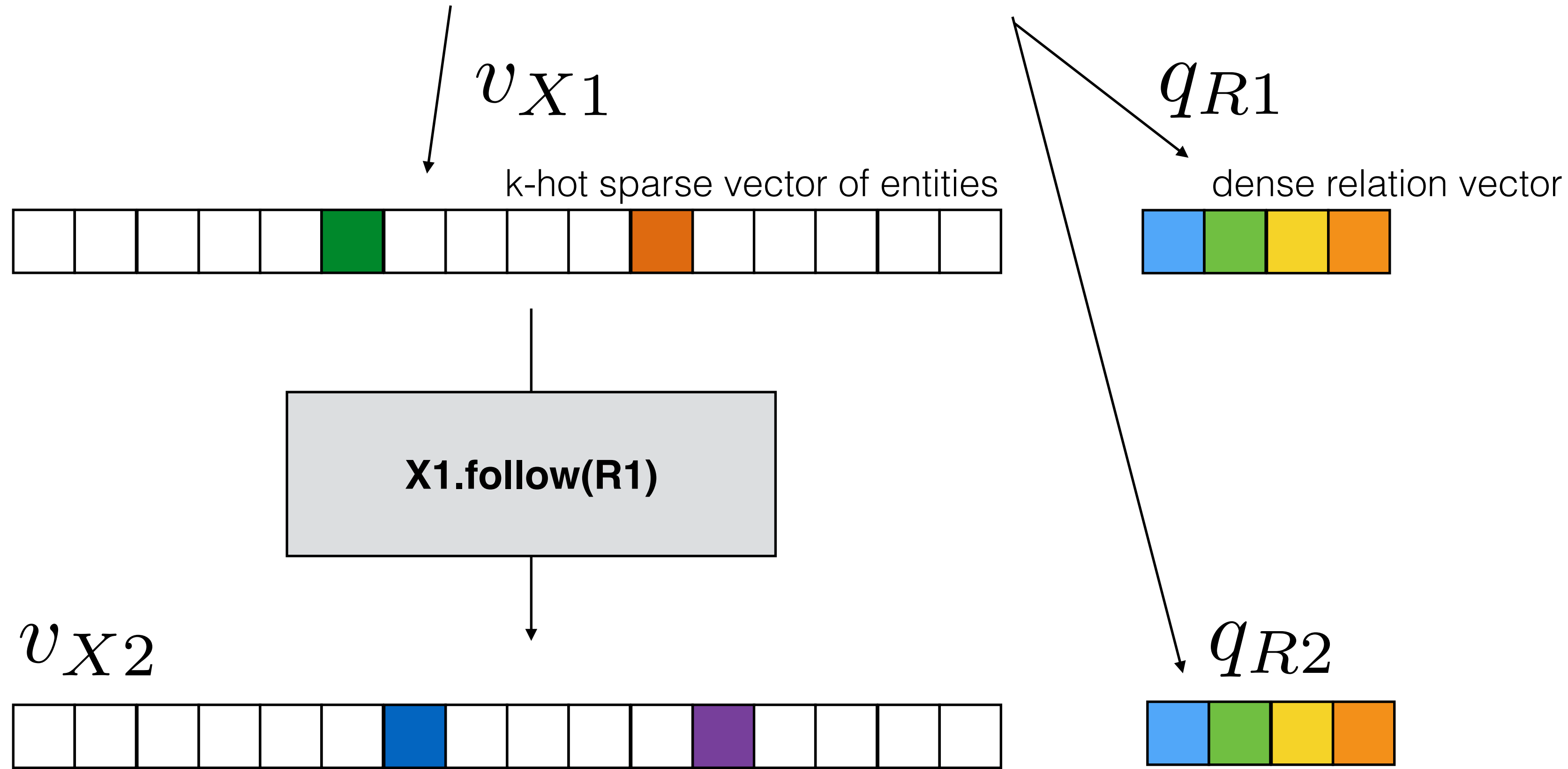
That_70s_Show



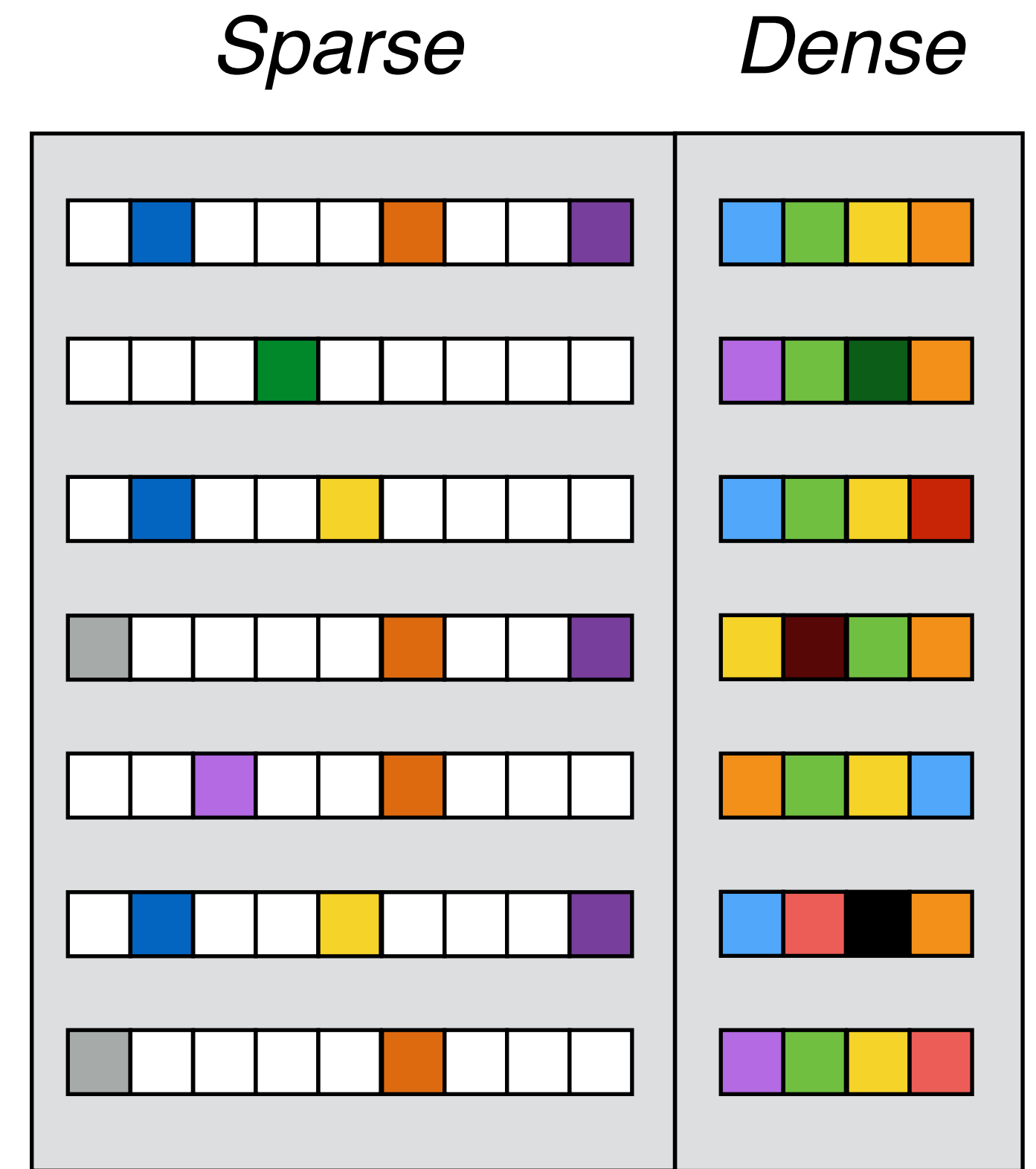
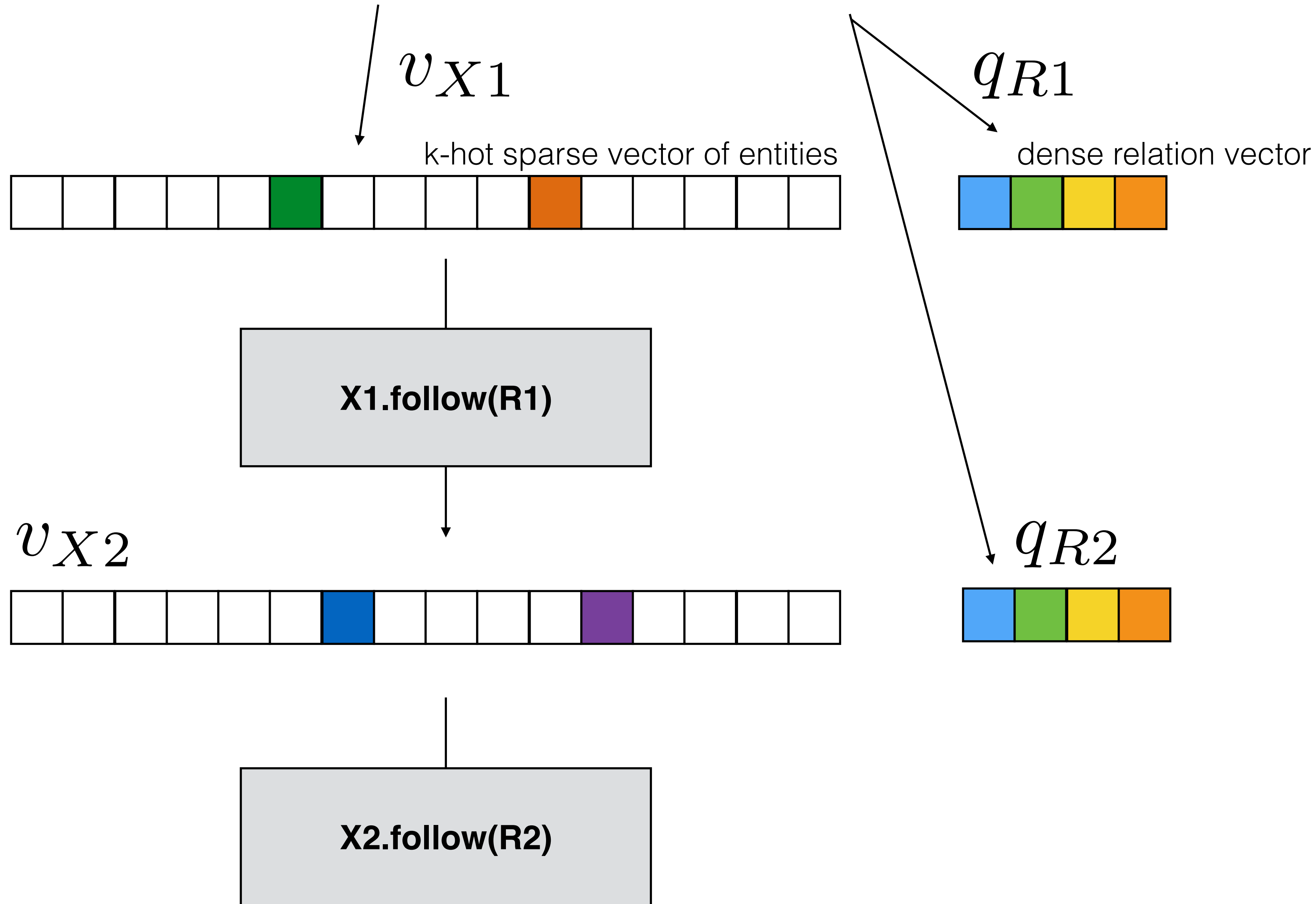
Which TV Networks has *Mila Kunis* appeared on?



Which TV Networks has *Mila Kunis* appeared on?



Which TV Networks has *Mila Kunis* appeared on?



Summary

$$v_{X.\text{follow}}(R) = [v_X A_{E \rightarrow M} \odot \mathcal{T}_K(q_R)] A_{M \rightarrow E}$$

Sparse vector of entities (points to v_X)

Dense relation vector (points to q_R)

Entity -> Mention TF-IDF matrix (points to $A_{E \rightarrow M}$)

Top-K inner product search (points to \mathcal{T}_K)

Mention -> Entity Coreference Matrix (points to $A_{M \rightarrow E}$)

\odot Element-wise Product

- Every operation is differentiable — can learn from denotations!
- Complexity depends only on **log** of #entities / #mentions!

Pre-training

Entity Mentions

Dense

... **Family Guy** is an American ...



... their children, **Meg**, Chris, Stewie ...



... In 1999, **Kunis** replaced Lacey Chabert ...



... created by **Seth MacFarlane** for Fox ...



... were **Topher Grace**, Mile Kunis ...



... originally aired on Fox from **August 23** ...



... wanted the show to have a **1970s** feel ...



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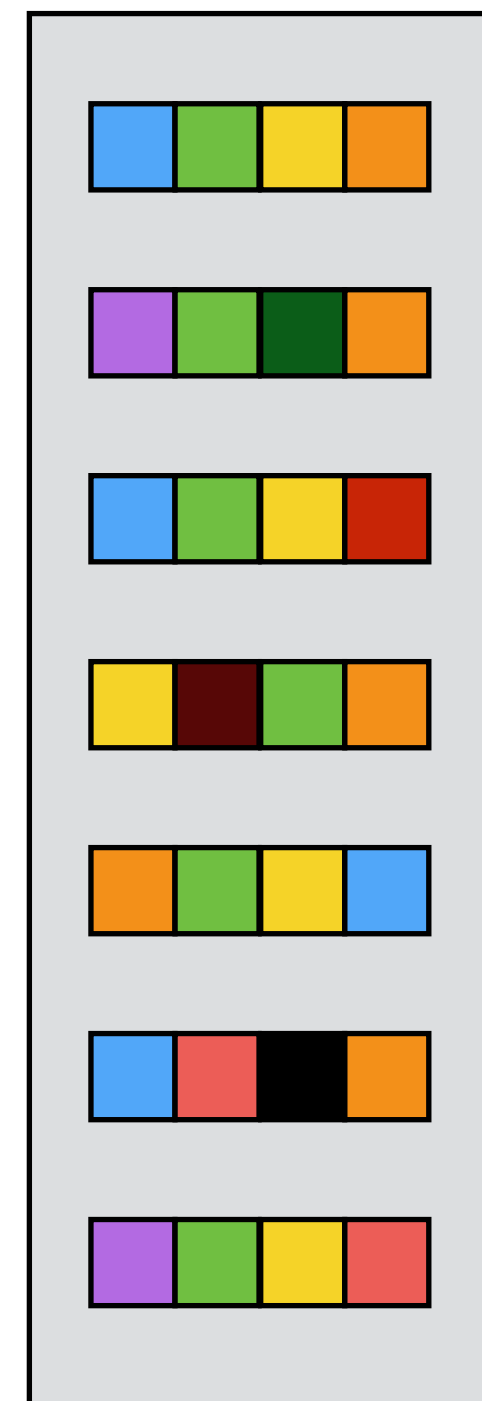
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Dense



- Distantly align KB facts to text passages:

Pre-training

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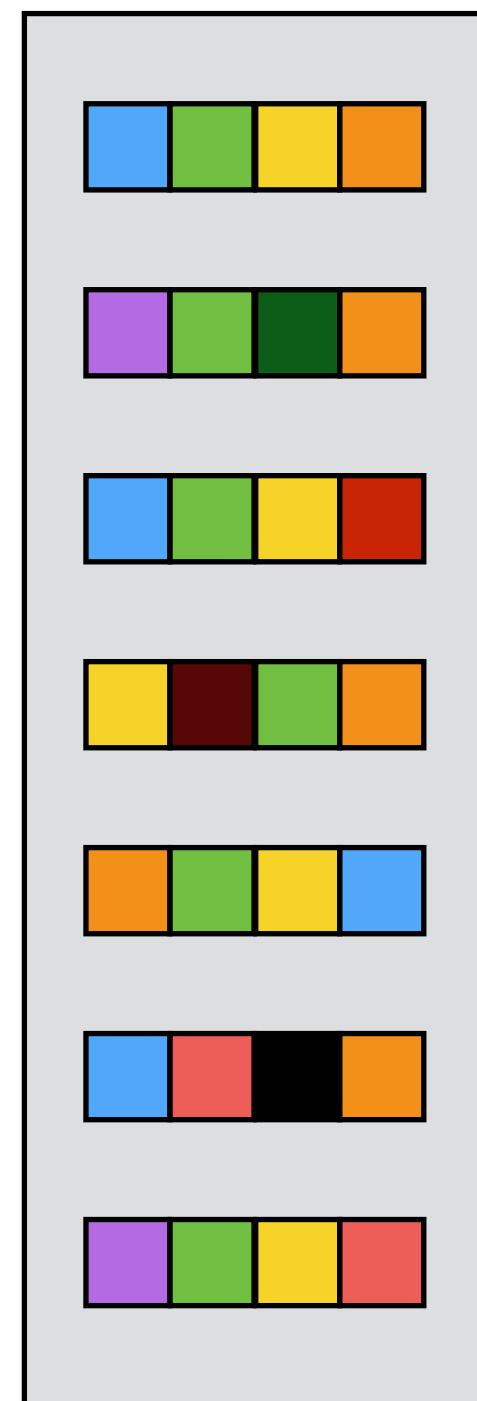
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Dense



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KB fact

(Quentin Tarantino, directed, Pulp Fiction)

Pulp Fiction is a 1994 film written and directed by Quentin Tarantino

Text

Pre-training

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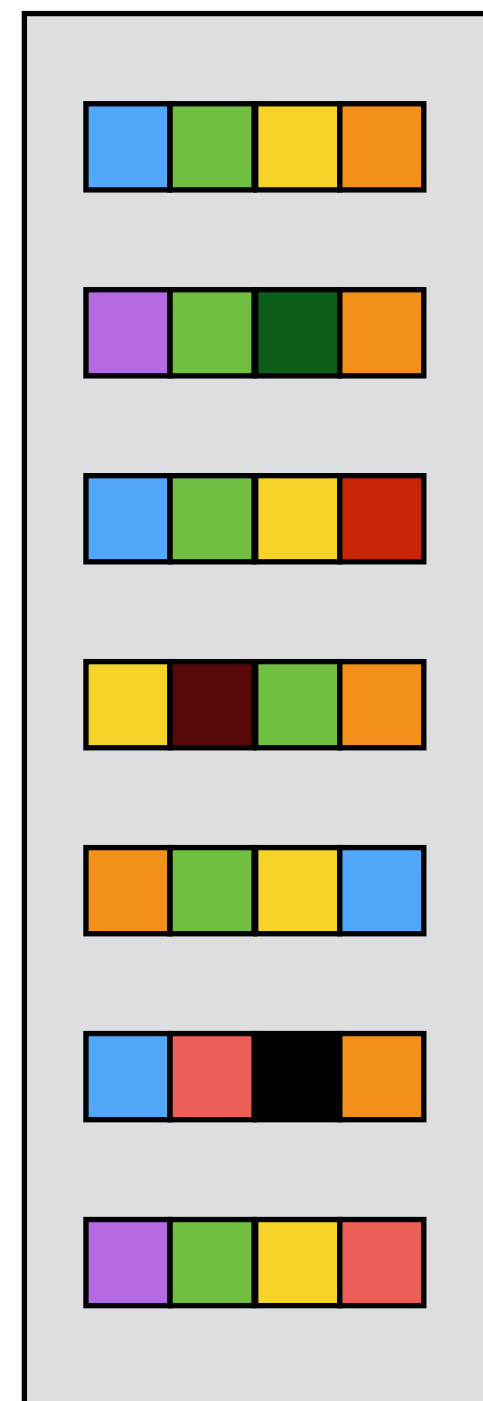
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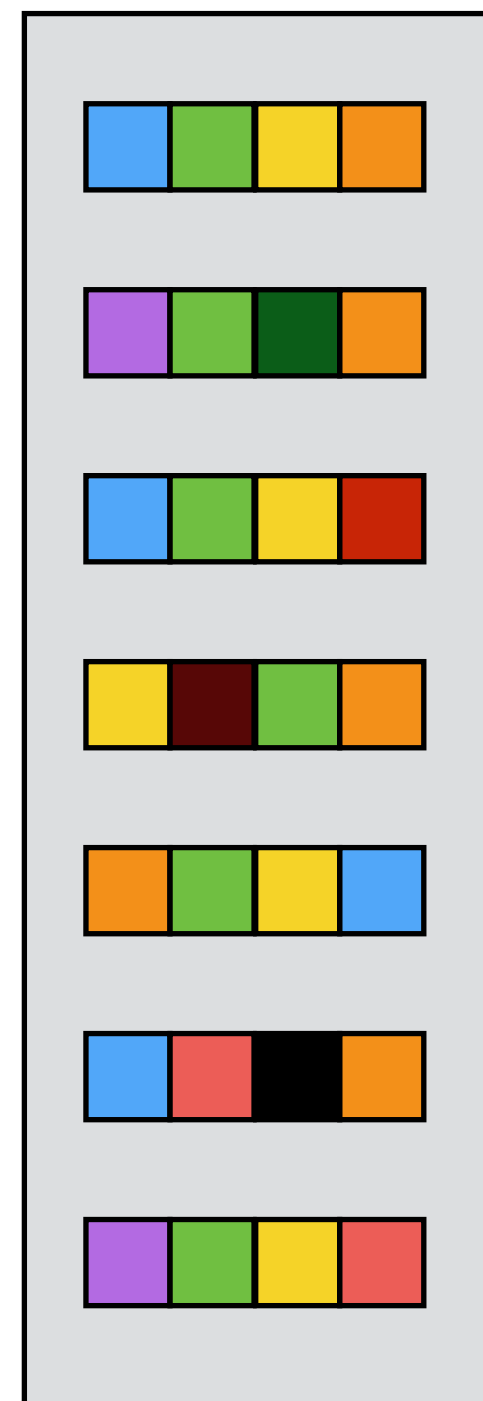
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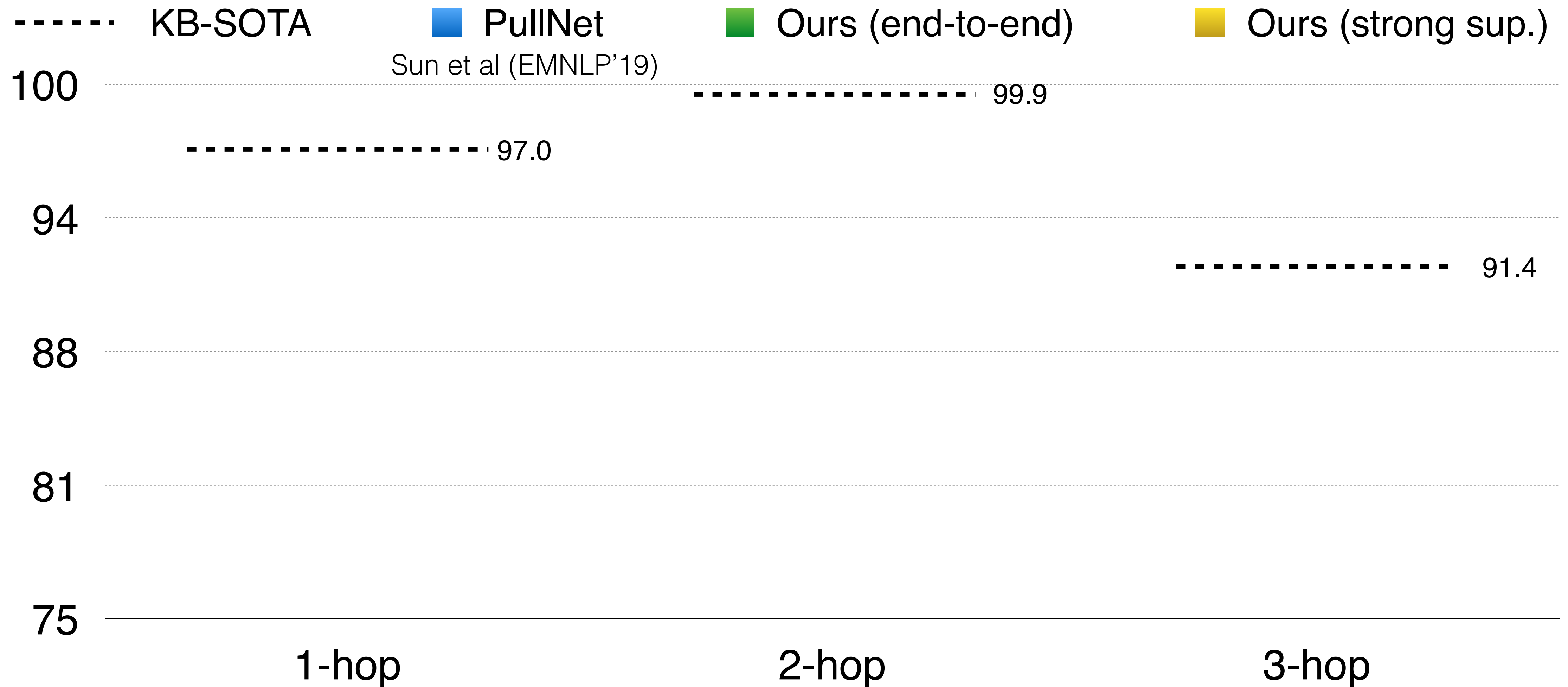
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MetaQA Results

Hits @1 Performance

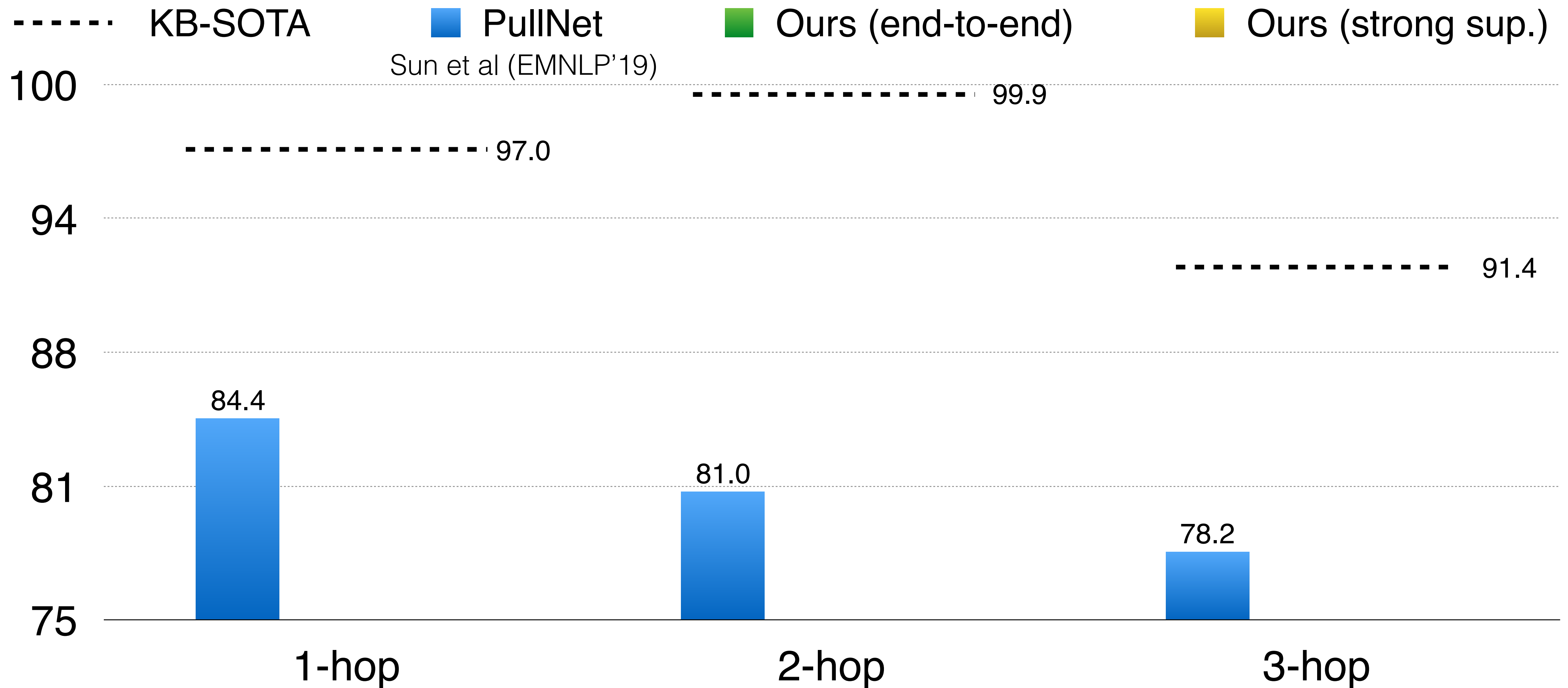
MetaQA Results

Hits @1 Performance



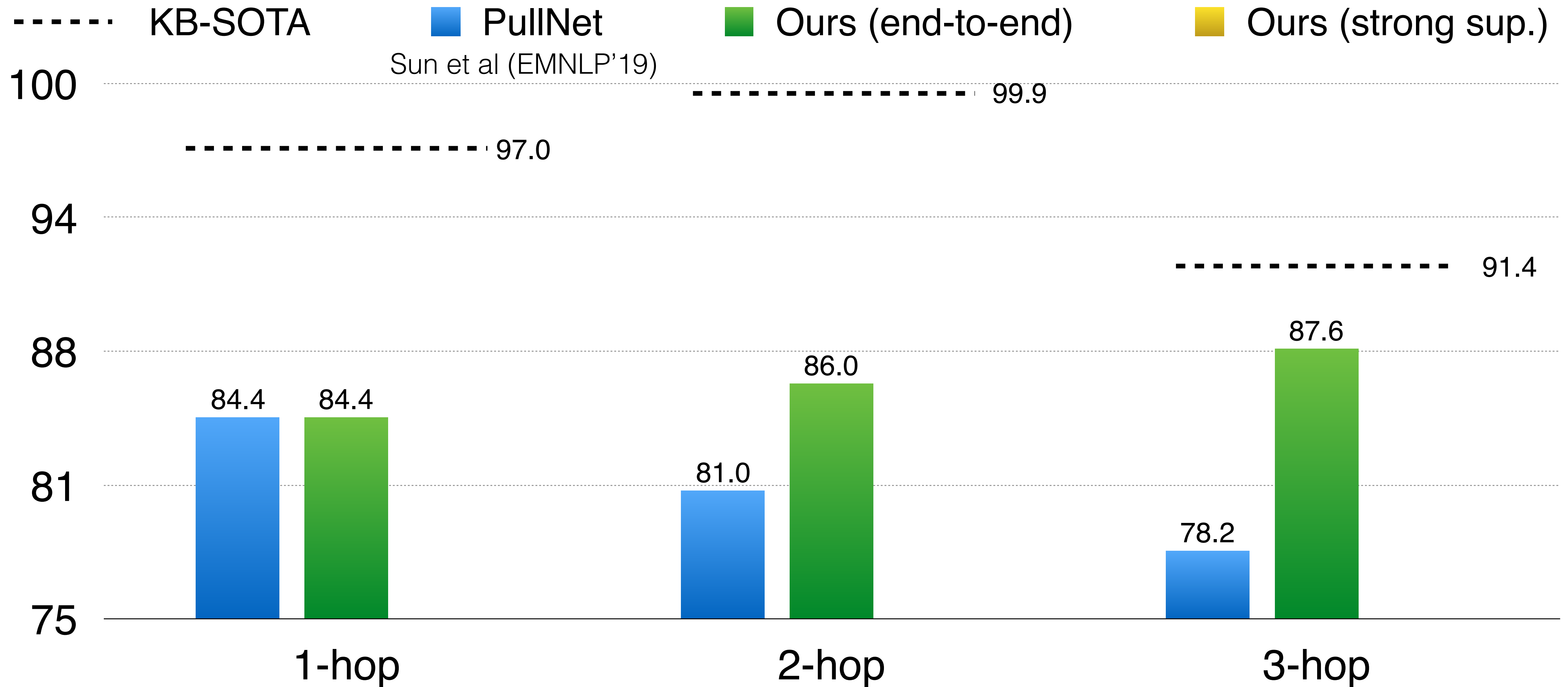
MetaQA Results

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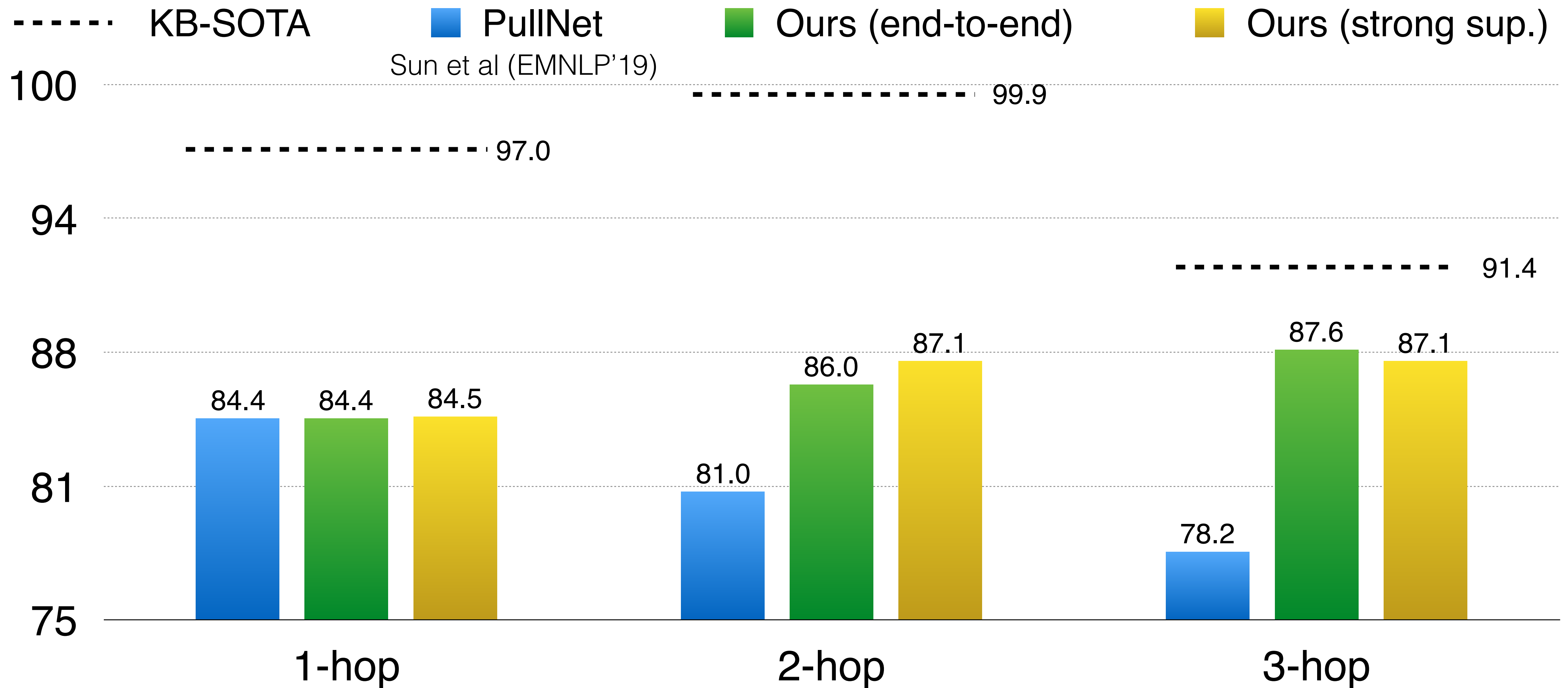
MetaQA Results

Hits @1 Performance



MetaQA Results

Hits @1 Performance



MetaQA Results

Queries / sec on a single 6-core CPU

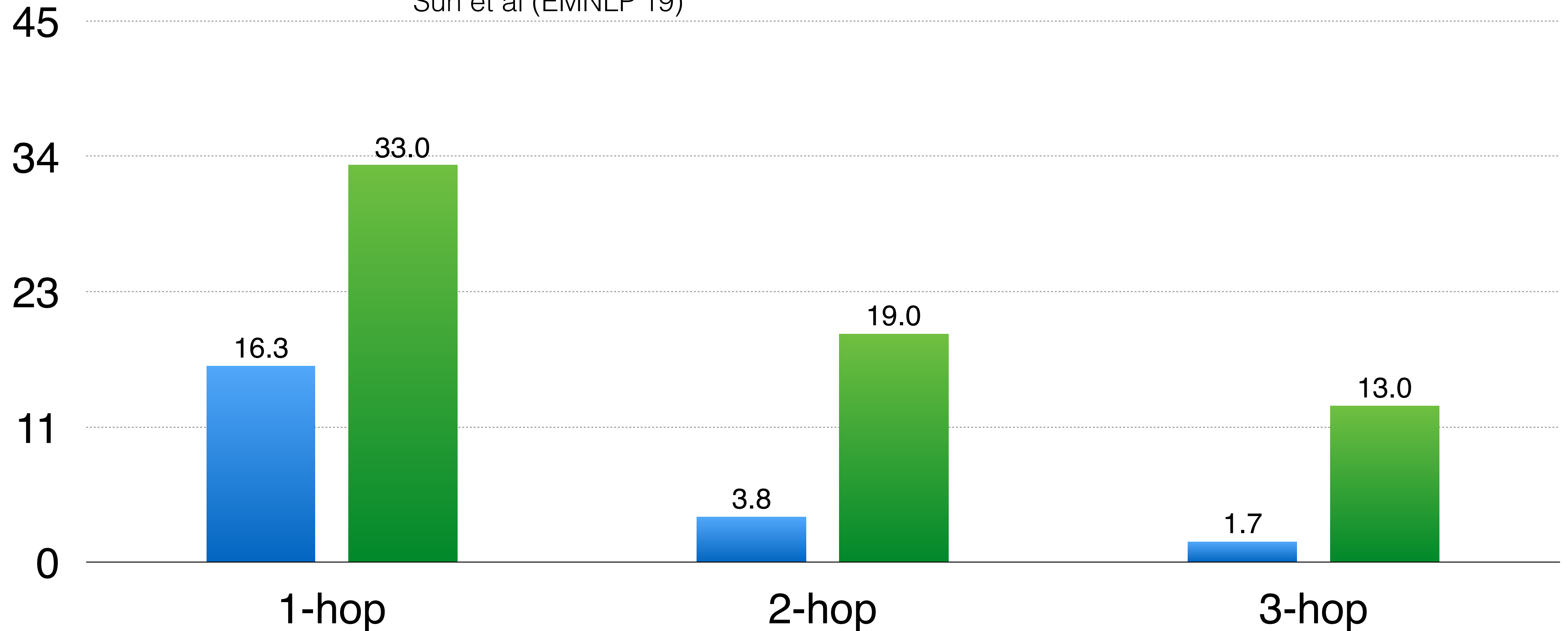
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 PullNet

 Ours

Sun et al (EMNLP'19)



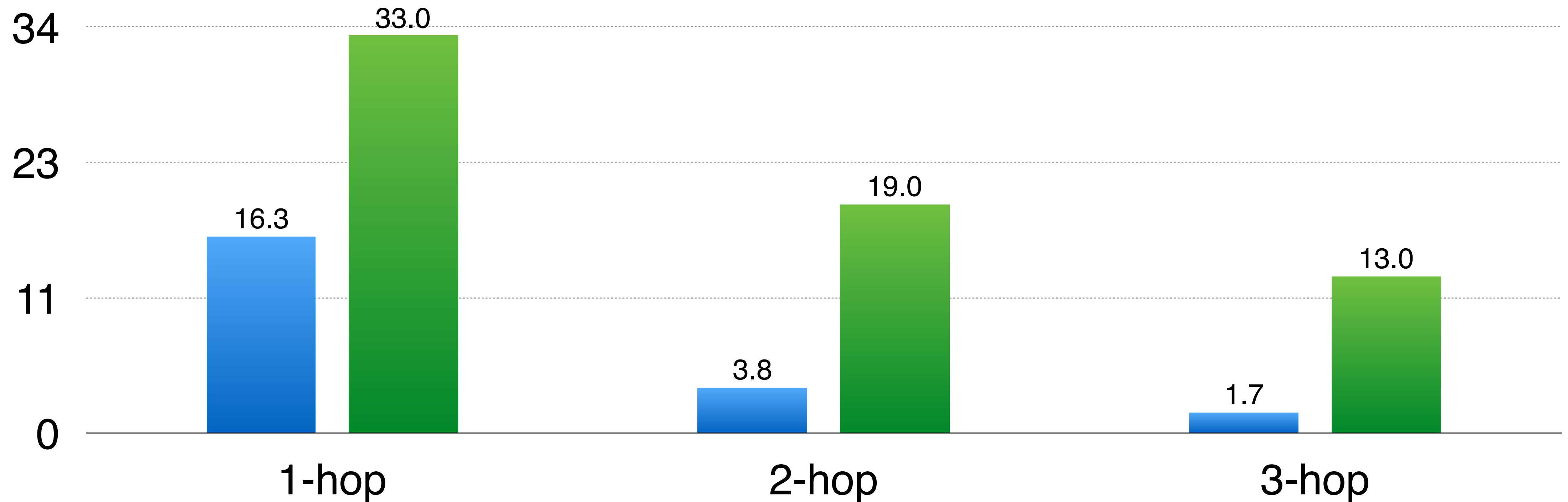
MetaQA Results

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Does iterative retrieval +
Graph Neural Network to read



New Dataset: WikiData Slot-filling

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- Constructed by aligning WikiData facts to Wikipedia

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- Constructed by aligning WikiData facts to Wikipedia
- 1-3 hop semi-synthetic *slot-filling* queries over ~300 relations

Q. Marcel de Graaff, place of birth, twinned administrative body?

Ans. Rotterdam -> Antwerp

Q. Muhammad Sanya, member of political party, chairperson, date of birth?

Ans. Civic United Front -> Ibrahim Lipumba -> 6 June 1952

New Dataset: WikiData Slot-filling

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- Task is to extract answer from an **unseen** corpus of 10K Wikipedia articles (120K passages)
 - ~200K entities
 - ~1.2M mentions

Baselines

- Cascaded versions of two open-domain QA models - PIQA [1] and DrQA [2]
- Relations were converted to natural language questions using templates

[1] Seo, Minjoon, et al. "Real-Time Open-Domain Question Answering with Dense-Sparse Phrase Index." ACL (2019).

[2] Chen, Danqi, et al. "Reading wikipedia to answer open-domain questions." ACL (2017).

Baselines

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Q. Marcel de Graaff, place of birth, twinned administrative body?

↓
Q1. Where was Marcel de Graaff born?

→ [PIQA / DrQA] →

Rotterdam

↓
Q2. Name a sister city of Rotterdam.

→ [PIQA / DrQA] →

Antwerp

[1] Seo, Minjoon, et al. "Real-Time Open-Domain Question Answering with Dense-Sparse Phrase Index." ACL (2019).

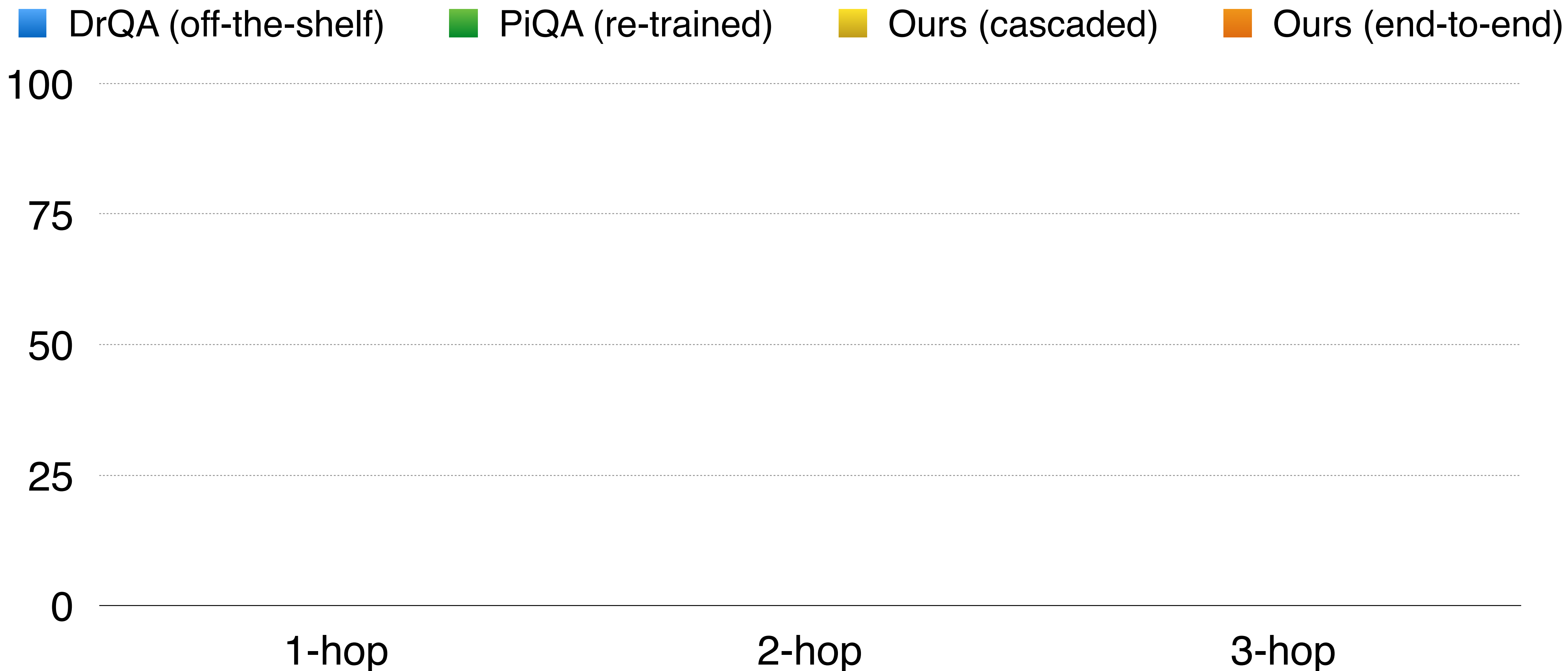
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WikiData Slot-Filling Results

Hits @1 Performance

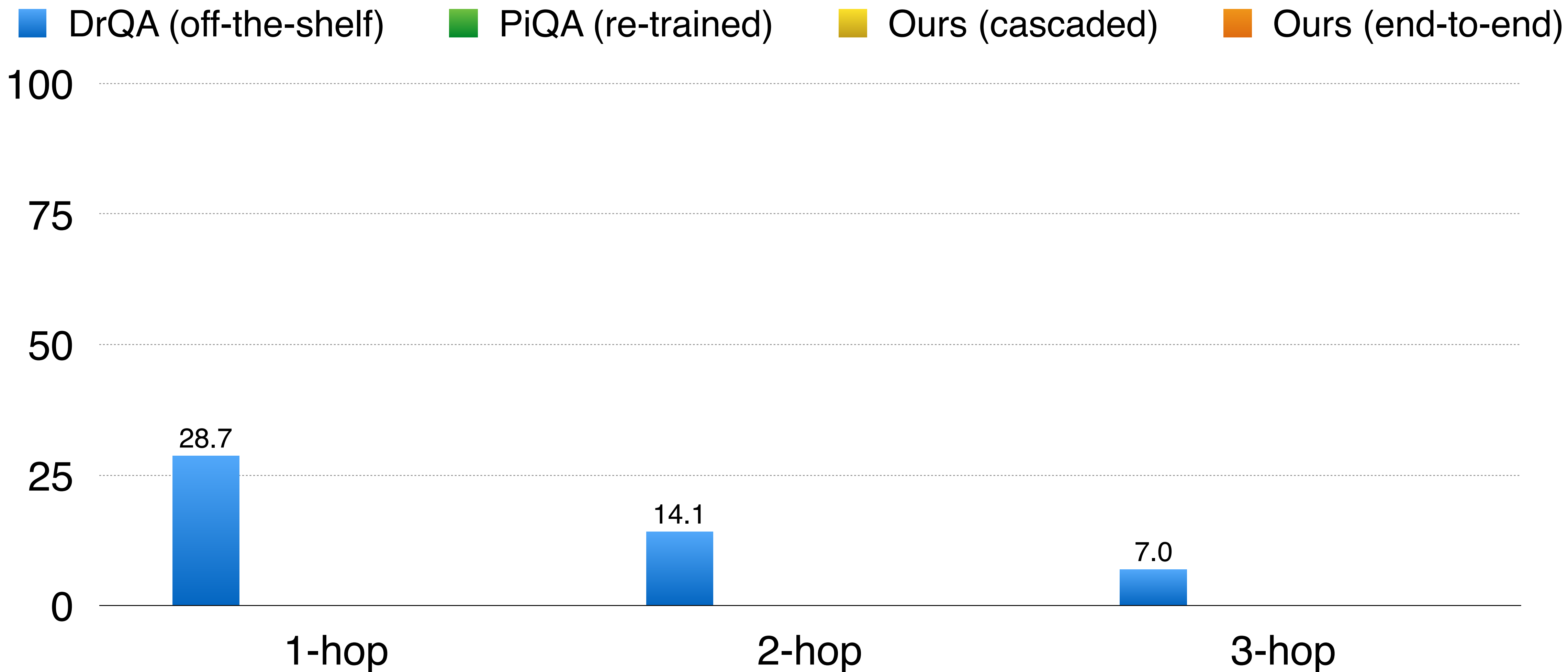
WikiData Slot-Filling Results

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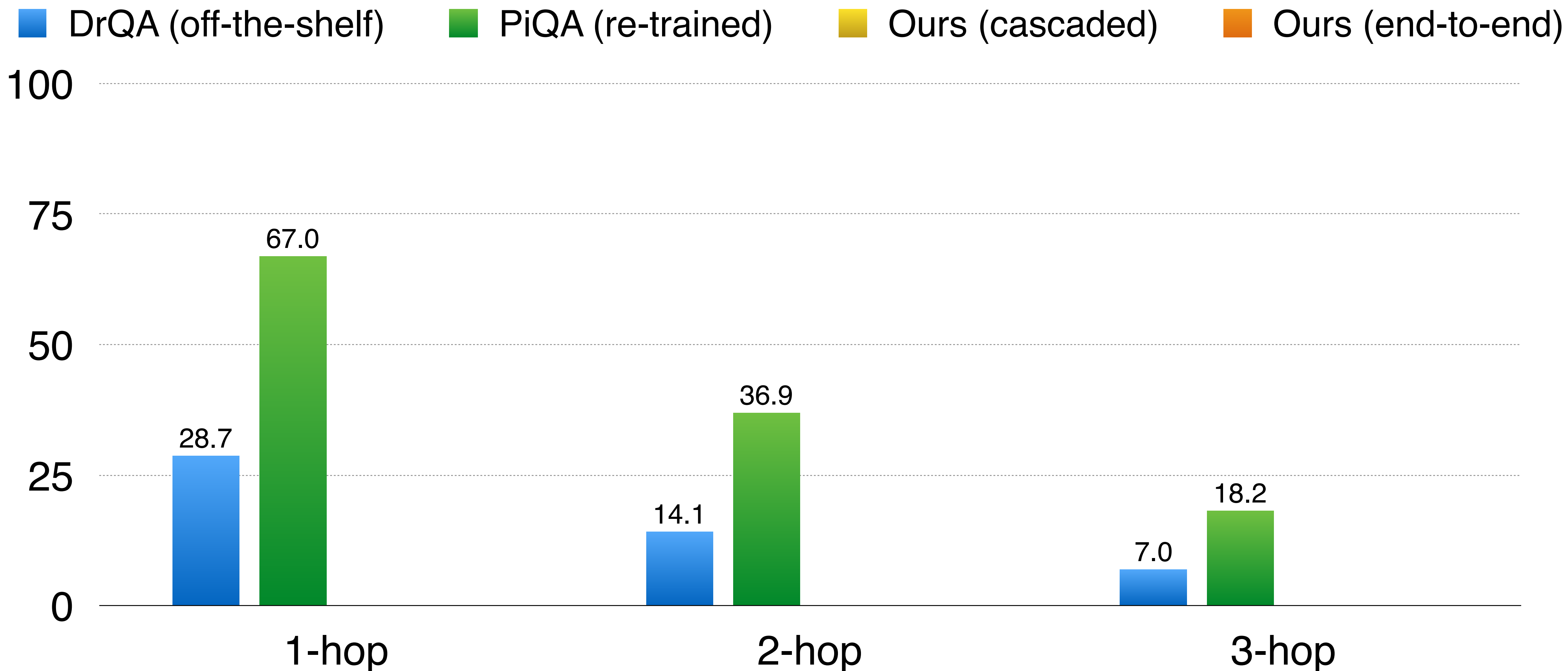
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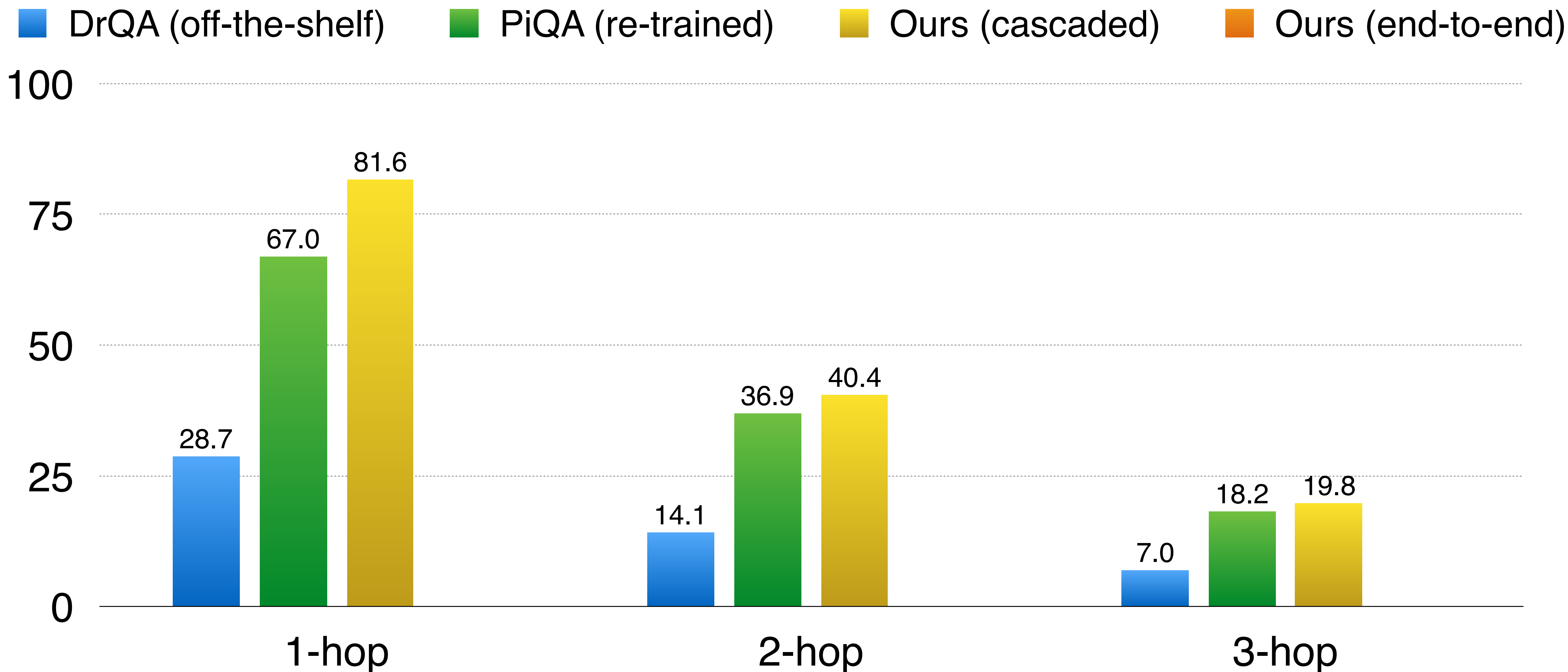
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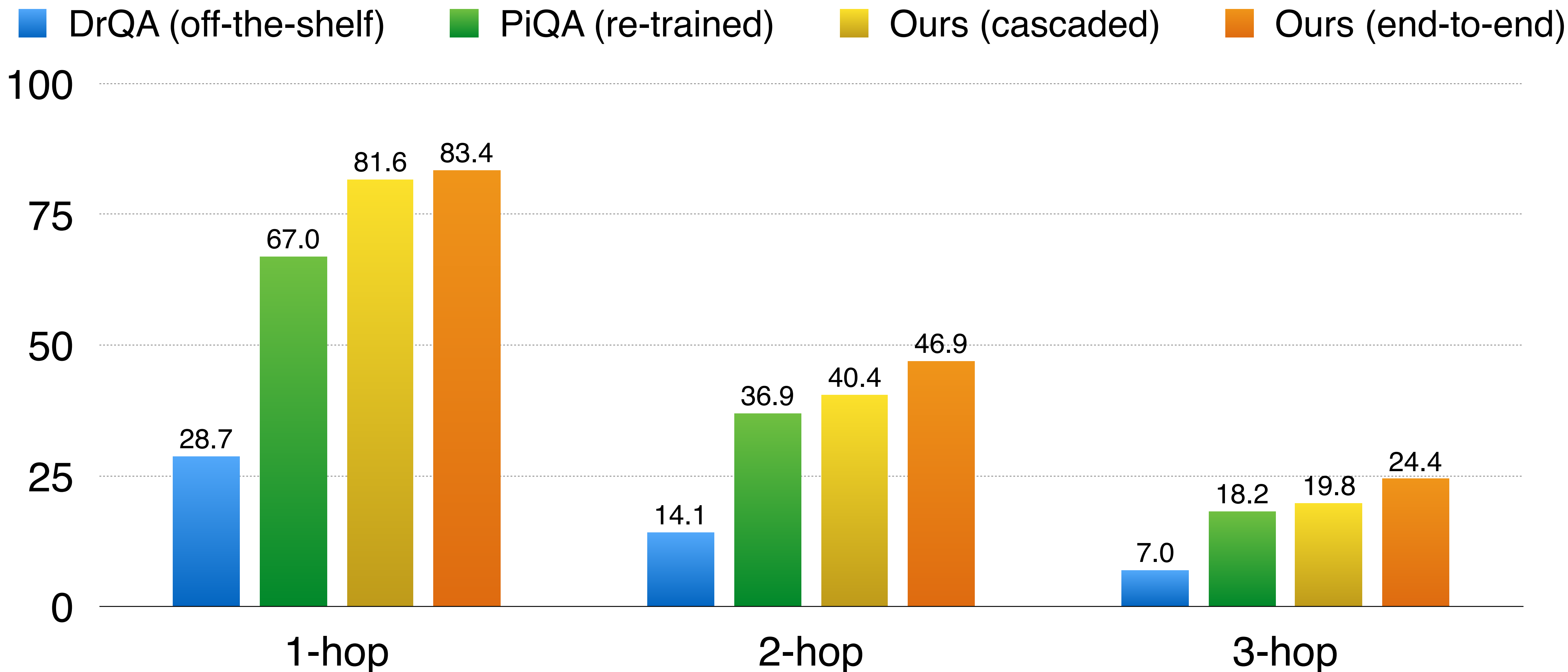
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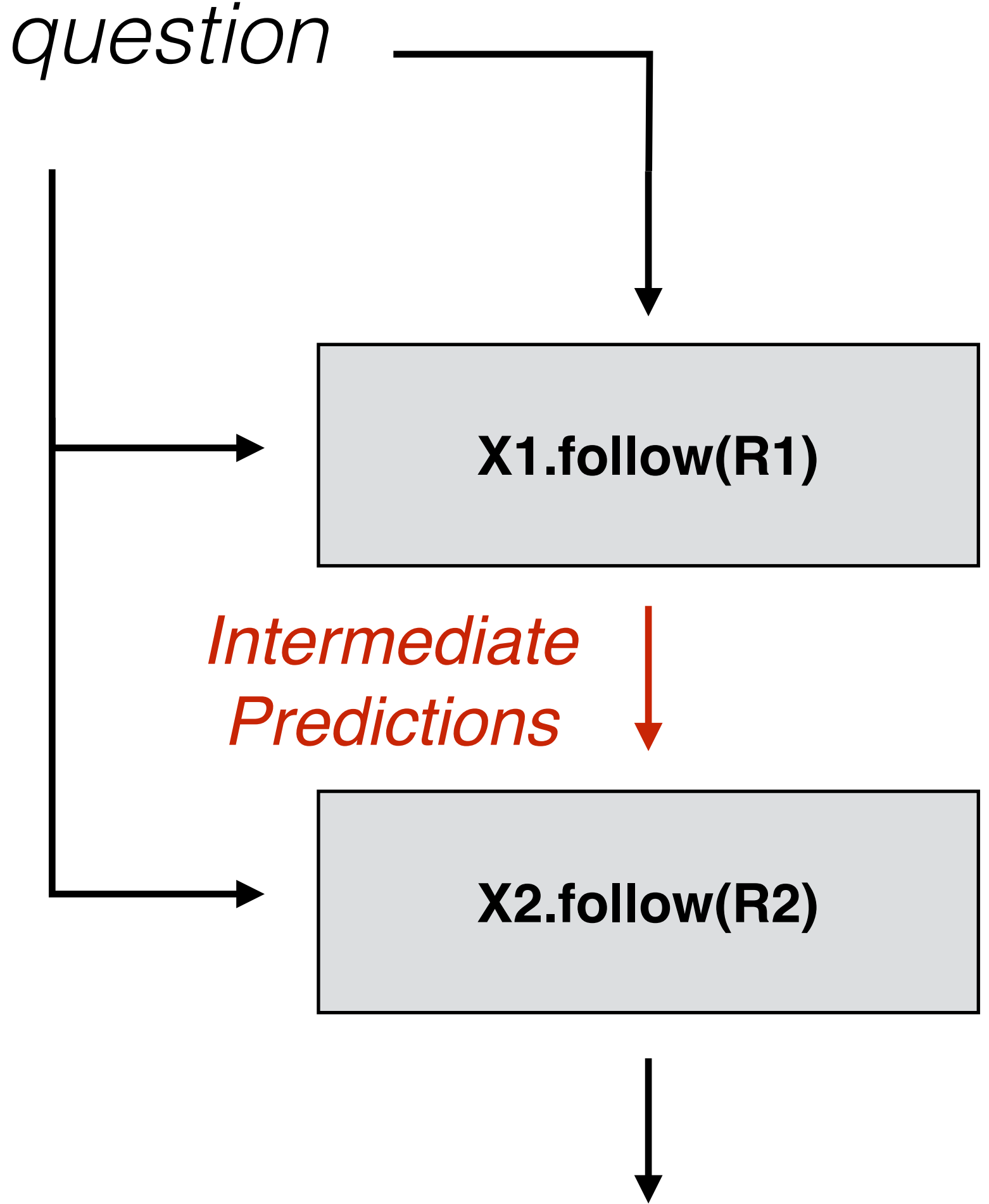


WikiData Slot-Filling Results

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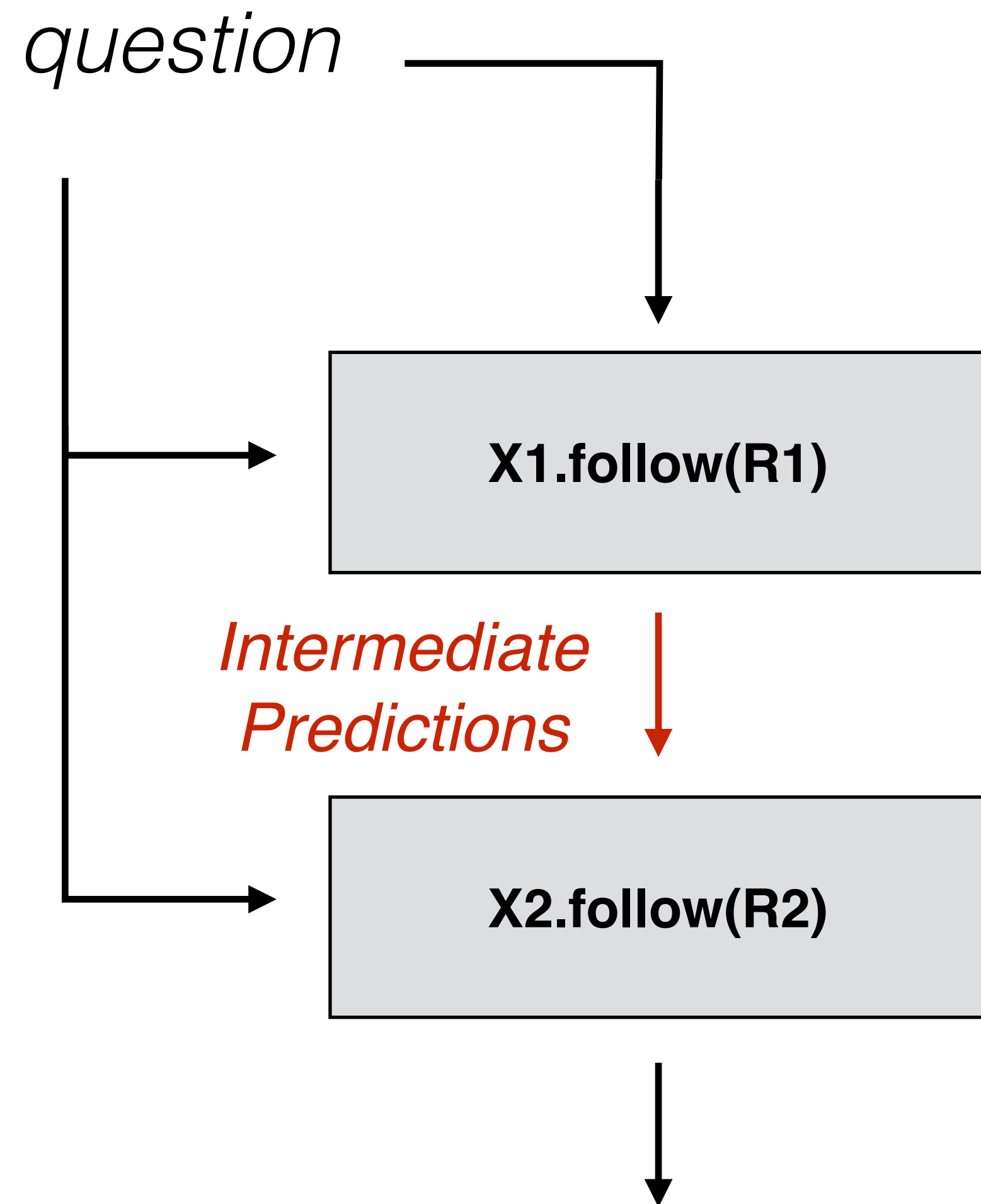


Analysis - Intermediate Predictions

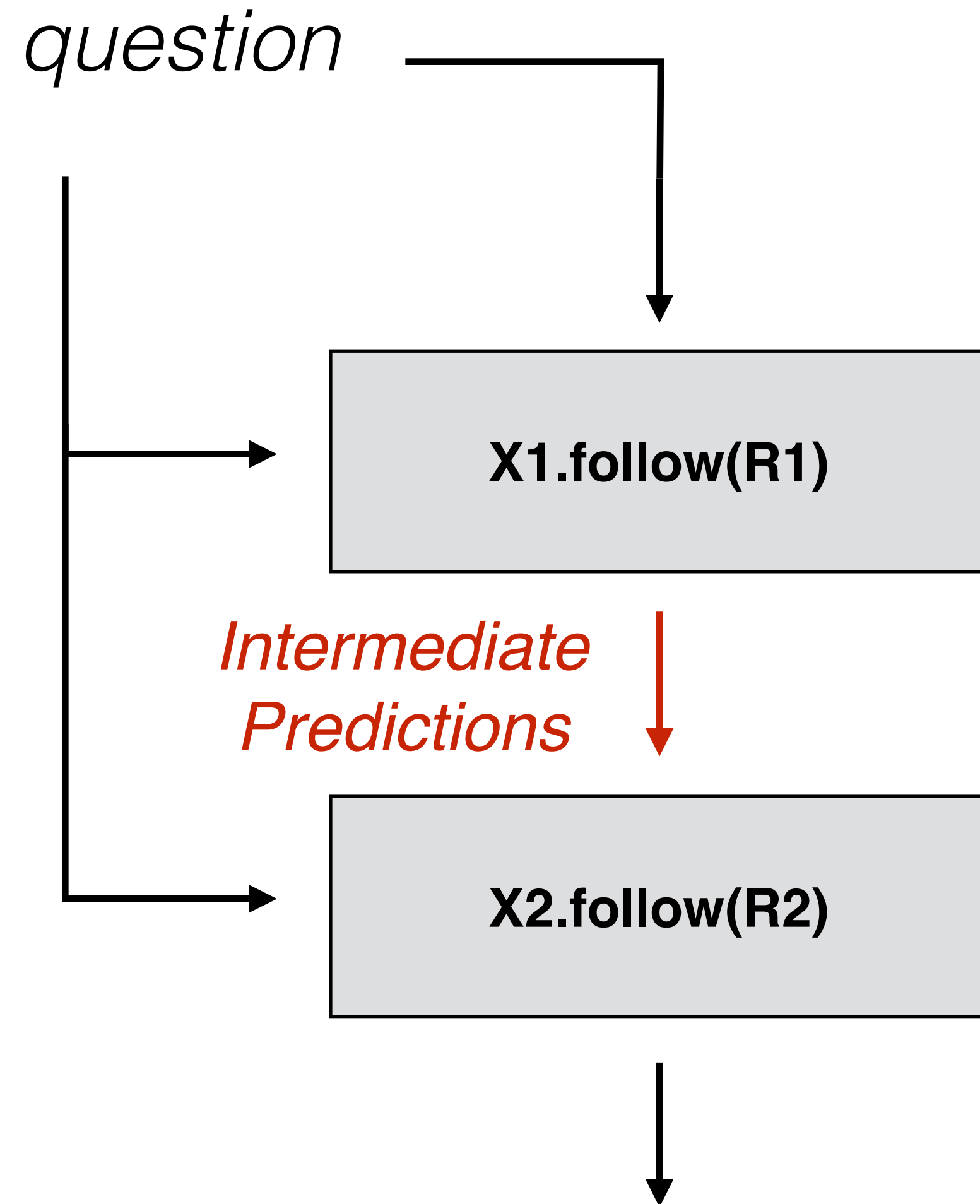


Analysis - Intermediate Predictions

- Inspected 100 **correctly answered** 2-hop questions

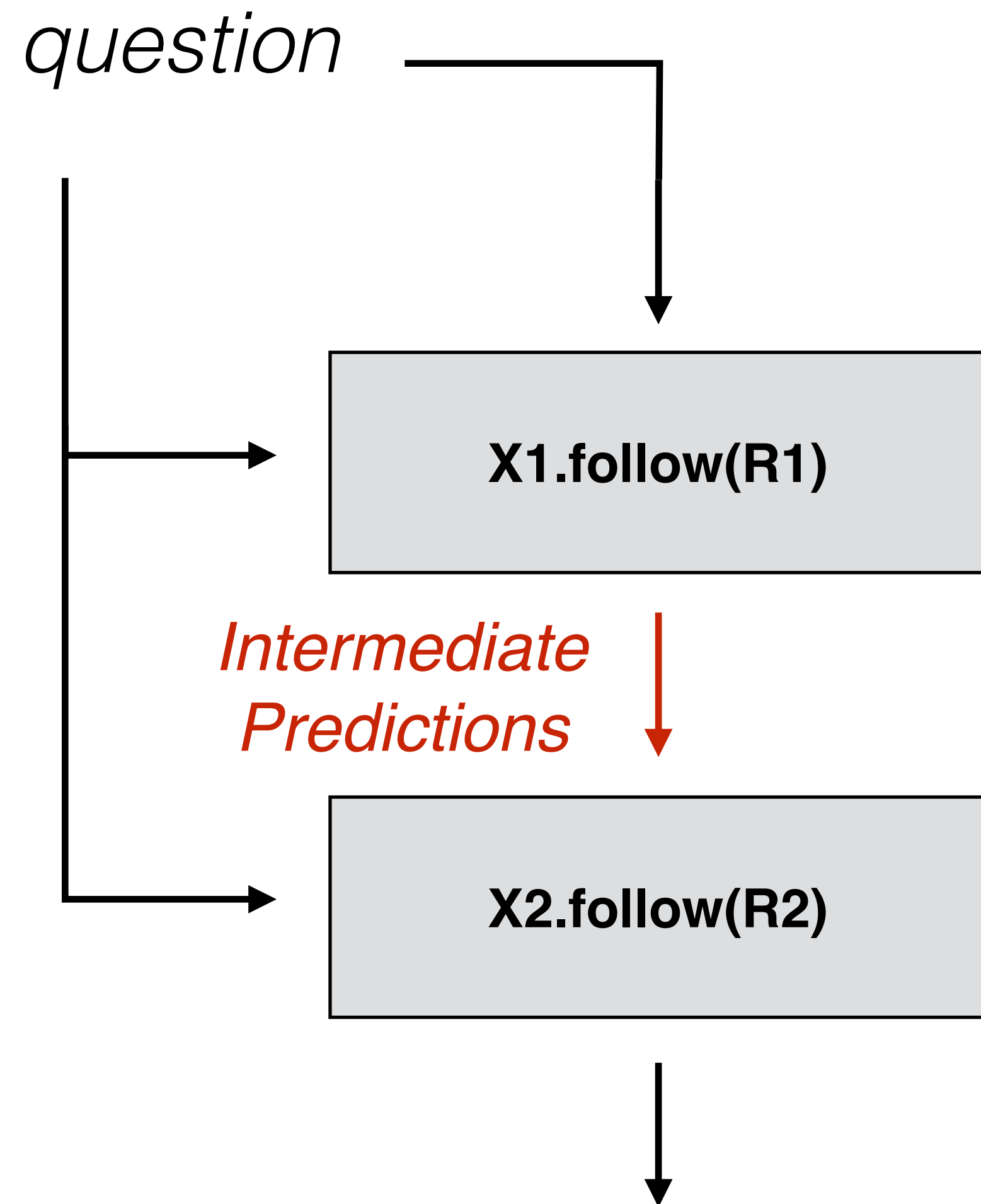


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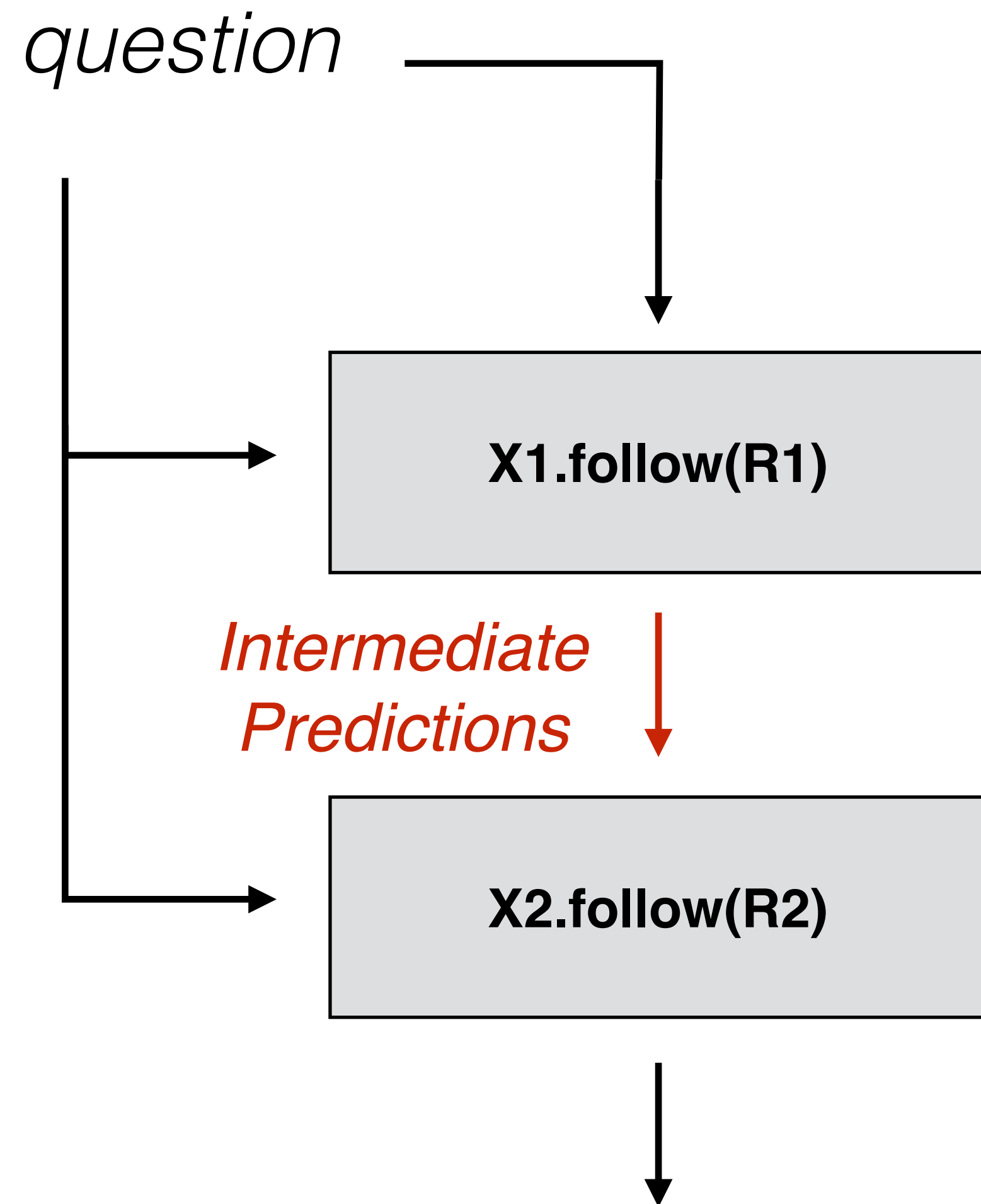
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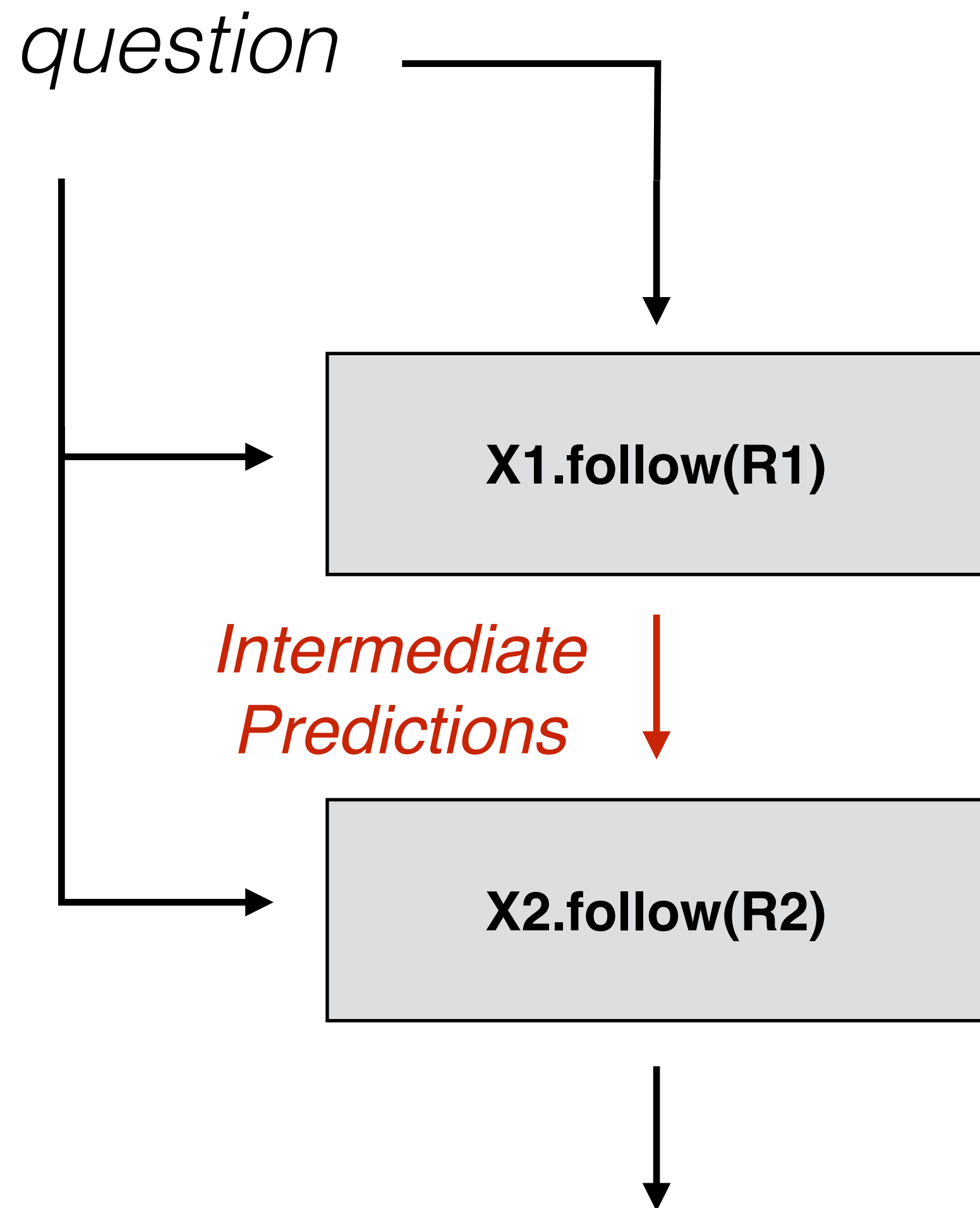
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 - This drops to **47%** for **incorrectly answered** questions

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Analysis - Intermediate Predictions



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 - This drops to **47%** for **incorrectly answered** questions
- Rest **17%** the model learned to answer in a single hop:

*What are the genres of the films directed by Justin Simien?
Intermediate = **drama**, Final = **drama***

*What genres are the movies acted by Jeremy Lin in?
Intermediate = **documentary**, Final = **documentary***

Conclusion

- Word embeddings provide linguistic knowledge to NLP systems
- Can mention / span embeddings provide world knowledge?

Future Directions

Enriching the Knowledge Base

- Beyond entities and relations
- Beyond English
- Beyond Text

Expanding to tasks other than QA

- Language Modeling
- Dialog
- Translation

Thank You.