

Querying unNorMaLiZED and Inc_mpl_te Knowledge Bases

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Stanford University



Automated Knowledge Base Construction (AKBC) 2016

June 17, 2016

Computing the answer

What is the second most populous city in California?

Computing the answer

What is the second most populous city in California?



semantic parsing

$\text{argmax}(\text{Type.City} \sqcap \text{ContainedBy.CA}, \text{Population}, 2)$

Computing the answer

What is the second most populous city in California?



semantic parsing

$\text{argmax}(\text{Type.City} \sqcap \text{ContainedBy.CA}, \text{Population}, 2)$



execute

San Diego

Computing the answer

Which states' capitals are also their largest cities by area?

Computing the answer

Which states' capitals are also their largest cities by area?



semantic parsing

$\mu x. \text{Type.USState} \sqcap \text{Capital}.\text{argmax}(\text{Type.City} \sqcap \text{ContainedBy}.x, \text{Area})$

Computing the answer

Which states' capitals are also their largest cities by area?



semantic parsing

$\mu x. \text{Type.USState} \sqcap \text{Capital.argmax}(\text{Type.City} \sqcap \text{ContainedBy}.x, \text{Area})$



execute

Arizona, Hawaii, Idaho, Indiana, Iowa, Oklahoma, Utah

Computing the answer

Which states' capitals are also their largest cities by area?



semantic parsing

$\mu x. \text{Type.USState} \sqcap \text{Capital.argmax}(\text{Type.City} \sqcap \text{ContainedBy}.x, \text{Area})$



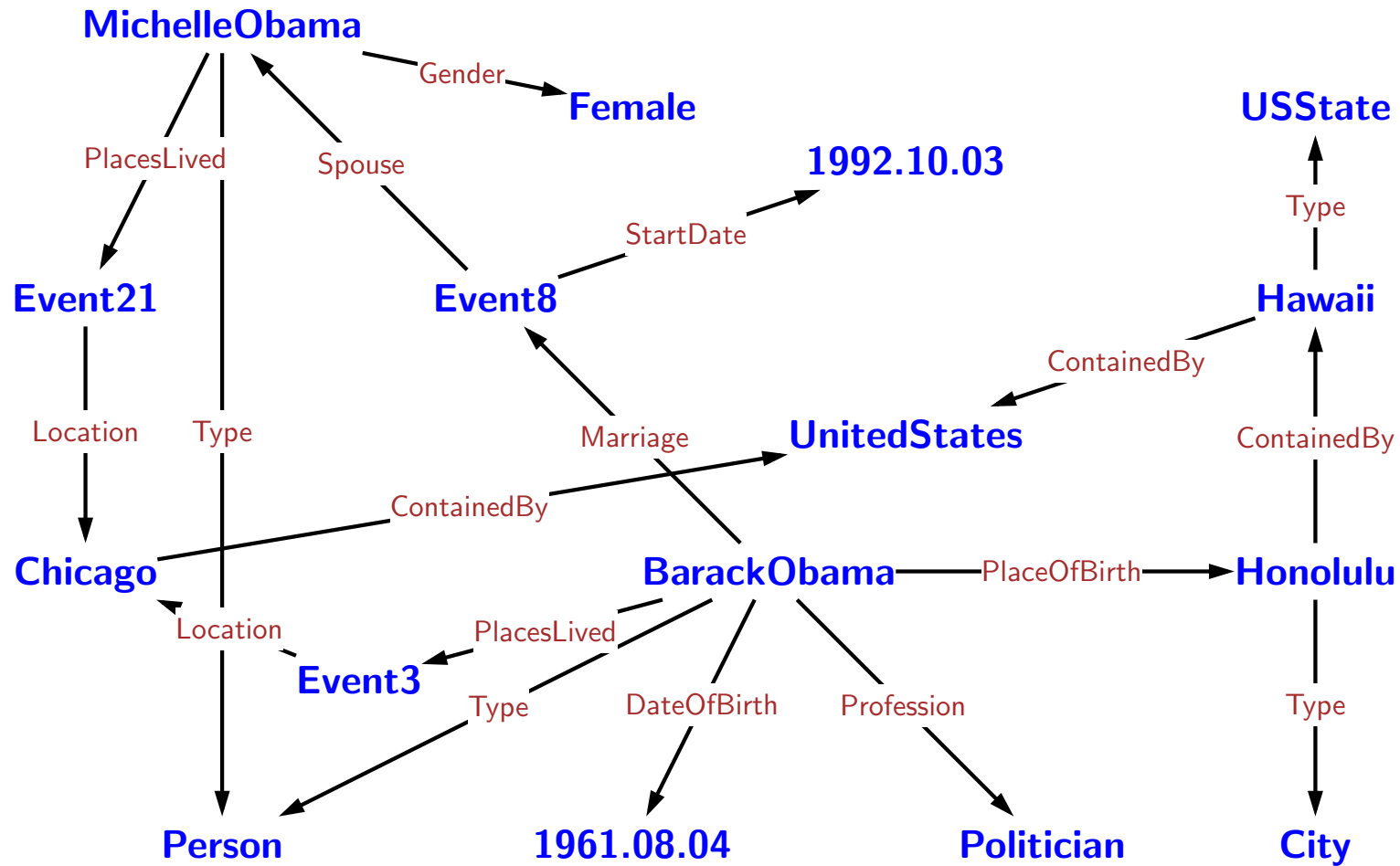
execute

Arizona, Hawaii, Idaho, Indiana, Iowa, Oklahoma, Utah

Strongly leverages KB structure!

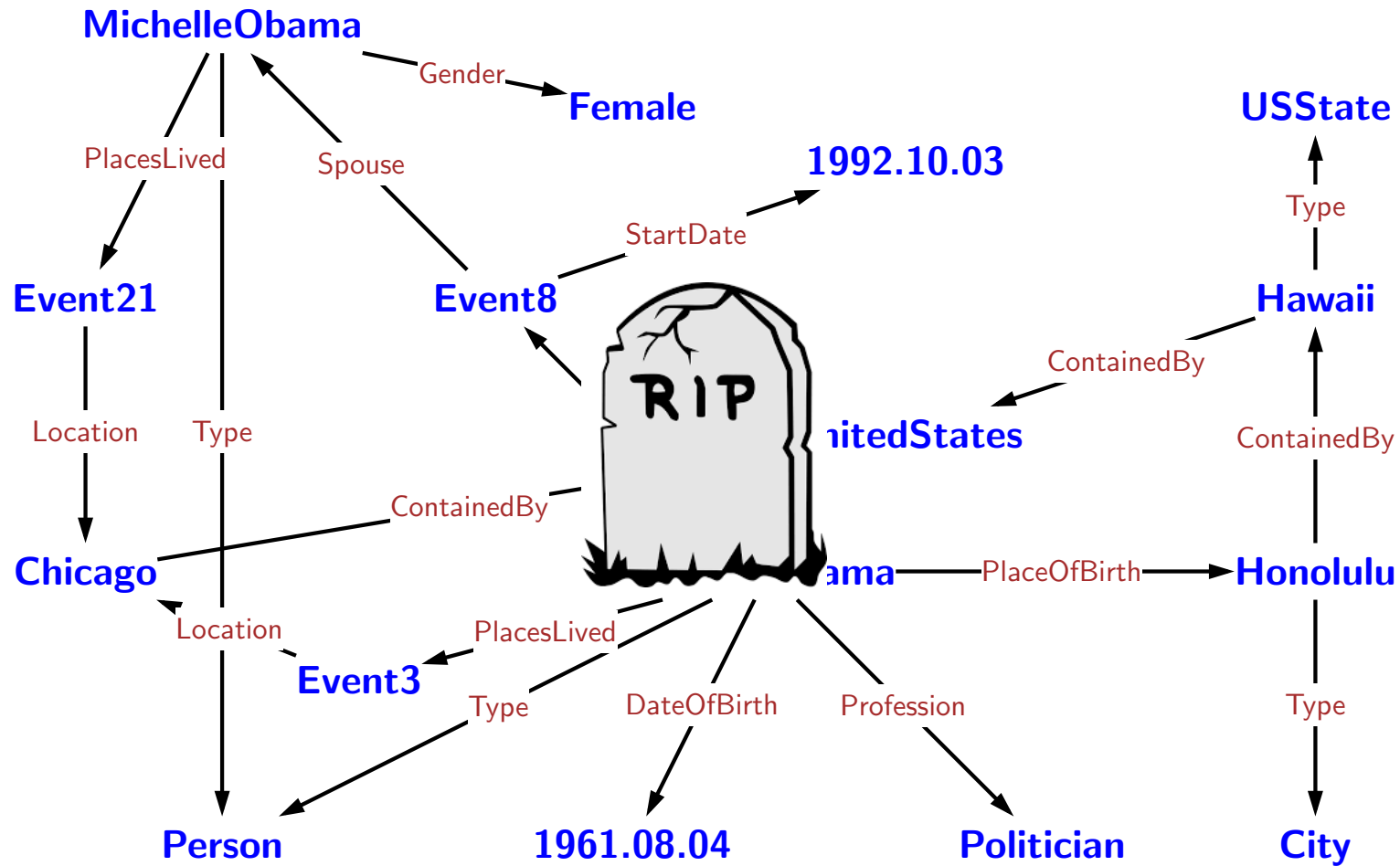
Freebase

100M **entities** (nodes) 1B **assertions** (edges)

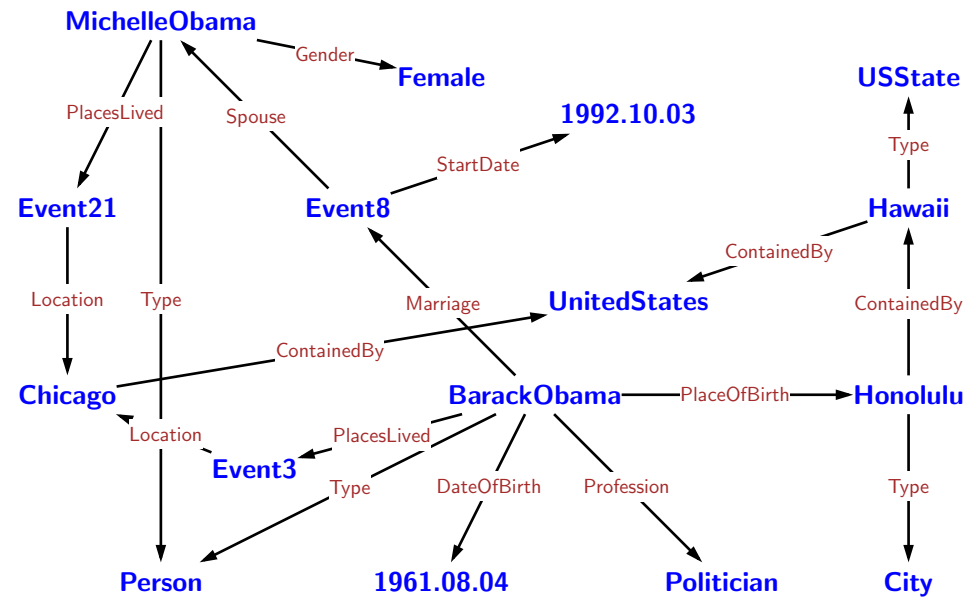


Freebase

100M entities (nodes) 1B assertions (edges)



*hiking trails near Palo Alto
dishes at Oren's Hummus
ACL 2014 papers*

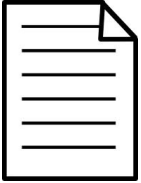


hiking trails near Palo Alto
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ACL 2014 papers

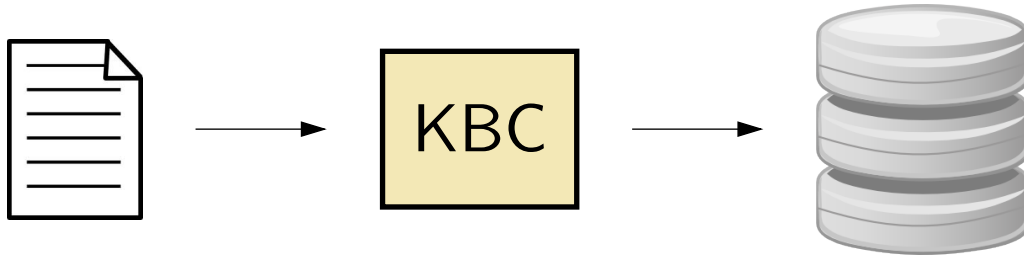


Fewer than 10% of WebQuestions answerable via Freebase

Obtaining better KBs



Obtaining better KBs



Obtaining better KBs



Obtaining better KBs



Philosophy

Focus on the **end-to-end** task of question answering.



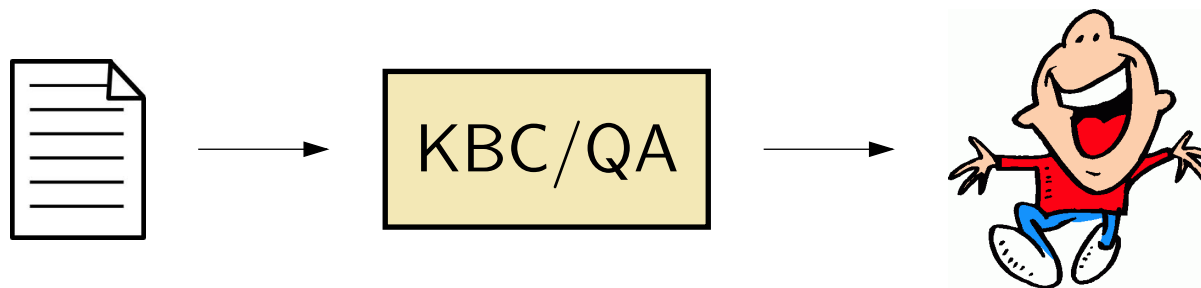
Let that end goal drive learning and construction of **intermediate** knowledge representations.

Philosophy

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Let that end goal drive learning and construction of **intermediate** knowledge representations.



Outline

On web pages

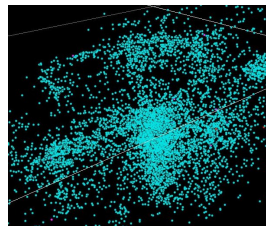
The screenshot shows a Ranker search result for 'All Italian Airlines'. The search bar at the top contains the text 'All Italian Airlines'. Below the search bar, there is a list of results. The first result is 'All Italian Airlines' with a score of 6,235. Below this, there is a list of airlines ranked from 1 to 7:

Rank	Airline
1	Air Dolomiti
2	Air Europe
3	Air Italy
4	Air One
5	Air Valée
6	Aldisavia
7	Alitalia-Linee Aeree Italiane

On tables

Year	Competition	Venue	Position	Event	Notes
Representing  Poland					
2001	World Youth Championships	Debrecen, Hungary	2nd	400 m	47.12
	European Junior Championships	Grosseto, Italy	1st	Medley relay	1:50.46
2003	European Junior Championships	Grosseto, Italy	1st	4x400 m relay	3:06.12
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In vector space



Simple semantic parsing on web pages



Panupong (Ice) Pasupat

ACL 2014

Semantic parsing on the web

Input:

- query x

hiking trails near Baltimore

- web page w

Semantic parsing on the web

Input:

The screenshot displays the EveryTrail website interface. At the top, there is a navigation bar with links for HOME, EXPLORE, MOBILE APPS, CREATE TRIP, and MY EVERYTRAIL. A search bar is located on the right side of the navigation bar. Below the navigation bar, there is a header section for "Hiking near Baltimore, Maryland". This section includes social media sharing options for "Like" (49 people like this) and "Tweet" (1). A paragraph of text explains that the list shows the most popular hiking trails based on user reviews, votes, and mobile downloads. Below this text, there is a "Sort" dropdown menu set to "Rating" and a checked checkbox for "show community trips".

The "Filter Trails" section is visible, with a sub-section titled "Guides". Two hiking guides are listed:

- Avalon Super Loop - Patapsco State Park**
Patapsco State Park, Maryland, United States (7.5 miles away)
★★★★★
Difficult: 12.7 miles, Full day
lots of ruins, waterfalls, trains, and river views
Do the entire Avalon Patapsco state park in 1 day! This loop covers the majority of the Avalon area, with multiple ruins, waterfalls and other artifacts to find along the way. Starting at the parking lot, you hike up the road a ways to the Ridge trail sign. The next leg is the maintenance loop which has an old old tractor to look at and some...
- Patapsco Valley State Park - Hilton Area 8 Miles/Moderate**
Catonsville, Maryland, United States (7.7 miles away)
Moderate: 7.8 miles, Half day
8 mile circuit hike including sections in the Avalon, Orange Grove and Glen Artney areas of PVSP.
OVERVIEW: One of the more scenic routes in the Patapsco Valley State Park in the Hilton Area which includes multiple stream crossings, viewings and waterfalls including Cascade waterfalls, two swinging bridge crossings, Ilchester Overlook, and Bloedes Dam. This is a moderate hike and can be hiked in either direction. Counterclockwise is an easier hike...

On the right side of the page, there is a map of Maryland and surrounding areas (Pennsylvania, Delaware, Virginia) with several red location pins. Below the map is a section titled "Popular places for Hiking" with a list of links: "Hiking in Maryland", "Hiking in Patapsco Valley State Park", "Hiking in Calvert Cliffs State Park", and "Hiking in Patuxent River State Park".

Semantic parsing on the web

Input:

EveryTrail

HOME | EXPLORE | MOBILE APPS | CREATE TRIP | MY EVERYTRAIL

Search GO

(Update Current Location) [Login](#) | [Signup](#)

Hiking near Baltimore, Maryland


[Like](#) 49 people like this. [Tweet](#) 1

This list shows the most popular Hiking near Baltimore, Maryland based on user reviews, votes, and mobile downloads. Plan your next trip with EveryTrail guides by downloading a guide to your mobile phone with the EveryTrail iPhone or Android app.

Sort: show community trips

Filter Trails


Guides



Avalon Super Loop - Patapsco State Park
Patapsco State Park, Maryland, United States (7.5 miles away)
★★★★★

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Popular places for Hiking

- [Hiking in Maryland](#)
- [Hiking in Patapsco Valley State Park](#)
- [Hiking in Calvert Cliffs State Park](#)
- [Hiking in Patuxent River State Park](#)

Semantic parsing on the web

Input:

- query x

hiking trails near Baltimore

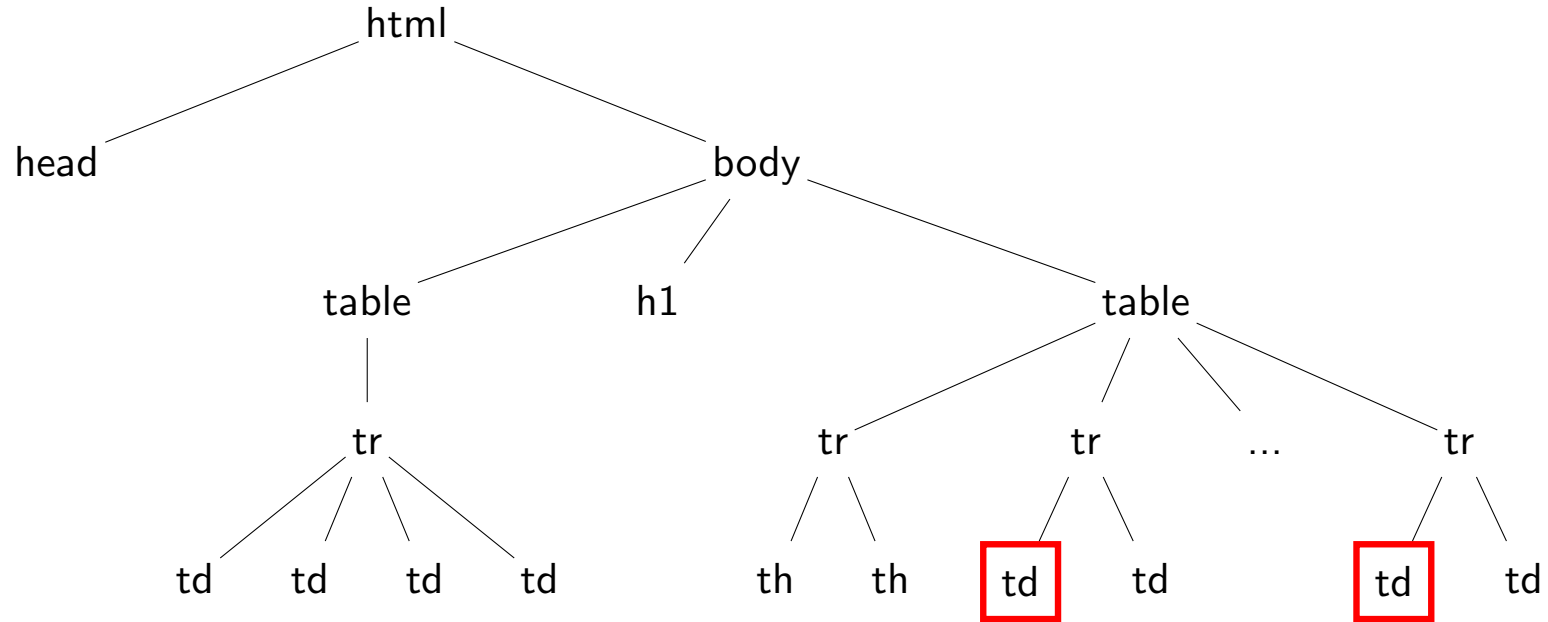
- web page w

Output:

- list of entities y

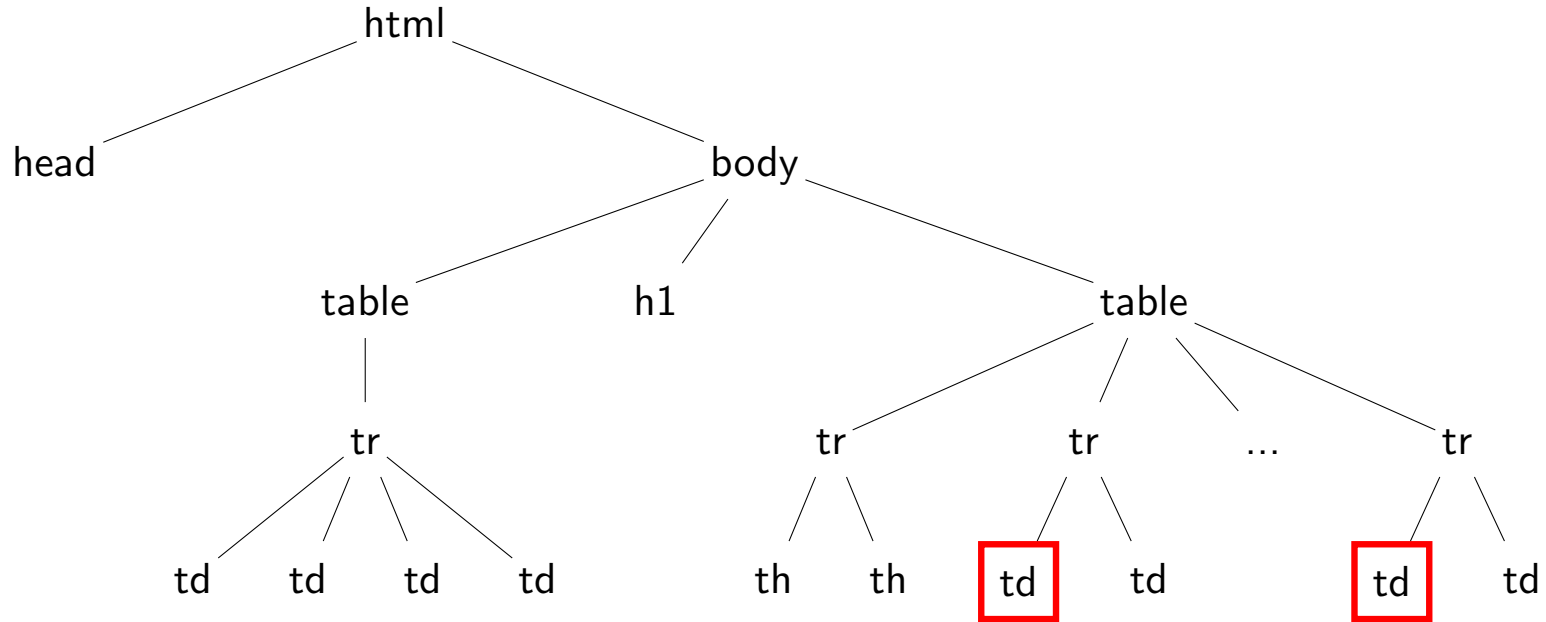
[Avalon Super Loop, Patapsco Valley State Park, ...]

Logical forms: XPath expressions



$z = /html[1]/body[1]/table[2]/tr/td[1]$

Logical forms: XPath expressions

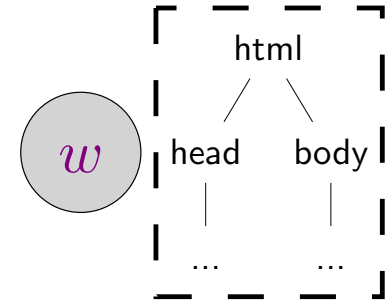


$z = /html[1]/body[1]/table[2]/tr/td[1]$

A low-level KB

Framework

*hiking trails
near Baltimore* x



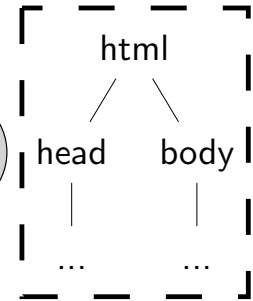
Framework

*hiking trails
near Baltimore* x

$(|\mathcal{Z}| \approx 8500)$

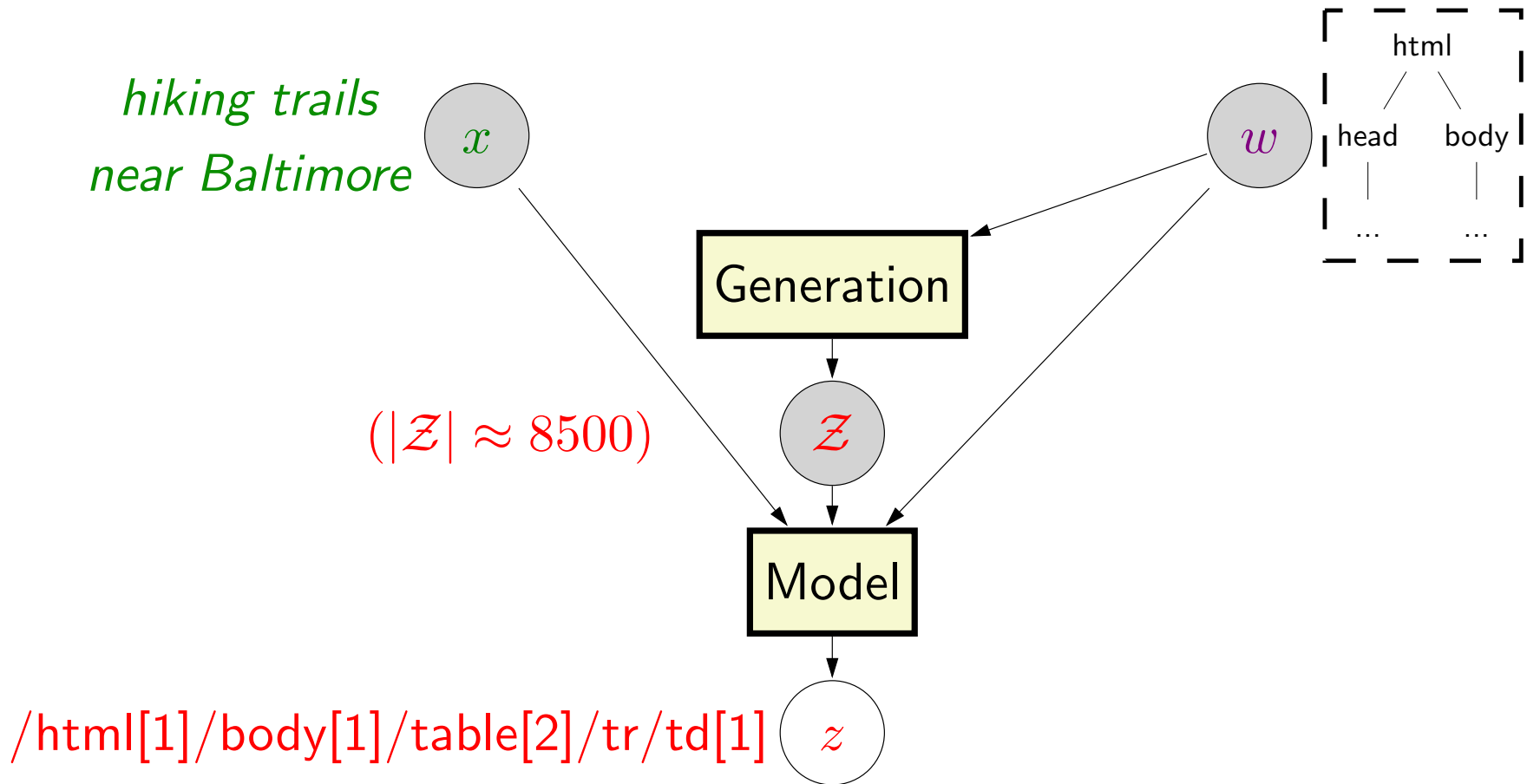
Generation

w

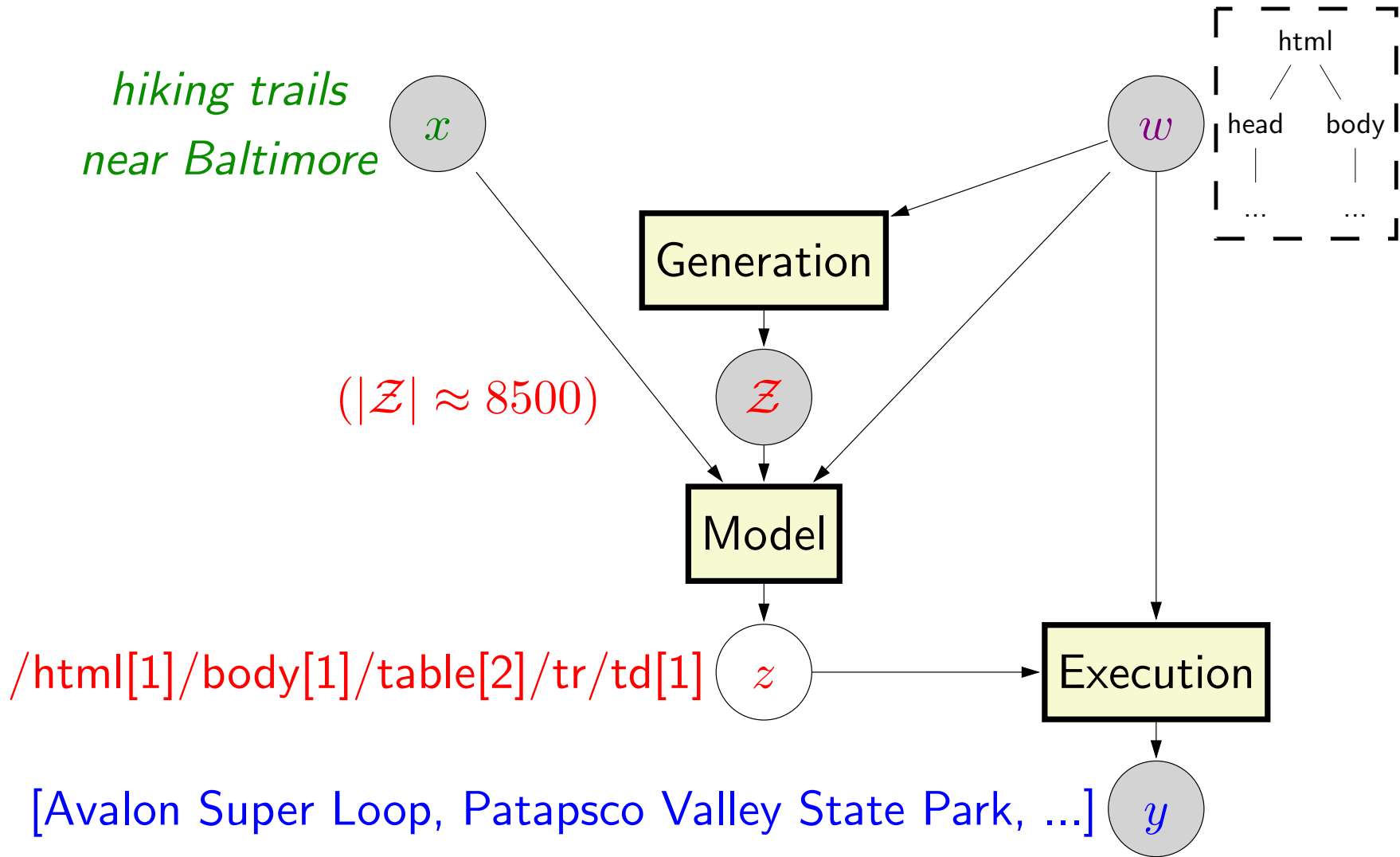


\mathcal{Z}

Framework



Framework



Dataset

airlines of italy

natural causes of global warming

lsu football coaches

bf3 submachine guns

badminton tournaments

foods high in dha

technical colleges in south carolina

songs on glee season 5

singers who use auto tune

san francisco radio stations

Dataset

Ranker find a list or topic

create a list recent people film tv music sports travel

home > places/travel > airlines

All Italian Airlines

List of Airlines 6,395 votes 19 items

A list of all Italian Airlines. This list focuses on passenger airlines including international, interco... TSA and the airports themselves have taken most of the headlines recently, airline companies h... 9/11. (And yet, the airlines survive.) While air travel was once seen as a symbol of luxury and we

VIEW: INFO SUBSCRIBE BLOG MORE OPTIONS

Rank	Name	Hubs
1	Air Dolomiti	Munich Airport, Verona Villafranca Airport, Tre Venezie Gliese Airport
2	Air Europe	Malpensa Airport
3	Air Italy	Malpensa Airport, Leonardo da Vinci-Fiumicino Airport, Verona Villafranca Airport
4	Air One	Malpensa Airport
5	Air Vallée	Prima Airport, Aosta Airport, Federico Fellini International Airport
6	Alidaunia	Foggia "Gino Lisa" Airport
7	Alitalia-Linee Aeree Italiane	Malpensa Airport, Leonardo da Vinci-Fis Airport

airlines of italy

10. Greenhouse Effect

Greenhouse effect is the process in which the atmosphere of the Earth trap some of the heat coming from the sun, making the Earth warm but due to burning fuels, cutting trees, the concentration of heat on Earth is increased to abnormal levels making greenhouse effect as one of the major causes of global warming. Carbon Dioxide, methane, nitrous oxide are the greenhouse gases which helps to keep the Earth warm. It is a natural phenomenon that takes place with the adequate concentrations of the greenhouse gases. But when the concentration of these gases rises, they disturb the climatic conditions, making the Earth more warm. These gases are not able to escape, which is the cause of worldwide increase in temperature. So the balance of carbon dioxide and other gases should be maintained so that it does not become the major reason of global warming.

9. Air Pollution

The harmful gases emitted from the vehicles and factories and the greenhouse gases cause pollution in the air and these gases not remain in the atmosphere. The smoke, rather in the atmosphere forms a thick full of harmful

natural causes of global warming

TEAMS SCHEDULES TICKETS FAN ZONE VIDEO + AUDIO FACILITIES DEPARTMENTS CONNECT VISITORS

Home > Teams > Football > COACHES

Football

NEWS SCHEDULES ROSTERS COACHES STATISTICS

Season 2013-14

2013 Football Coaches

 Les Miles Head Coach	 Cam Cameron Coordinator/Quarterbacks Coach	 John Chavis Defensive Coordinator	 Frank Wilson Running Backs Coach/Receiving Coordinator
 Steve Ensminger Tight Ends Coach	 Brick Haley Defensive Line Coach	 Adam Henry Wide Receivers Coach	
 Thomas McGaughey Special Teams Coordinator	 Corey Raymond Defensive Backs Coach	 Greg Studrawa Offensive Line Coach	
 Steve Kragthorpe Administrator	 Tommy Moffitt Strength & Conditioning Coordinator	 Dr. Sam Nader Assistant Athletics Director - Football	

lsu football coaches

Dataset statistics

2773 examples

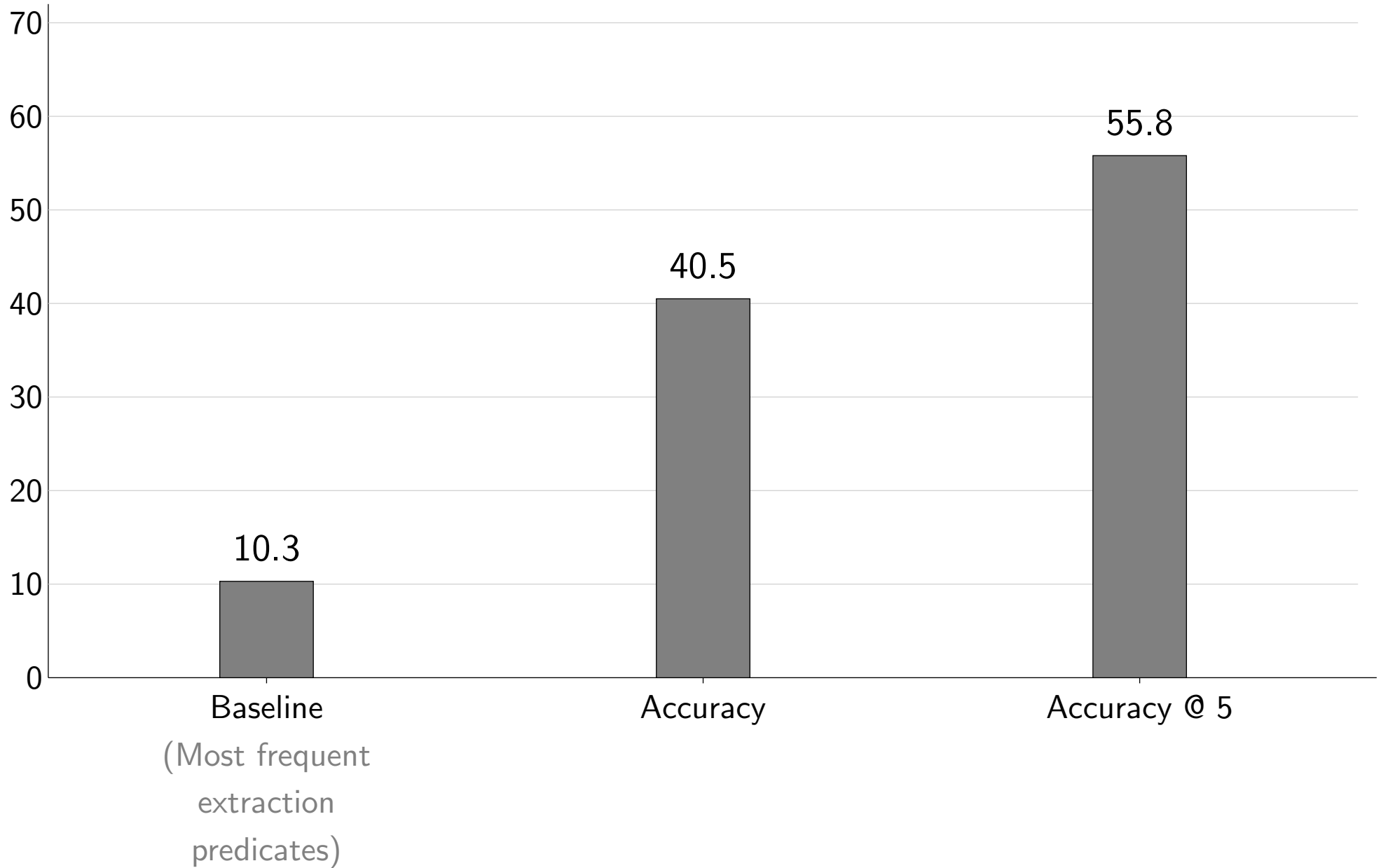
2269 unique queries

894 unique headwords ← long tail!

1483 unique web domains ← long tail!

(≠ wrapper induction)

Results



Correct prediction

Query: *disney channel movies*

All Disney Channel Original Movies
by hannersbananers created 23 Apr 2011 | last updated - 24 Apr 2011

In order based on date.

Showing all 91 Titles Sort by: List order

[Log In](#) to copy items to your own lists. View: [Grid] [List] [Table]

Northern Lights (1997 TV Movie)
(111 mins.)
Director: Linda Yellen
Stars: Diane Keaton, Maury Chaykin, Joseph Cross, Kathleen York
[Add to Watchlist](#)

Under Wraps (1997 TV Movie)
Three kids accidentally re-animate a mummy on Halloween. (95 mins.)
Director: Greg Beeman
Stars: Adam Wylie, Mario Yedidia, Clara Bryant, Ken Hudson Campbell

/html[1]/body/div[2]/div/div/div[3]/div[1]/div/div/div/div/b

Ranking error

Query: *doctors at emory*



Aaron, Maria MD	Ophthalmology
Abboushi, Nour MD	Plastic Surgery
Abdou, Mahmoud MD	Cardiovascular Disease
Abramowsky, Carlos MD	Pathology
Abruzzo, Todd MD	Radiology

/html/body/div[3]/div[4]/table/tbody/tr/td[2]

Need better understanding of entities/categories

Coverage error

Query: *hedge funds in new york*

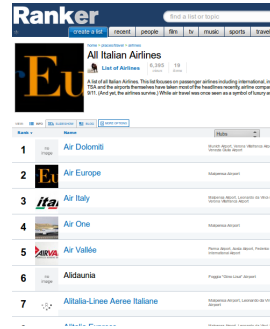
Rank ↕	Firm	Headquarters ↕
1	Bridgewater Associates	 Westport, CT
2	Man Group	 London
3	J.P. Morgan Asset Management	 New York
4	Brevan Howard Asset Management	 London
5	Och-Ziff Capital Management Group	 New York
6	Paulson & Co.	 New York
7	BlackRock Advisors	 New York

/html/body/div[3]/div[3]/div[4]/.../table/tbody/tr/td[2]/a

Need compositionality

Outline

On web pages



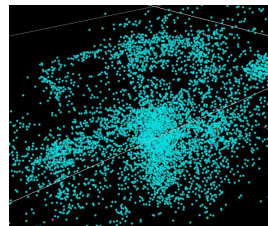
The screenshot shows the Ranker website interface. At the top, there's a search bar and navigation links for 'recent', 'people', 'tv', 'music', 'sports', and 'travel'. Below the search bar, there's a section titled 'All Italian Airlines' with a 'List of Airlines' link. The main content is a ranked list of airlines:

Rank	Airline	Headquarters
1	Air Dolomiti	Merano, Veneto, Italy
2	Air Europe	Milano, Italy
3	Air Italy	Milano, Italy
4	Air One	Milano, Italy
5	Air Valle	Prato, Tuscany, Italy
6	Aldania	Prato, Tuscany, Italy
7	Alitalia-Linee Aeree Italiane	Milano, Italy

On tables

Year	Competition	Venue	Position	Event	Notes
Representing  Poland					
2001	World Youth Championships	Debrecen, Hungary	2nd	400 m	47.12
	European Junior Championships	Grosseto, Italy	1st	Medley relay	1:50.46
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2006	Universiade	Izmir, Turkey	7th	400 m	46.89
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2009	Universiade	Belgrade, Serbia	2nd	4x400 m relay	3:05.69

In vector space



Semantic parsing on tables



Panupong (Ice) Pasupat

ACL 2015, ACL 2016

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In what city did Piotr's last 1st place finish occur?

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How long did it take this competitor to finish the 4x400 meter relay at Universiade in 2005?

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2009	Universiade	Belgrade, Serbia	2nd	4x400 m relay	3:05.69

Where was the competition held immediately before the one in Turkey?

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How many times has this competitor placed 5th or better in competition?

Dataset

Statistics:

- 22000 question/answers
- 2100 tables
- 6.3 columns and 27.5 rows per table

Dataset

Statistics:

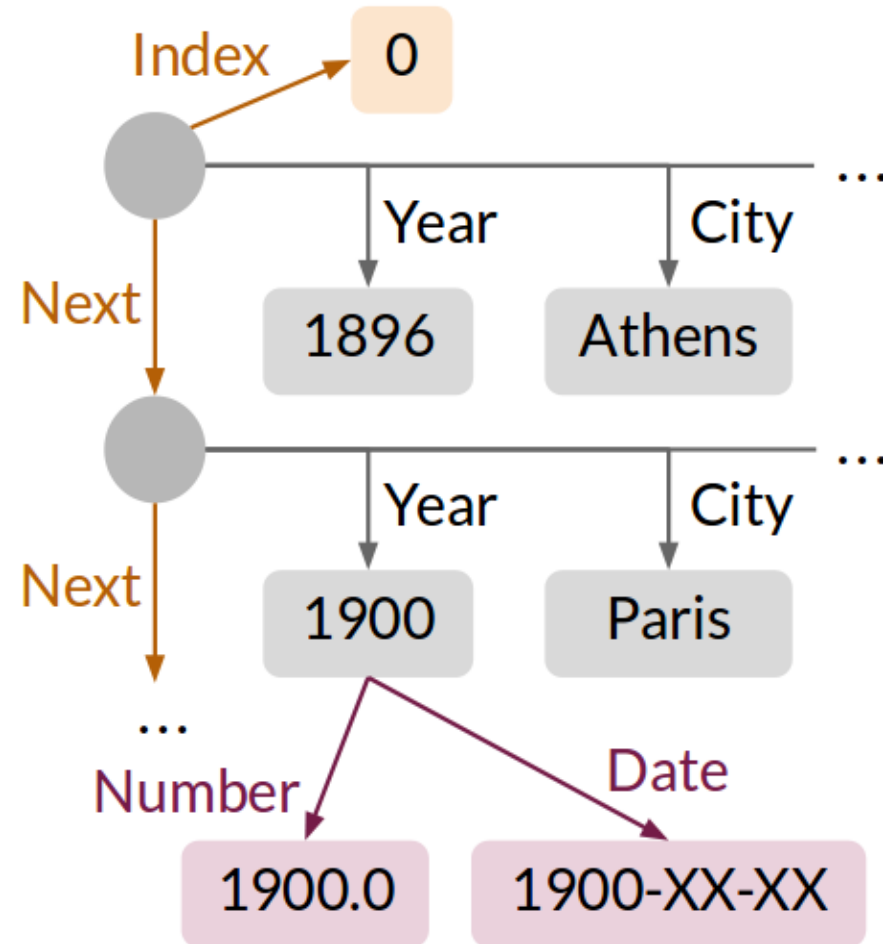
- 22000 question/answers
- 2100 tables
- 6.3 columns and 27.5 rows per table

Challenges:

- High logical complexity (conjunction, disjunction, superlatives, comparatives, aggregation, arithmetic)
- Tables are unnormalized
- Train and test tables are distinct; need to generalize!

Knowledge representation

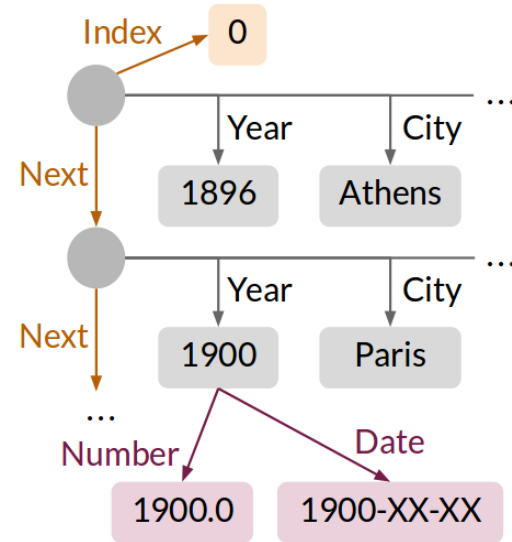
Year	City	Country	Nations
1896	Athens	Greece	14
1900	Paris	France	24
1904	St. Louis	USA	12
...
2004	Athens	Greece	201
2008	Beijing	China	204
2012	London	UK	204



Add normalization / auxiliary edges (custom functions), push resolution to semantic parsing

Model

Year	City	Country	Nations
1896	Athens	Greece	14
1900	Paris	France	24
1904	St. Louis	USA	12
...
2004	Athens	Greece	201
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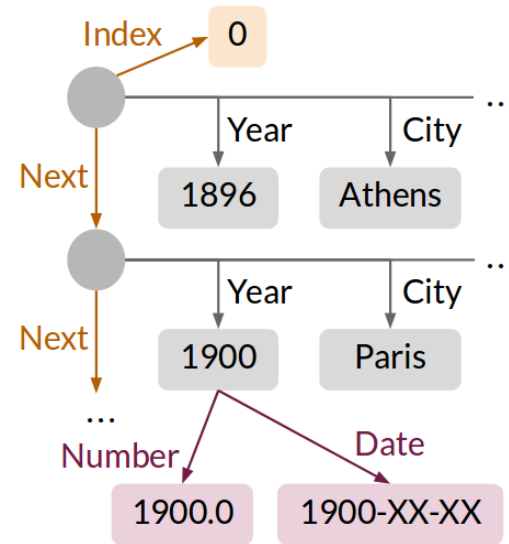


Greece held its last Summer Olympics in which year?

2004

Model

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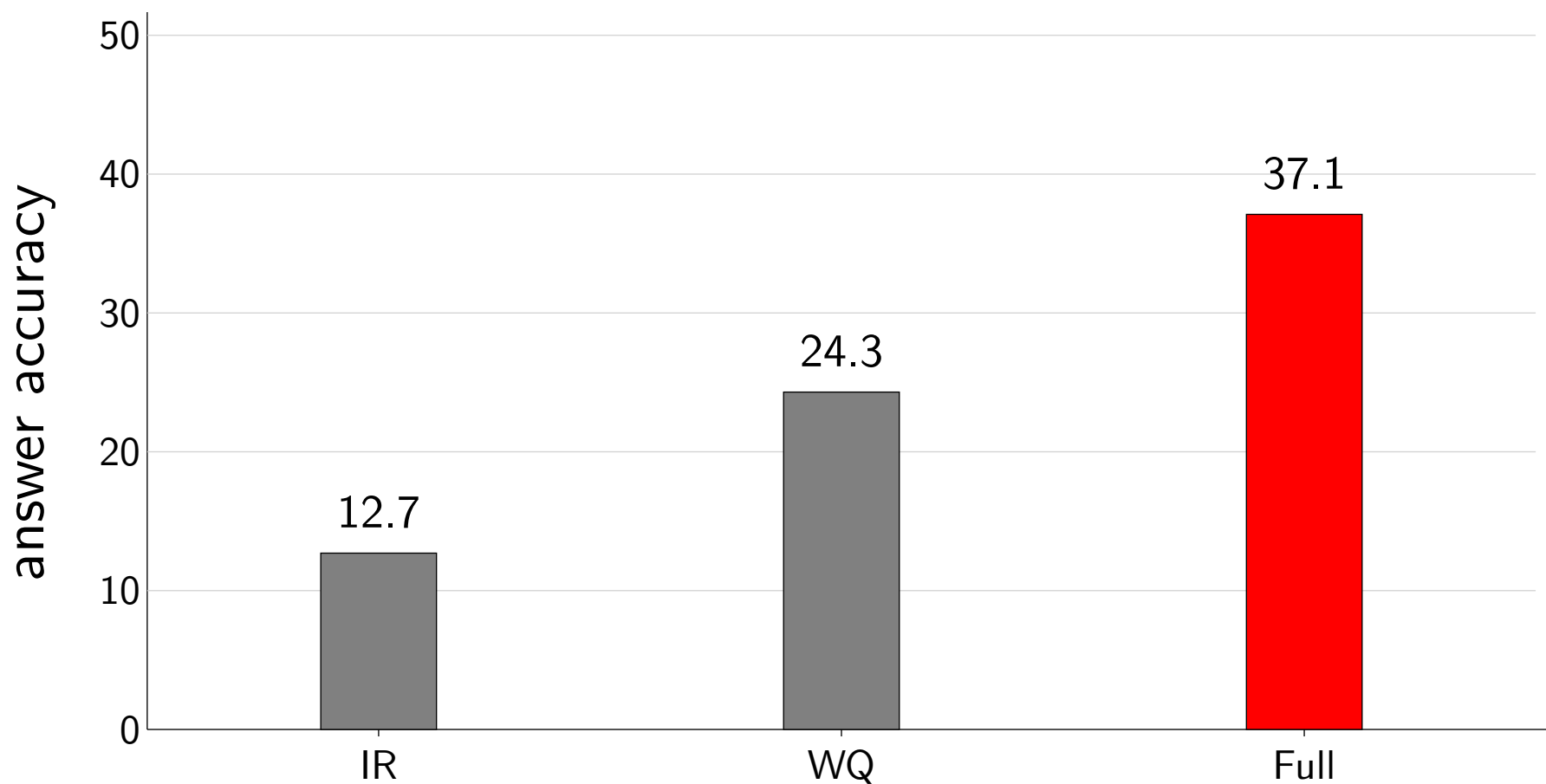
$\mathbf{R}[\text{Date}].\mathbf{R}[\text{Year}].\text{argmax}(\text{Country}.\text{Greece}, \text{Index})$

2004

Results

IR: Train classifier to pick answer directly from table.

WQ: Use logical complexity of our previous Freebase work.

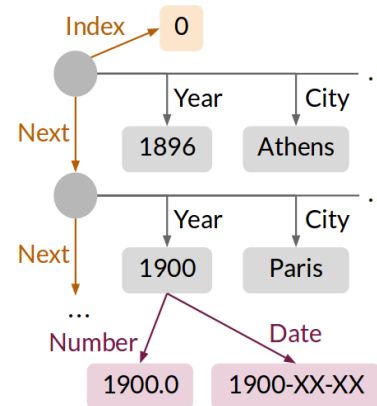


Oracle accuracy

Can the system even generate a set of candidates containing the answer?

How many times did Greece hold the summer olympics?

Year	City	Country	Nations
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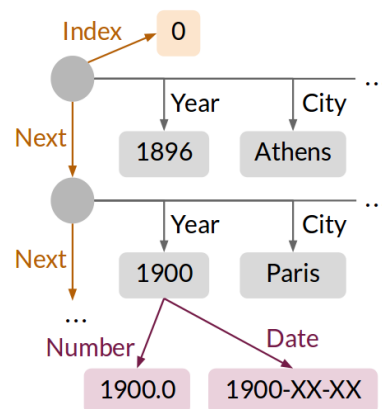
2

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2

Method

ACL 2015

ACL 2016 (dynamic prog. on denotations)

LF accuracy

53.5%

76.0%

Error analysis

Unhandled operations (19%):

- *Was there more gold medals won than silver?*
- *Which movies were number 1 for at least two **consecutive** weeks?*
- *How many titles had the **same** author listed as the illustrator?*

Error analysis

Unhandled operations (19%):

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Table normalization:

- *In what city did Piotr's last 1st place finish occur? ...[Bangkok, Thailand]...*
- *How long does the show defcon 3 last? ...[2pm-3pm]...*

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Table normalization:

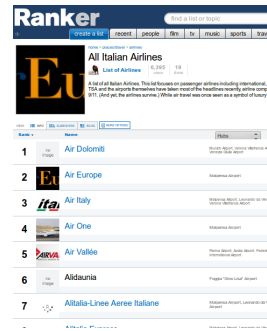
- *In what city did Piotr's last 1st place finish occur? ...[Bangkok, Thailand]...*
- *How long does the show defcon 3 last? ...[2pm-3pm]...*

Lexical mismatch:

- *Mexican* ⇒ Mexico, *airplane* ⇒ Model

Outline

On web pages

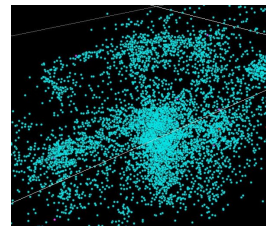


The screenshot shows a Ranker website page titled "All Italian Airlines". It features a search bar at the top and a list of airlines ranked from 1 to 7. The airlines listed are: 1. Alitalia, 2. Air Dolomiti, 3. Air Europa, 4. Alitalia, 5. Air One, 6. Air Valle, and 7. Alitalia-Linee Aeree Italiane. Each entry includes the airline's logo and name.

On tables

Year	Competition	Venue	Position	Event	Notes
Representing  Poland					
2001	World Youth Championships	Debrecen, Hungary	2nd	400 m	47.12
	European Junior Championships	Grosseto, Italy	1st	Medley relay	1:50.46
2003	European Junior Championships	Grosseto, Italy	1st	4x400 m relay	3:06.12
	European Junior Championships	Tampere, Finland	3rd	400 m	46.69
2005	European U23 Championships	Tampere, Finland	2nd	4x400 m relay	3:08.62
	European U23 Championships	Erfurt, Germany	11th (sf)	400 m	46.62
	European U23 Championships	Erfurt, Germany	1st	4x400 m relay	3:04.41
	Universiade	Izmir, Turkey	7th	400 m	46.89
2006	Universiade	Izmir, Turkey	1st	4x400 m relay	3:02.57
	World Indoor Championships	Moscow, Russia	2nd (h)	4x400 m relay	3:06.10
	European Championships	Gothenburg, Sweden	3rd	4x400 m relay	3:01.73
2007	European Indoor Championships	Birmingham, United Kingdom	3rd	4x400 m relay	3:08.14
	Universiade	Bangkok, Thailand	7th	400 m	46.85
2008	Universiade	Bangkok, Thailand	1st	4x400 m relay	3:02.05
	World Indoor Championships	Valencia, Spain	4th	4x400 m relay	3:08.76
	Olympic Games	Beijing, China	7th	4x400 m relay	3:00.32
2009	Universiade	Belgrade, Serbia	2nd	4x400 m relay	3:05.69

In vector space



Compositional Queries in Vector Space



Kelvin Guu



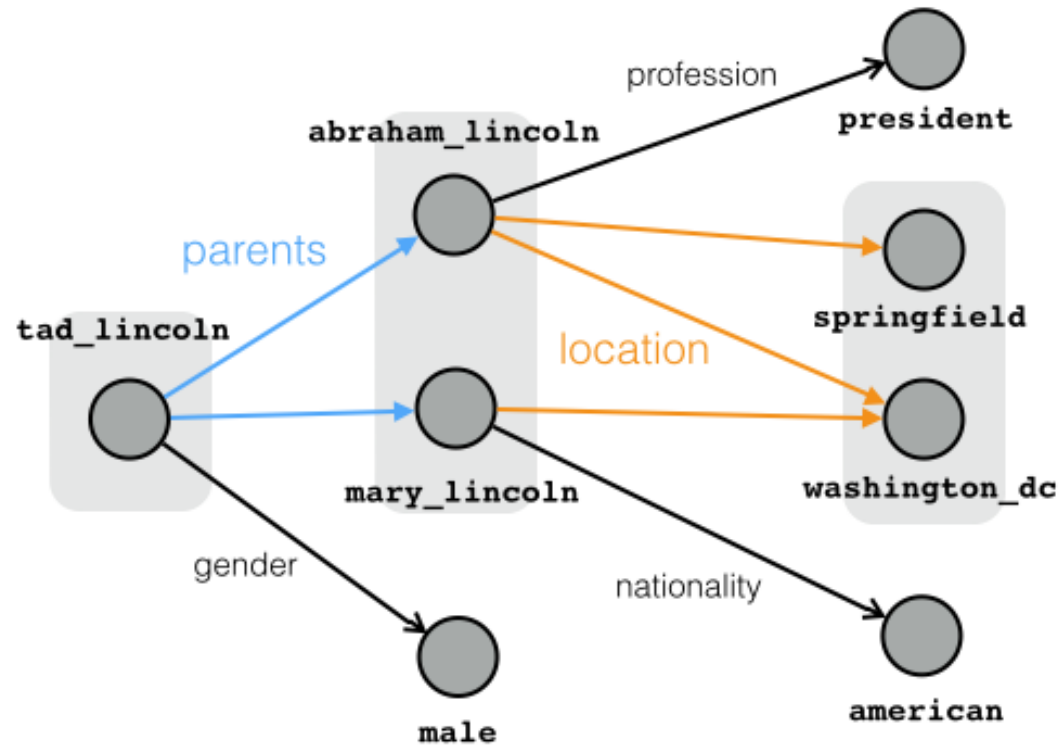
John Miller

Focus on path queries

TadLincoln/Parents/Location

Focus on path queries

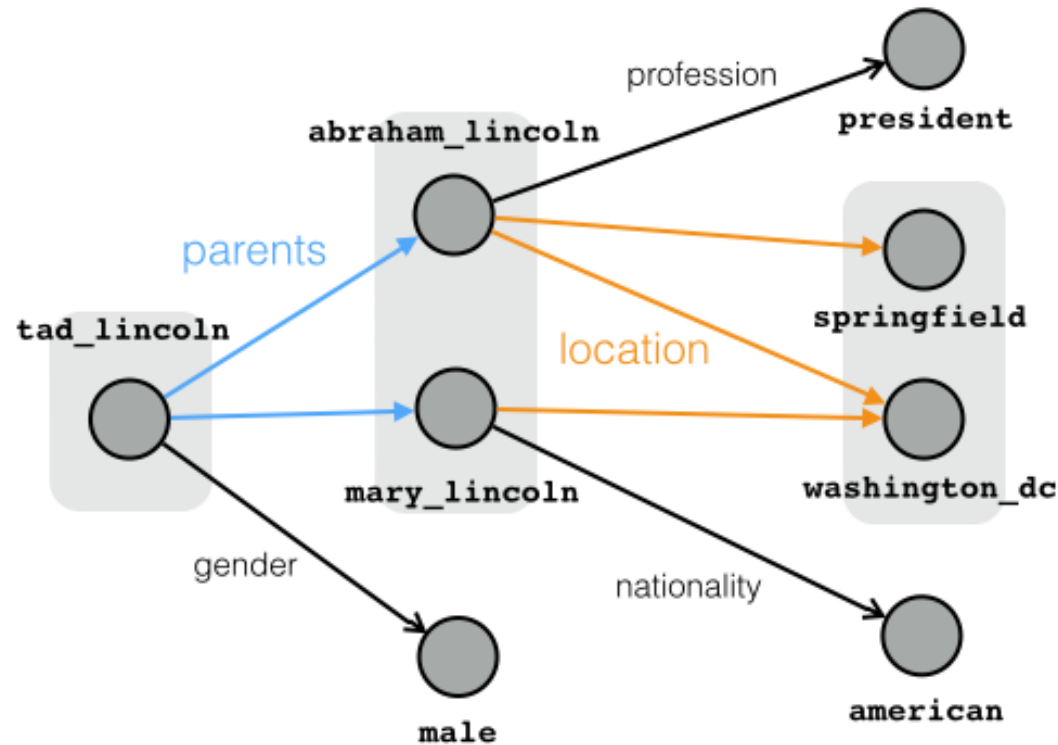
TadLincoln/Parents/Location



Strength: compositionality

Focus on path queries

TadLincoln/Parents/Location



Strength: compositionality

Weaknesses: can't handle fact incompleteness, hypotheticals

abraham_lincoln/daughter/ethnicity

Vector space relation modeling

Score(entity1, relation, entity2)

Vector space relation modeling

$$\text{Score}(\text{entity1}, \text{relation}, \text{entity2})$$

Prior work:

- Tensor factorization [Nickel et al., 2011]
- Neural Tensor Network [Socher et al., 2013]
- TransE [Bordes et al., 2013]
- Universal schema [Riedel et al., 2013]
- General framework + comparison [Yang et al., 2015]
- Compositional embedding of paths [Neelakantan et al., 2015]

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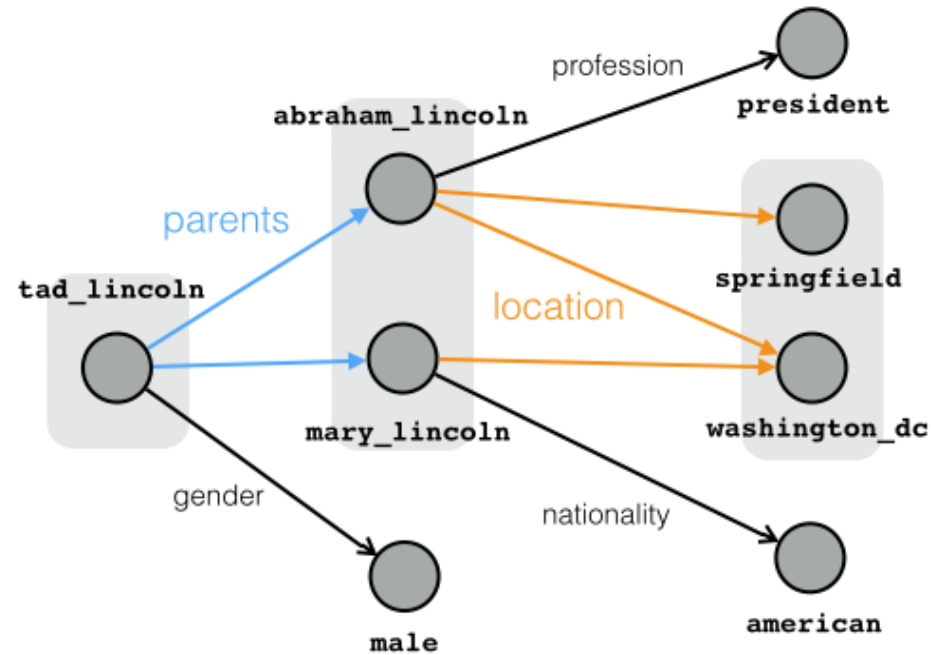
Strength: handles incompleteness

Weakness: no compositionality

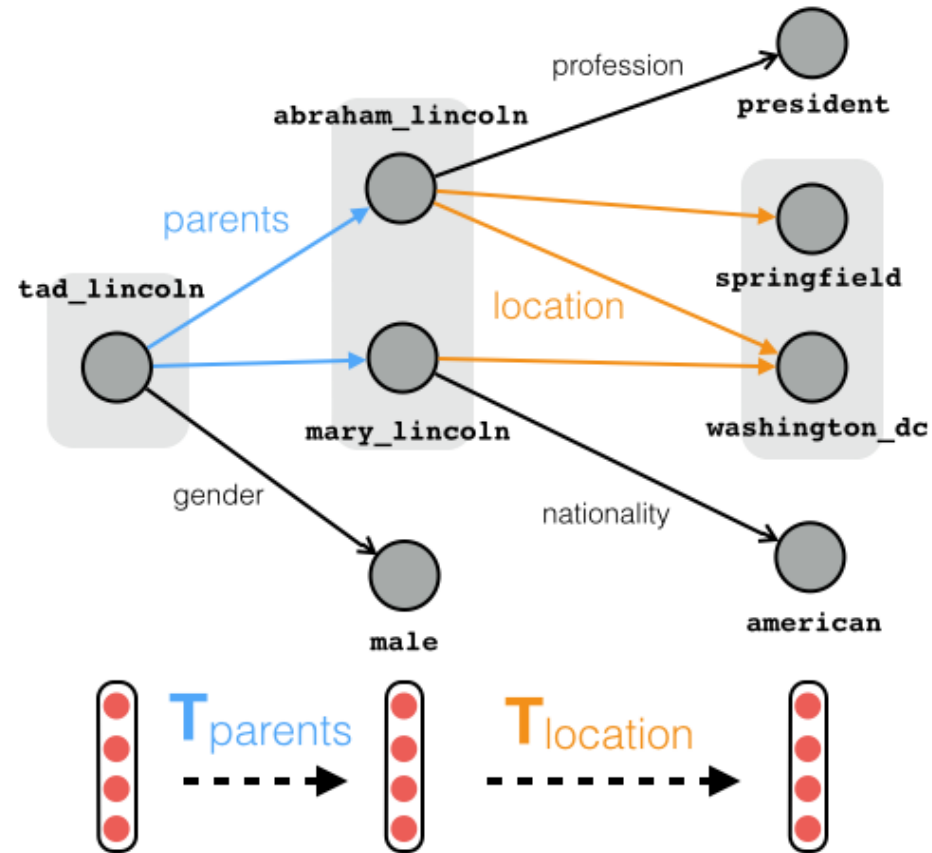
Goal

Compositionality + Handle Incompleteness

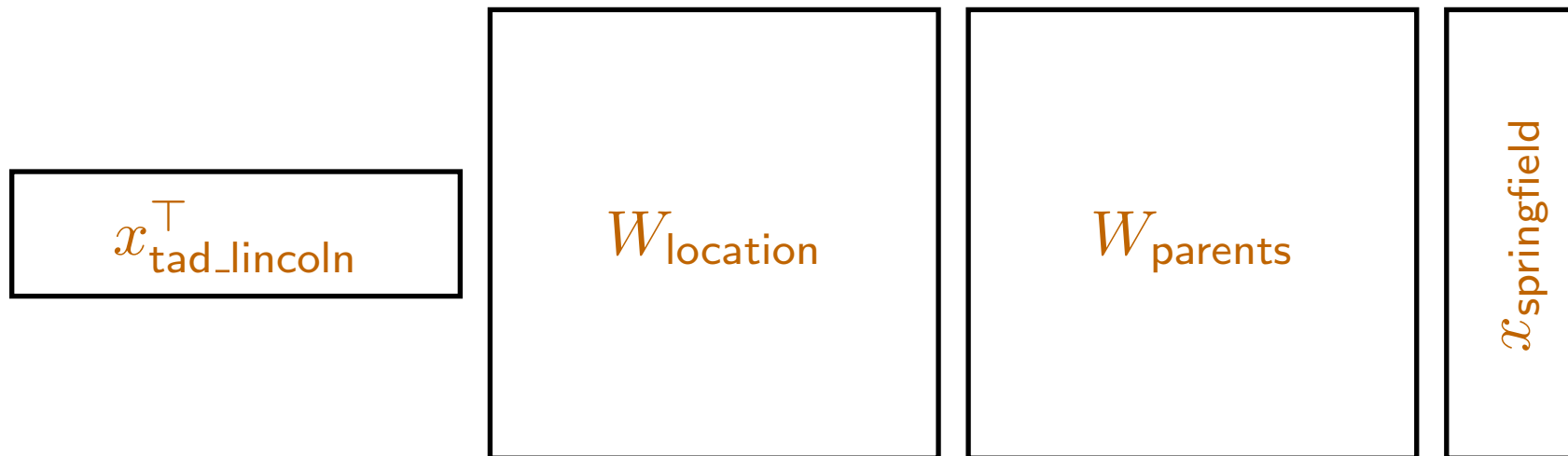
Path queries in vector space



Path queries in vector space



Path queries in vector space: example



Experimental setup: models



Bilinear [Nickel et al., 2012]:

$$\mathbb{T}_r(v) = v^\top W_r$$

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Bilinear [Nickel et al., 2012]:

$$\mathbb{T}_r(v) = v^\top W_r$$

Bilinear-Diag [Yang et al., 2015]:

$$\mathbb{T}_r(v) = v^\top \text{diag}(w_r)$$

TransE [Bordes et al., 2013]:

$$\mathbb{T}_r(v) = v + w_r$$

Experimental setup: datasets

		WordNet	Freebase
Relations		11	13
Entities		38,696	75,043
Base	Train	112,581	316,232
	Test	10,544	23,733
Paths	Train	2,129,539	6,266,058
	Test	46,577	109,557

(paths length 1-5 generated randomly)

Experimental setup: training

SINGLE: standard training

abraham_lincoln/location \Rightarrow springfield

stephen_curry/birthdate \Rightarrow 1988

...

...

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COMP: compositional training

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...

...

tad_lincoln/parents/location ⇒ springfield

stephen_curry/wife/birthdate ⇒ 1989

...

...

Experiments: knowledge base completion

abraham_lincoln/location \Rightarrow springfield

Path query task		Bilinear			Bilinear-Diag			TransE		
		SINGLE	COMP	(%red)	SINGLE	COMP	(%red)	SINGLE	COMP	(%red)
WordNet	MQ	84.7	89.4	30.7	59.7	90.4	76.2	83.7	93.3	58.9
	H@10	43.6	54.3	19.0	7.9	31.1	25.4	13.8	43.5	34.5
Freebase	MQ	58.0	83.5	60.7	57.9	84.8	63.9	86.2	88	13.0
	H@10	25.9	42.1	21.9	23.1	38.6	20.2	45.4	50.5	9.3
KBC task		SINGLE	COMP	(%red)	SINGLE	COMP	(%red)	SINGLE	COMP	(%red)
WordNet	MQ	76.1	82.0	24.7	76.5	84.3	33.2	75.5	86.1	43.3
	H@10	19.2	27.3	10.0	12.9	14.4	1.72	4.6	16.5	12.5
Freebase	MQ	85.3	91.0	38.8	84.6	89.1	29.2	92.7	92.8	1.37
	H@10	70.2	76.4	20.8	63.2	67.0	10.3	78.8	78.6	-0.9

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Surprising it works: train on paths, test on single edges...

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Compositional training improves KBC!

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Think of it as a form of **path regularization**

Final remarks

KBC + QA

- Knowledge bases provide structure for difficult **aggregation** questions (computing the answer)

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Question-dependent KB

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- Multiple levels of compositionality (think n -gram backoff)

dog-friendly hiking trails near Palo Alto

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[dog-friendly] [hiking trails near Palo Alto]

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/body/div[2]/(CLICK)/body/div/(SEARCH)/body/div[3]



Query a low-level KB

What about unstructured text?

Reading comprehension dataset

In meteorology, precipitation is any product of the condensation of atmospheric water vapor that falls under **gravity**. The main forms of precipitation include drizzle, rain, sleet, snow, **graupel** and hail... Precipitation forms as smaller droplets coalesce via collision with other rain drops or ice crystals **within a cloud**. Short, intense periods of rain in scattered locations are called “showers”.

What causes precipitation to fall?

gravity

What is another main form of precipitation besides drizzle, rain, snow, sleet and hail?

graupel

Where do water droplets collide with ice crystals to form precipitation?

within a cloud

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Log. reg	51.0%
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Code and data



worksheets.codalab.org

Collaborators

Panupong Pasupat

Kelvin Guu

John Miller

Funding

Google

Microsoft

DARPA

Thank you!