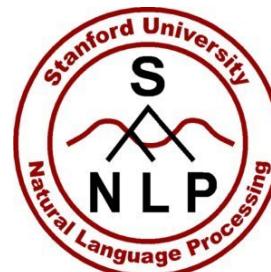


# Querying unNorMaLIZED and Inc\_mpl\_te Knowledge Bases

Percy Liang

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

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

# 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

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



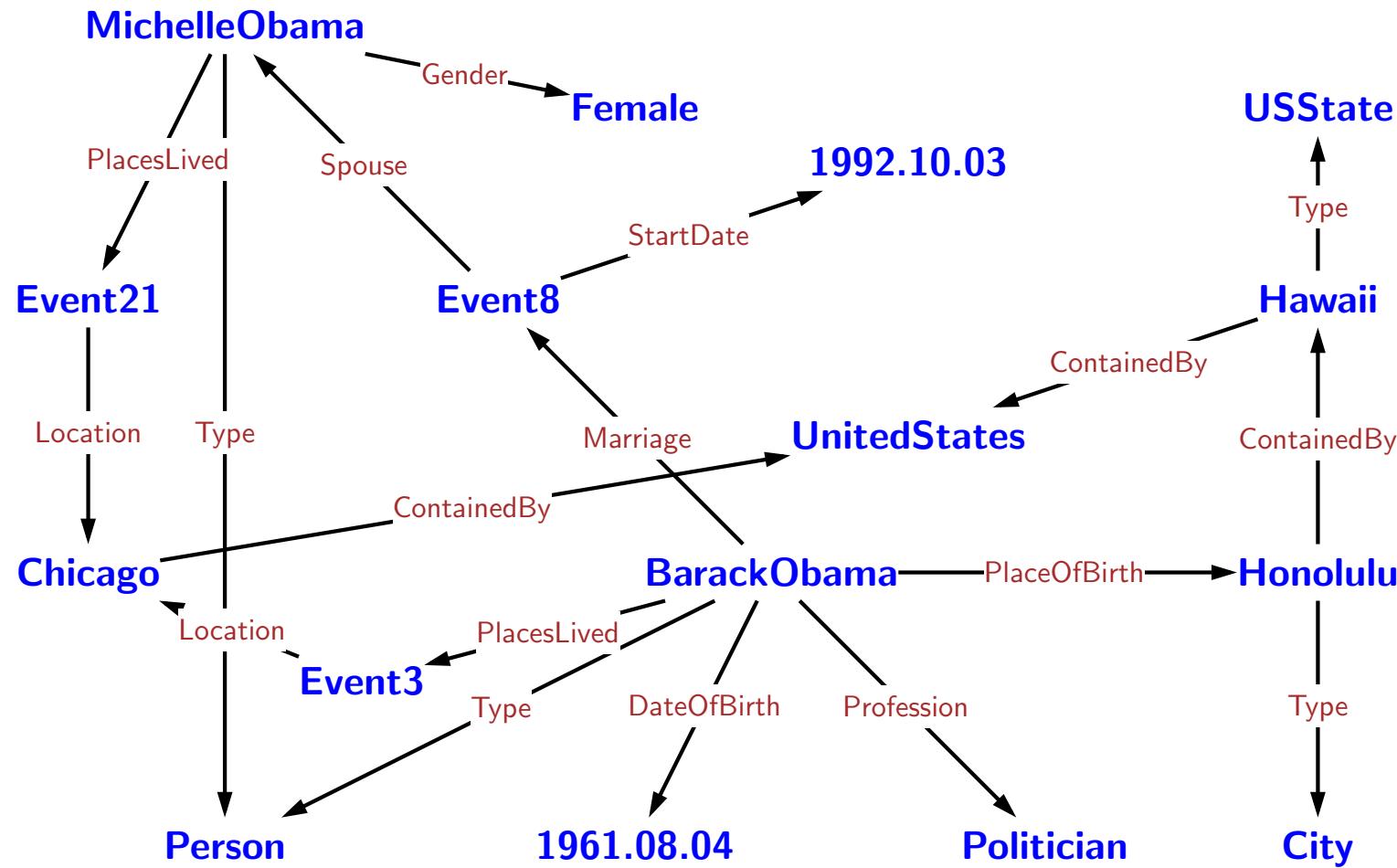
execute

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

**Strongly leverages KB structure!**

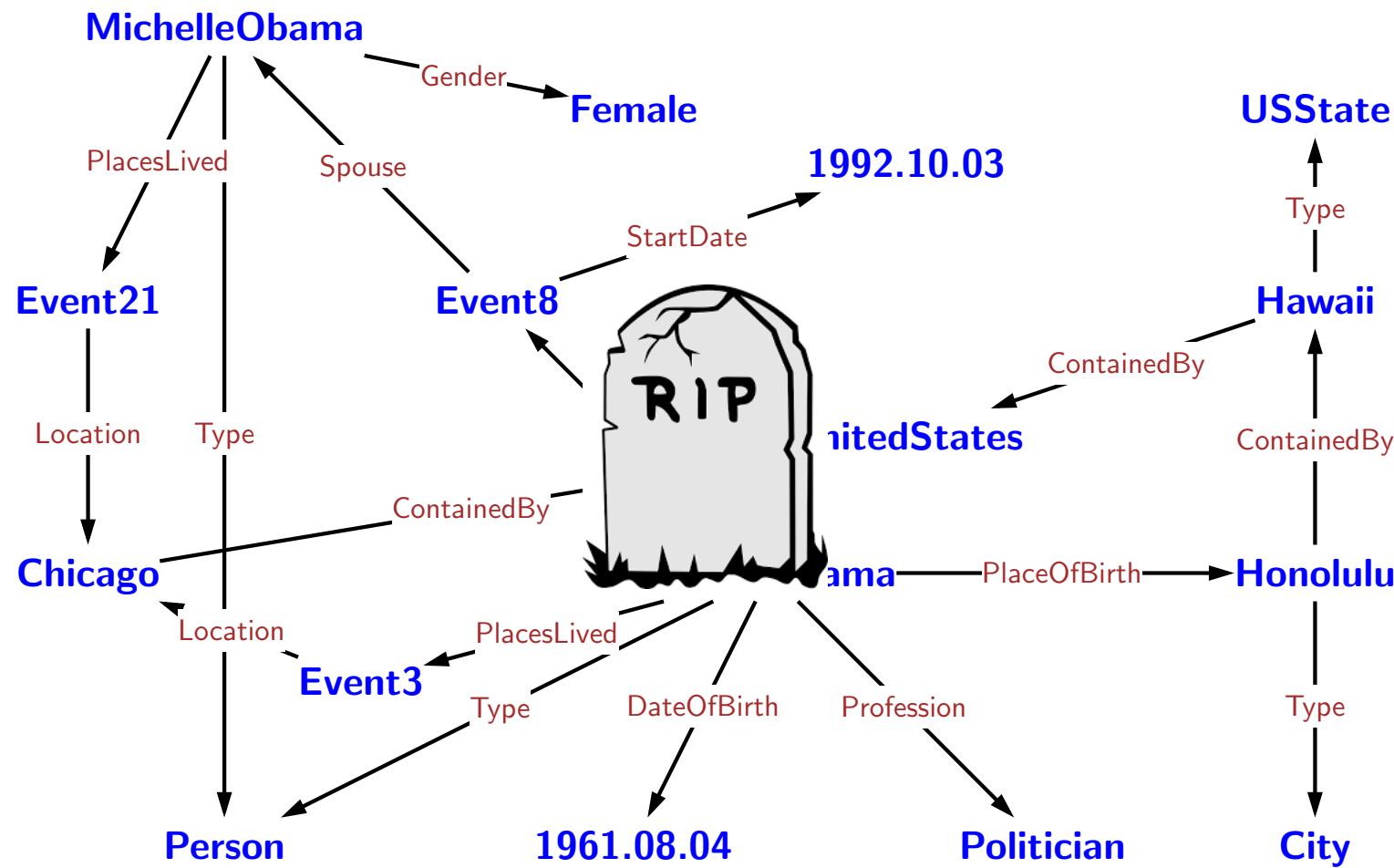
# Freebase

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

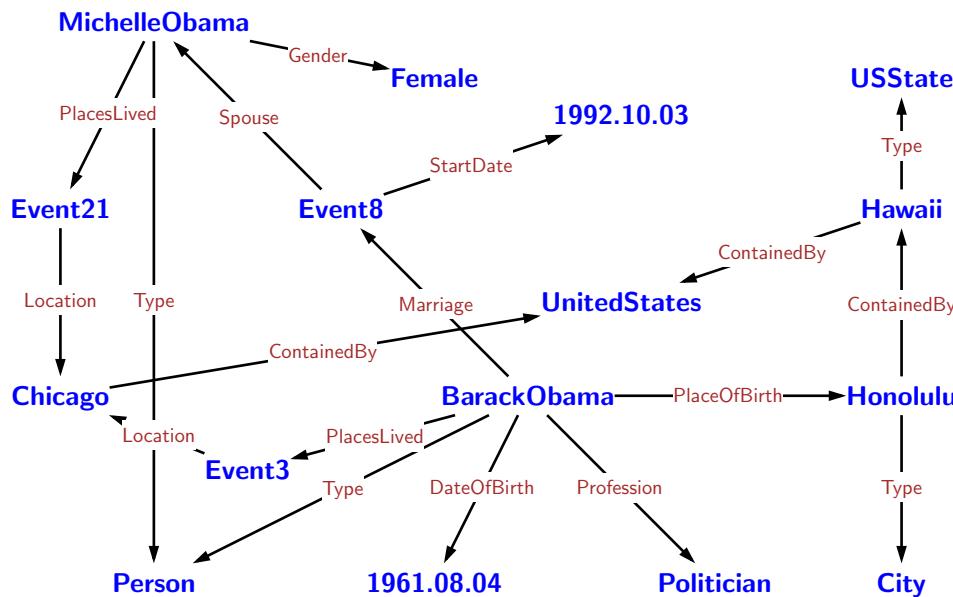


# Freebase

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



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

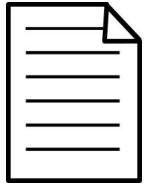


*hiking trails near Palo Alto  
dishes at Oren's Hummus  
ACL 2014 papers*

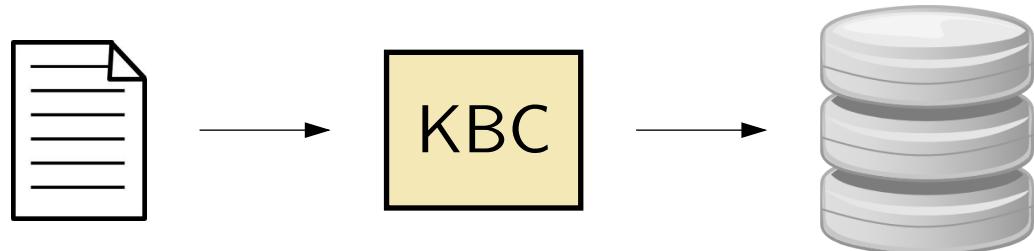


Fewer than 10% of WebQuestions answerable via Freebase

# Obtaining better KBs



# Obtaining better KBs



# Obtaining better KBs



# Obtaining better KBs



# Philosophy

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



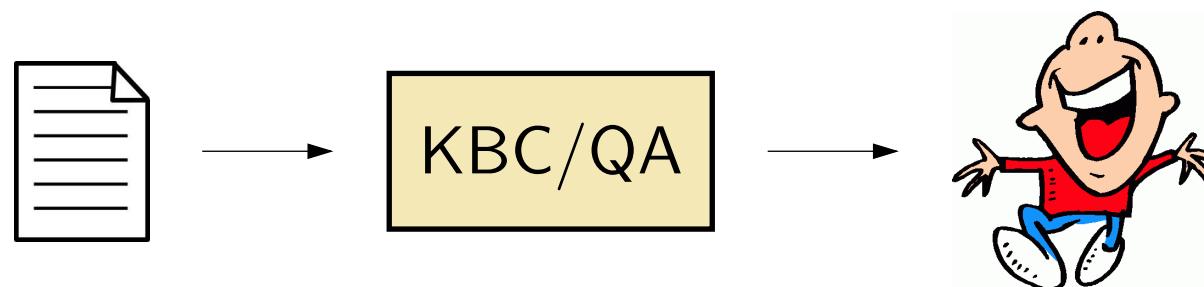
Let that end goal drive learning and construction of **intermediate** knowledge representations.

# Philosophy

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

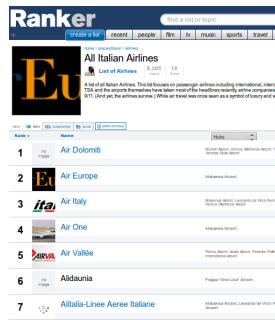


Let that end goal drive learning and construction of **intermediate** knowledge representations.



# Outline

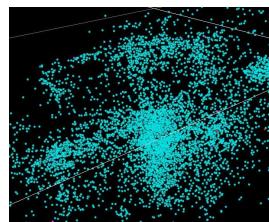
On web pages



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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2009			2nd	4x400 m relay	3:05.69

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:

 EveryTrail

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

(Update Current Location)

Login | Signup

## Hiking near Baltimore, Maryland

49 people like this.  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)  
 **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 Arney 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 waterfall, 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...



The map shows the state of Maryland with various hiking trails marked by red icons. Major cities like Baltimore, Washington D.C., and Philadelphia are labeled. The map also includes labels for Lancaster, York, Columbia, Bethesda, Reston, and Alexandria. A legend in the top left corner shows a yellow person icon for trails and a red dot for locations. A Google logo is in the bottom right corner.

**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:

**EveryTrail**

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

(Update Current Location) Search GO Login | Signup

## Hiking near Baltimore, Maryland

Like 49 people like this. Tweet 1

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Sort: Rating   show community trips

**Filter Trails**

**Guides**

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Baltimore City, Baltimore, 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*

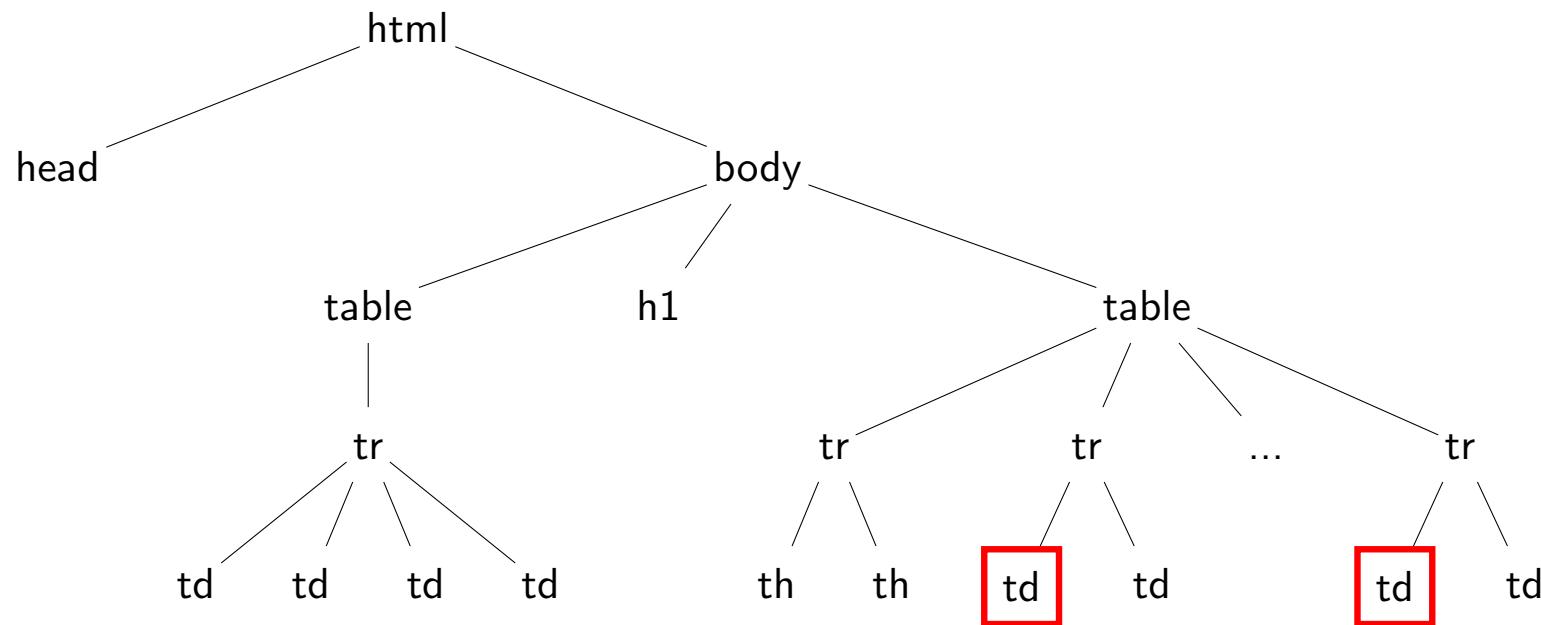
- web page  $w$

Output:

- list of entities  $y$

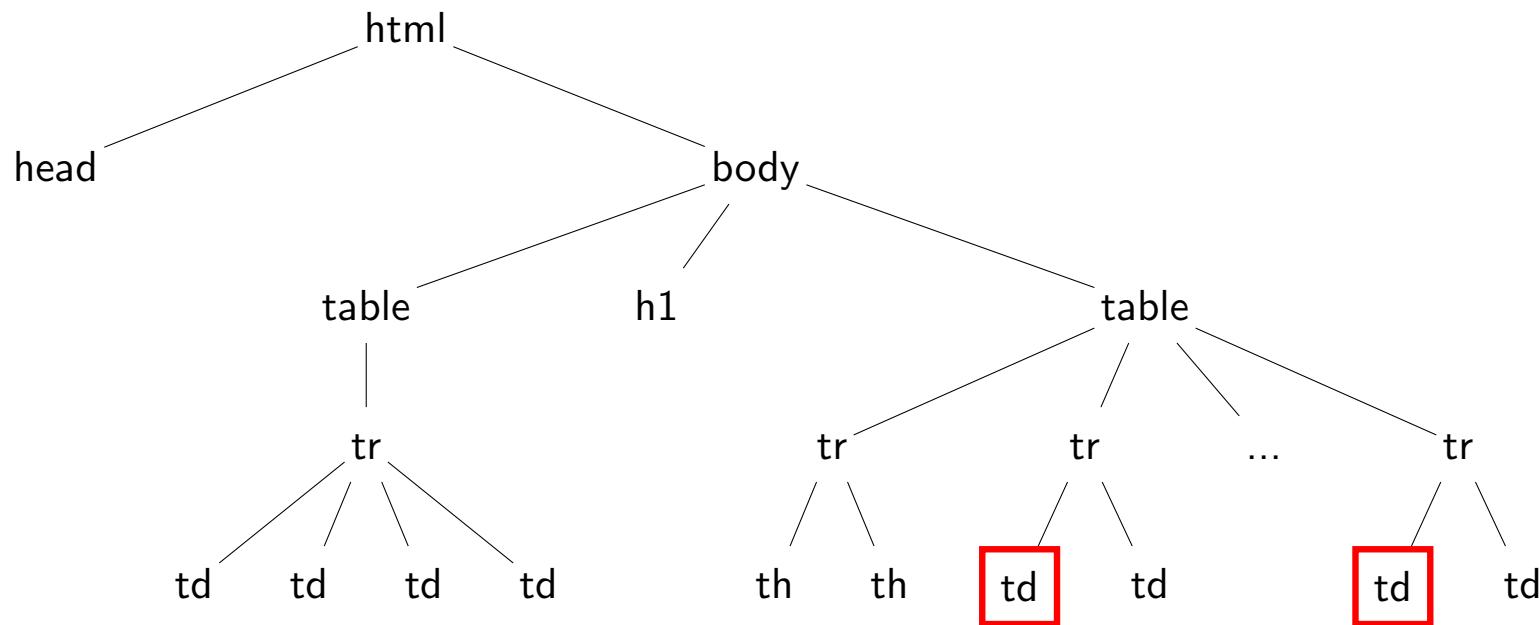
[Avalon Super Loop, Patapsco Valley State Park, ...]

# Logical forms: XPath expressions



$\textcolor{red}{z} = /html[1]/body[1]/table[2]/tr/td[1]$

# Logical forms: XPath expressions

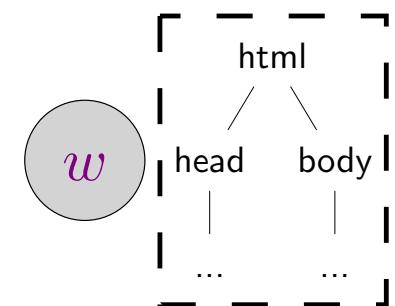
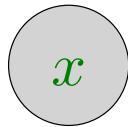


$\textcolor{red}{z} = /html[1]/body[1]/table[2]/tr/td[1]$

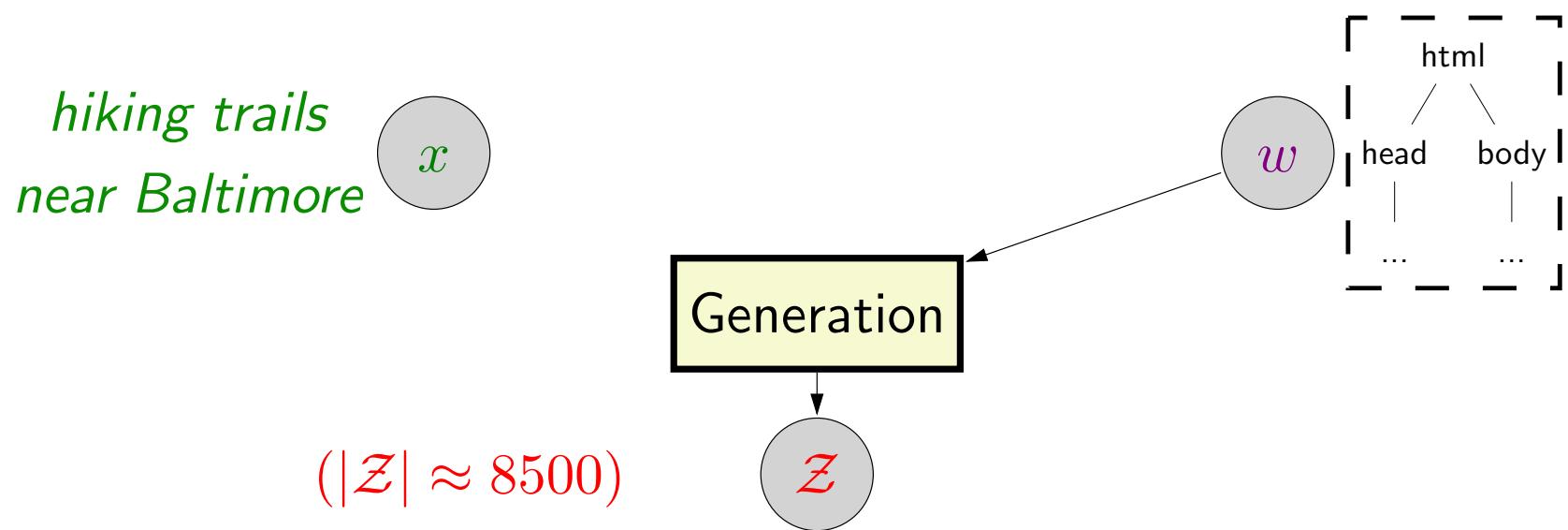
A low-level KB

# Framework

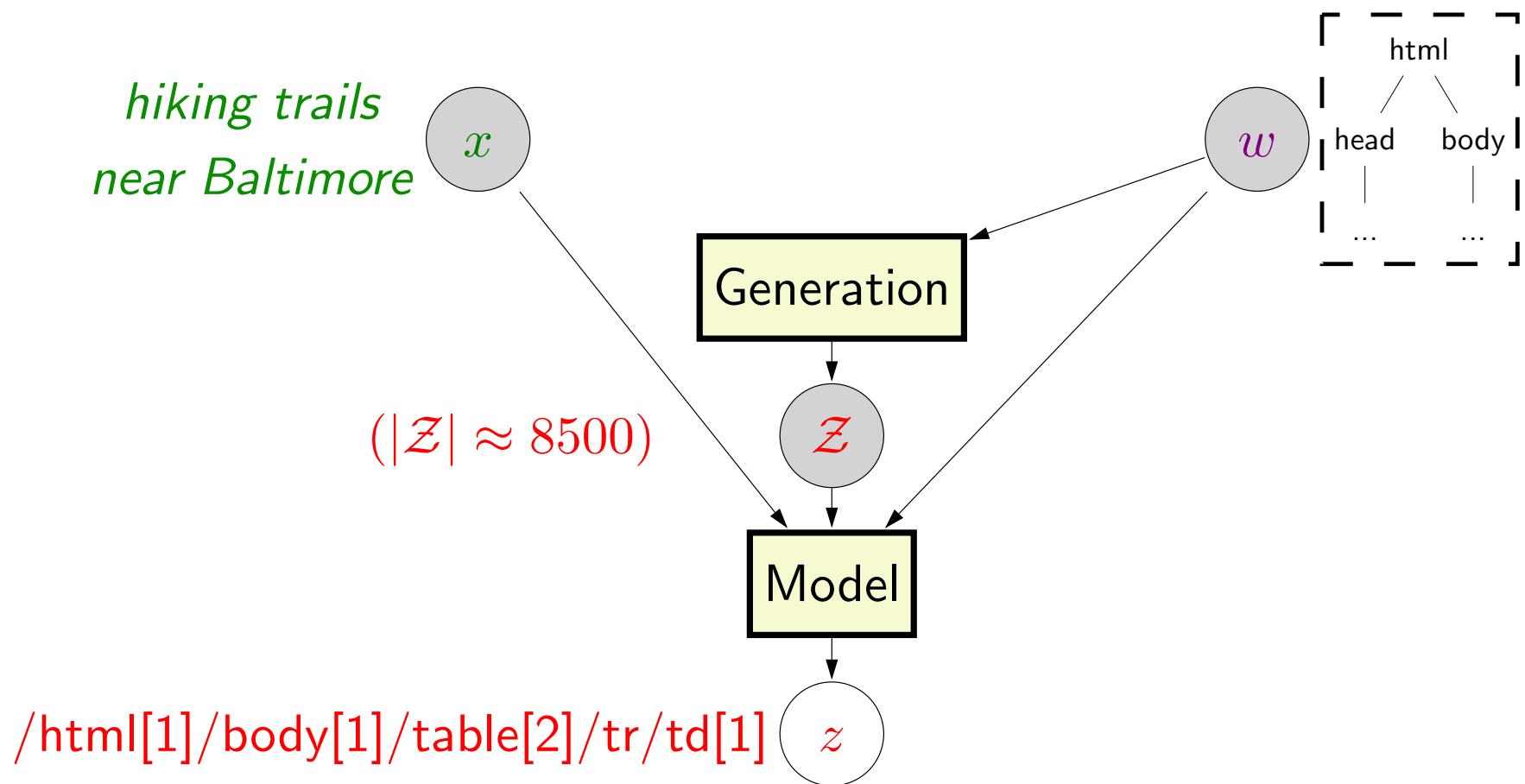
*hiking trails  
near Baltimore*



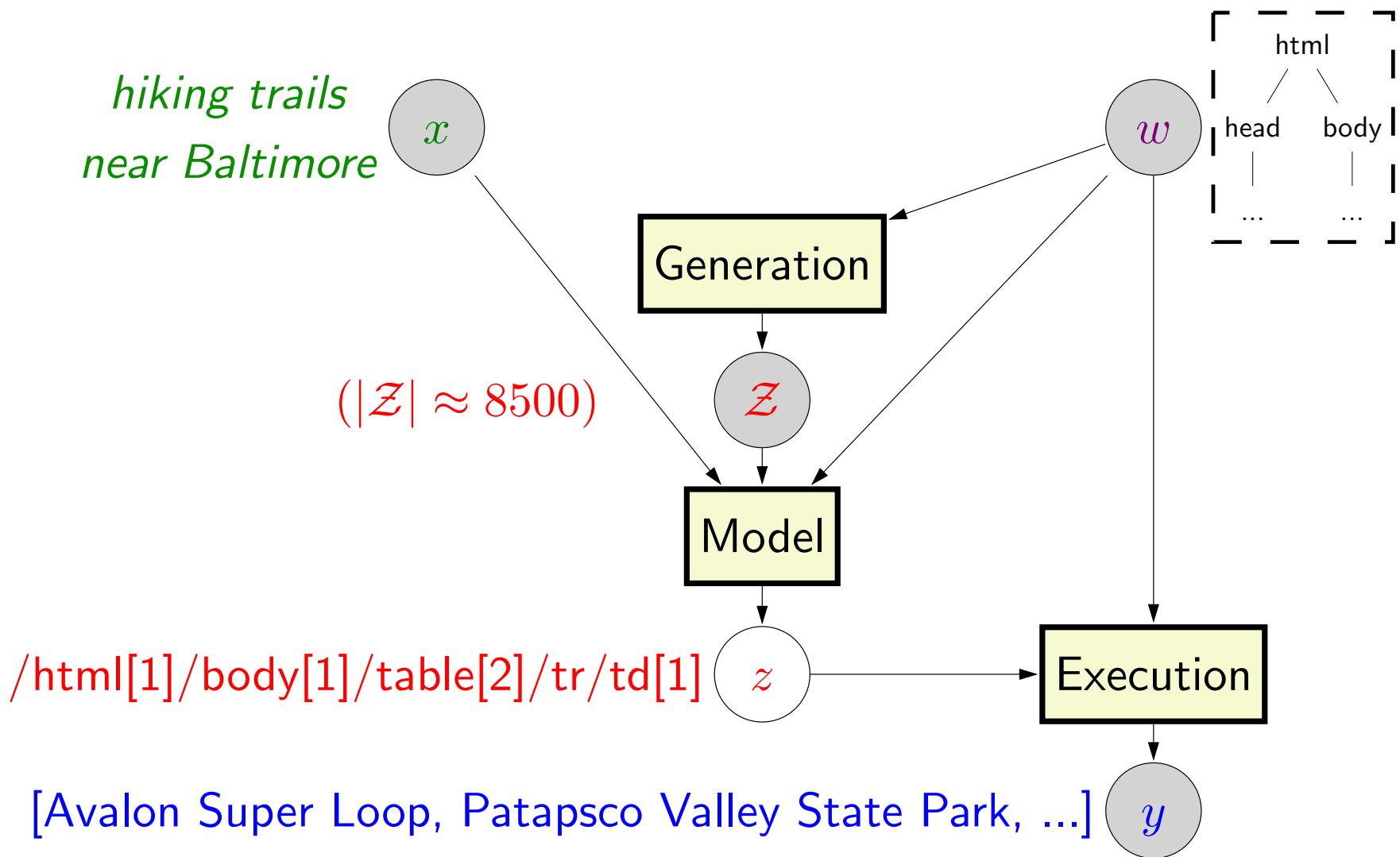
# Framework



# 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

The screenshot shows a list titled 'All Italian Airlines' on the Ranker platform. The list includes:

Rank	Name	Hubs
1	Air Dolomiti	Munich Airport, Verona Villafranca Airport, Trieste Venezia Guglielmo Marconi Airport
2	Air Europe	Malpensa Airport
3	Air Italy	Malpensa Airport, Leonardo da Vinci-Piaggio Airport, Verona Villafranca Airport
4	Air One	Malpensa Airport
5	Air Vallée	Perma Airport, Asola Airport, Federico Fellini International Airport
6	Alidaunia	Foggia "Giro Liso" Airport
7	Alitalia-Linee Aeree Italiane	Malpensa Airport, Leonardo da Vinci-Fiumicino Airport

*airlines of italy*

### 10. Greenhouse Effect

The diagram illustrates the greenhouse effect with a sun at the top emitting yellow arrows of heat towards Earth. The Earth's surface reflects some of this heat back up as yellow arrows. A layer of gases in the atmosphere traps some of this reflected heat, represented by a thick blue arrow pointing back down towards the Earth. Labels include 'The Greenhouse Effect', 'Earth', 'Atmosphere', 'Surface', and 'Space'.

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 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

A cartoon illustration shows a person wearing a large, multi-layered mask standing next to a factory. The factory has a pipe emitting a dark, billowing plume of smoke. The background shows a city skyline with buildings and trees.

The harmful gases emitted from the vehicles and factories and the greenhouse gases cause pollution in the air and these gases are not captured in the atmosphere. The smoke, rather, remains in the atmosphere forming clouds full of harmful

*natural causes of global warming*

The screenshot shows a grid of 12 football coaches for the 2013 season. Each coach is shown with a portrait, name, and title:

Coach	Title
Les Miles	Head Coach
Cam Cameron	Offensive Line Coach
John Chavis	Defensive Coordinator
Frank Wilson	Running Backs/Recruiting 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	Bench & Conditioning Coordinator
Dr. Sam Nader	Assistant Athletics Director - Football

*isu football coaches*

# Dataset statistics

2773 examples

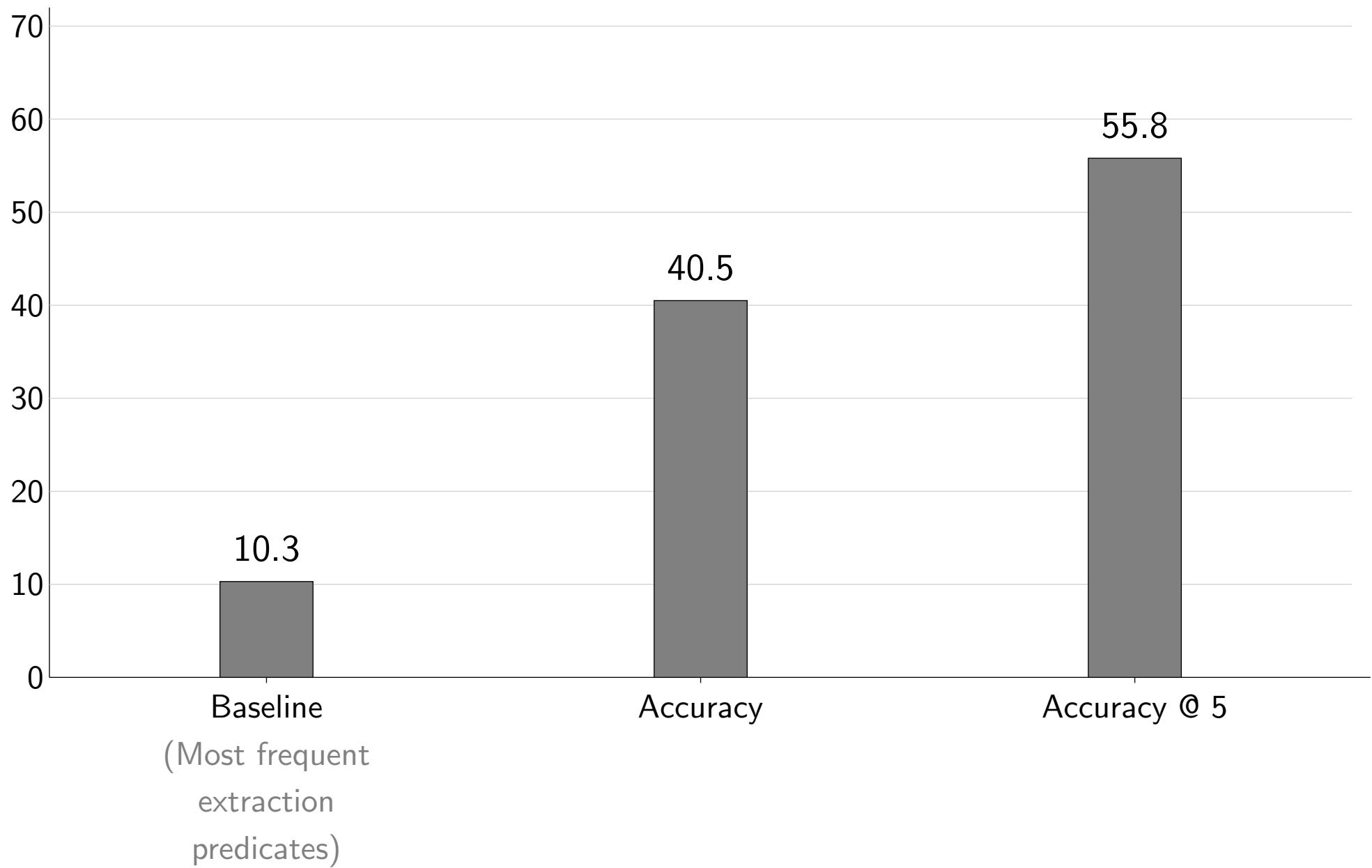
2269 unique queries

894 unique headwords ← long tail!

1483 unique web domains ← long tail!

( $\neq$  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

View:

Log in to copy items to your own lists.

**Northern Lights** (1997 TV Movie)

10  
(111 mins.)

Director: Linda Yellen  
Stars: Diane Keaton, Maury Chaykin, Joseph Cross, Kathleen York

Add to Watchlist

**Under Wraps** (1997 TV Movie)

6.5/10  
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/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*

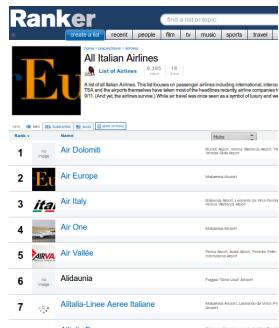
Rank	Firm	Headquarters
1	Bridgewater Associates	🇺🇸 Westport, CT
2	Man Group	🇬🇧 London
3	J.P. Morgan Asset Management	🇺🇸 New York
4	Brevan Howard Asset Management	🇬🇧 London
5	Och-Ziff Capital Management Group	🇺🇸 New York
6	Paulson & Co.	🇺🇸 New York
7	BlackRock Advisors	🇺🇸 New York

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

**Need compositionality**

# Outline

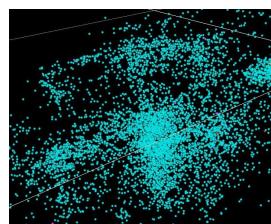
On web pages



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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	European Championships	Gothenburg, Sweden	2nd (h)	4x400 m relay	3:02.57
2007	European Indoor Championships	Birmingham, United Kingdom	3rd	4x400 m relay	3:01.73
	Universiade	Bangkok, Thailand	3rd	4x400 m relay	3:08.14
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	Universiade	Belgrade, Serbia	4th	4x400 m relay	3:08.76
2009	World Indoor Championships	Valencia, Spain	7th	4x400 m relay	3:00.32
	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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<b>Representing  Poland</b>					
2001	World Youth Championships	Debrecen, Hungary	2nd	400 m	47.12
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*In what city did Piotr's last 1st place finish occur?*

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

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

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	Olympic Games	Beijing, China	7th	4x400 m relay	3:00.32
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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			1st	Medley relay	1:50.46
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2009	Universiade	Belgrade, Serbia	2nd	4x400 m relay	3:05.69

*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:

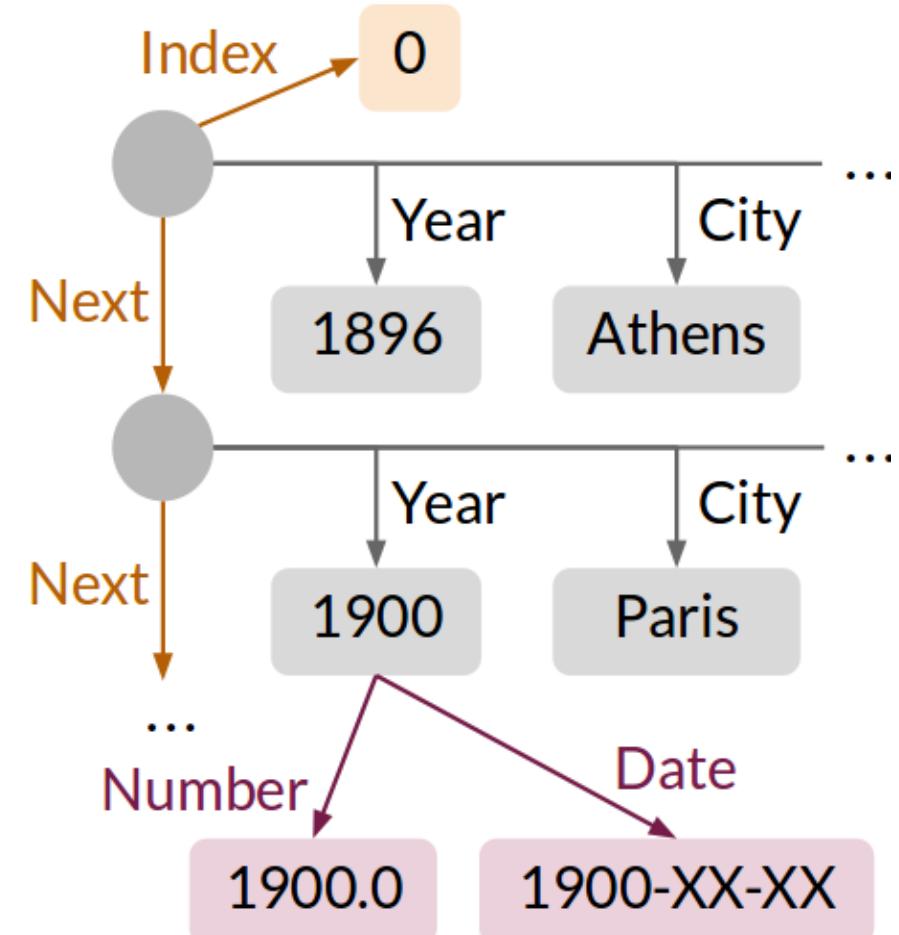
- 22000 question/answers
- 2100 tables
- 6.3 columns and 27.5 rows per table

## Challenges:

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

# Knowledge representation

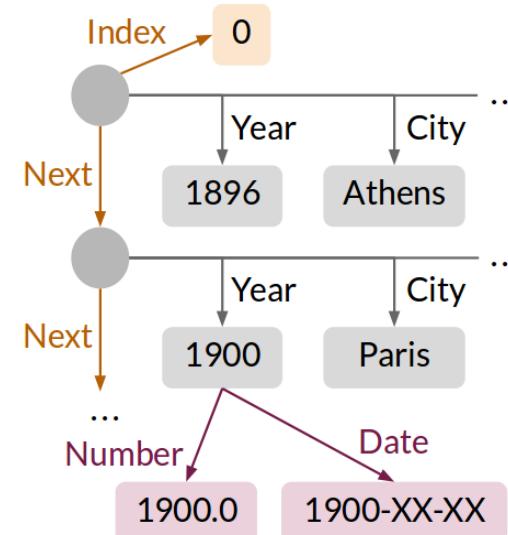
Year	City	Country	Nations
1896	Athens	Greece	14
1900	Paris	France	24
1904	St. Louis	USA	12
...	...	...	...
2004	Athens	Greece	201
2008	Beijing	China	204
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Add normalization / auxiliary edges (custom functions), push resolution to semantic parsing

# Model

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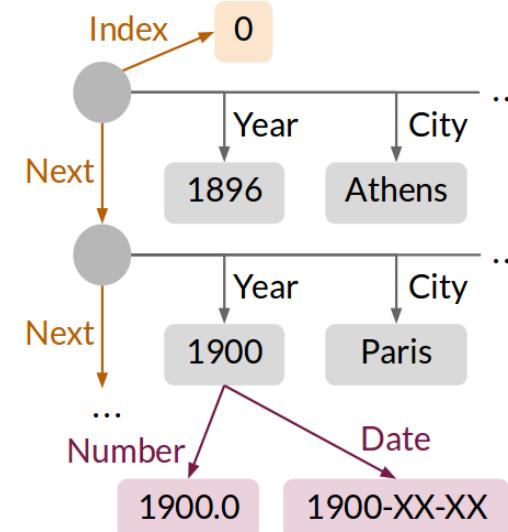


*Greece held its last Summer Olympics in which year?*

2004

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**R[Date].R[Year].argmax(Country.Greece, Index)**

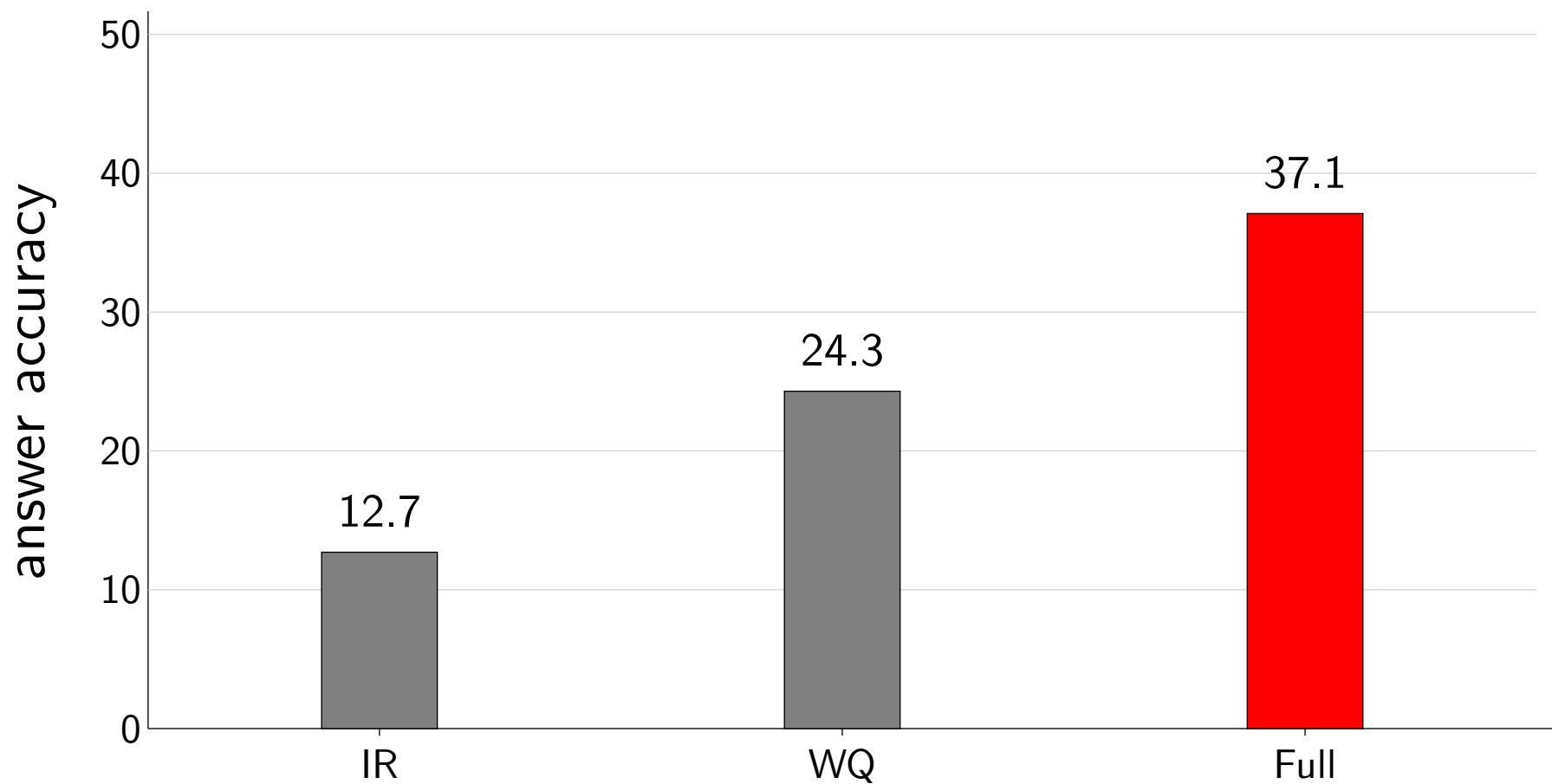


2004

# Results

IR: Train classifier to pick answer directly from table.

WQ: Use logical complexity of our previous Freebase work.

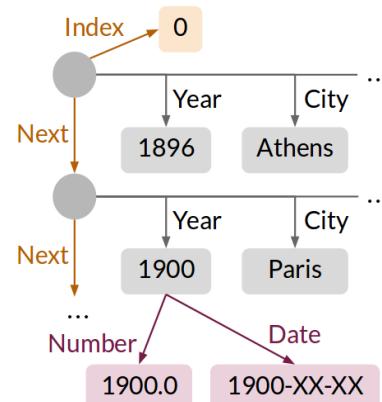


# Oracle accuracy

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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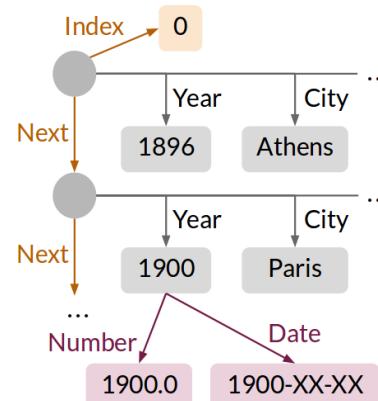
2

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2

## Method

ACL 2015

ACL 2016 (dynamic prog. on denotations) 76.0%

## LF accuracy

53.5%

# Error analysis

Unhandled operations (19%):

- *Was there more gold medals won than silver?*
- *Which movies were number 1 for at least two consecutive weeks?*
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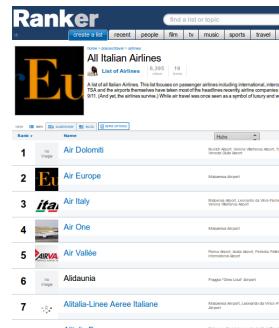
- *In what city did Piotr's last 1st place finish occur? ...[Bangkok, Thailand]...*
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Lexical mismatch:

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

# Outline

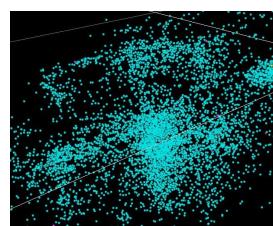
On web pages



On tables

Year	Competition	Venue	Position	Event	Notes
Representing <b>Poland</b>					
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	Tampere, Finland	3rd	4x400 m relay	3:06.12
	European U23 Championships	Erfurt, Germany	2nd	4x400 m relay	3:08.62
2005	Universiade	Izmir, Turkey	11th (sf)	400 m	46.62
	Universiade	Izmir, Turkey	1st	4x400 m relay	3:04.41
2006	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	World Indoor Championships	Valencia, Spain	4th	4x400 m relay	3:02.05
	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



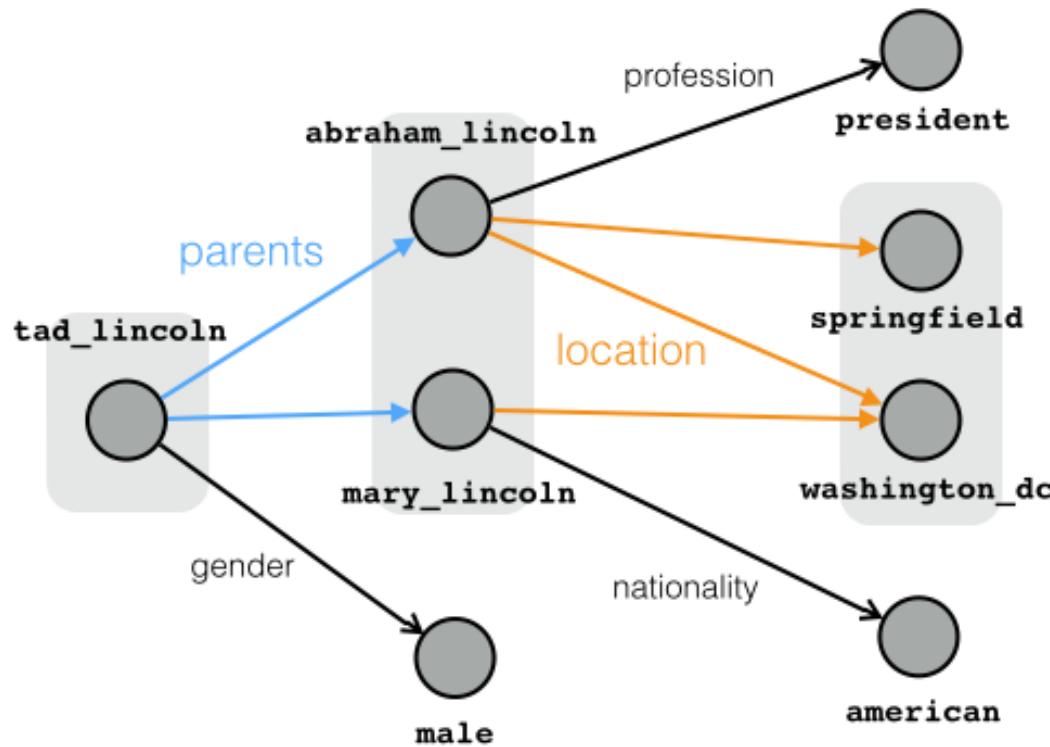
John Miller

# Focus on path queries

TadLincoln/Parents/Location

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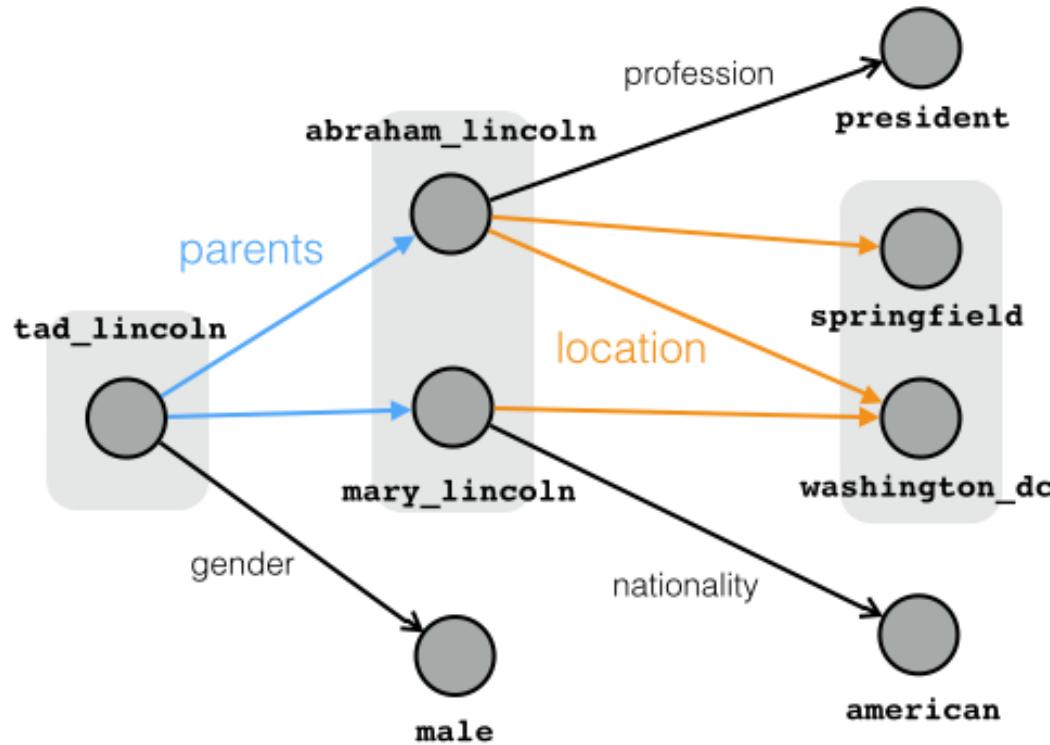
TadLincoln/Parents/Location



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

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

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Prior work:

- Tensor factorization [Nickel et al., 2011]
- Neural Tensor Network [Socher et al., 2013]
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- General framework + comparison [Yang et al., 2015]
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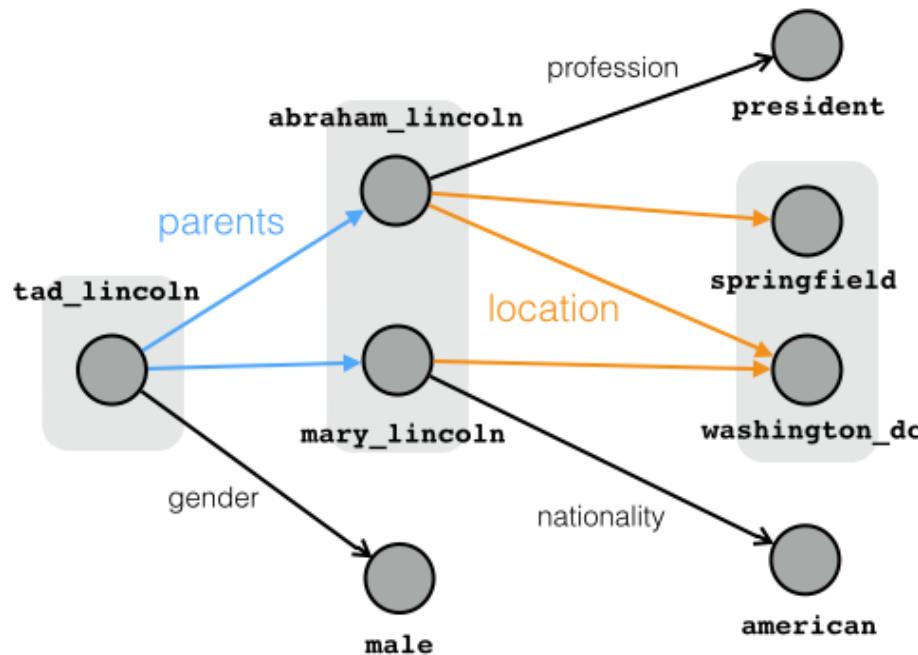
Strength: handles incompleteness

Weakness: no compositionality

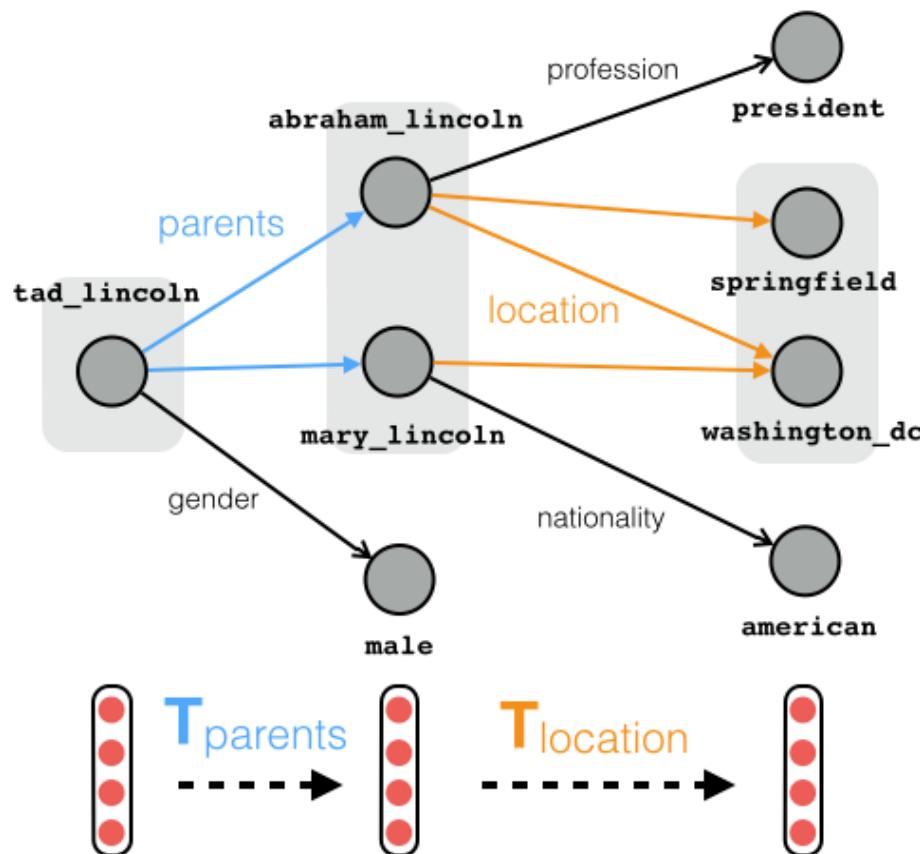
# Goal

Compositionality + Handle Incompleteness

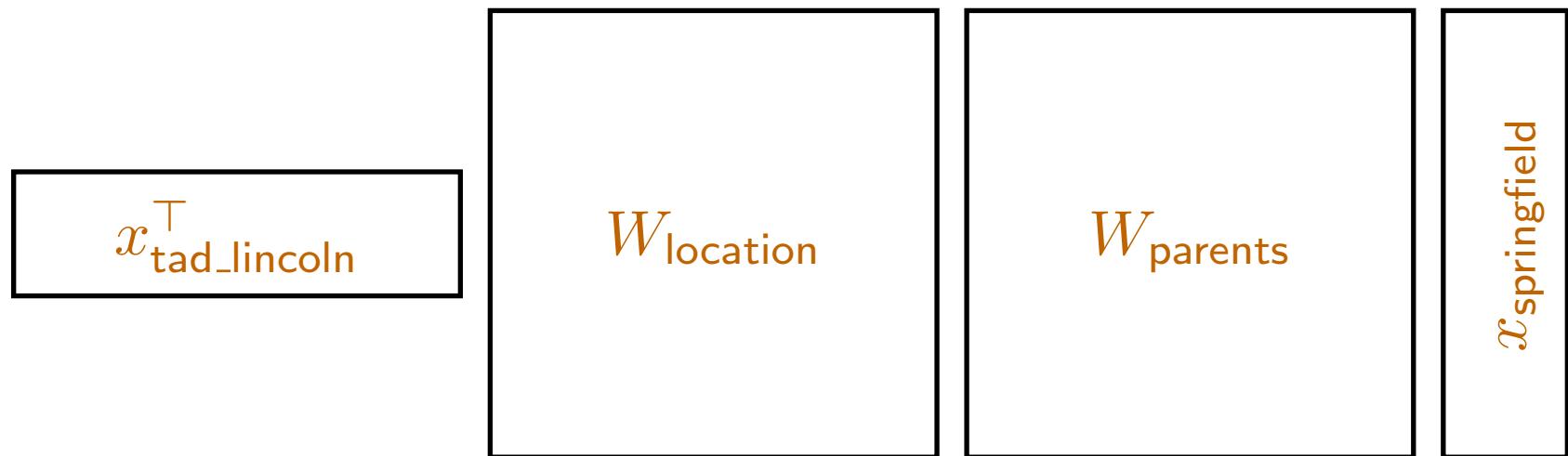
# Path queries in vector space



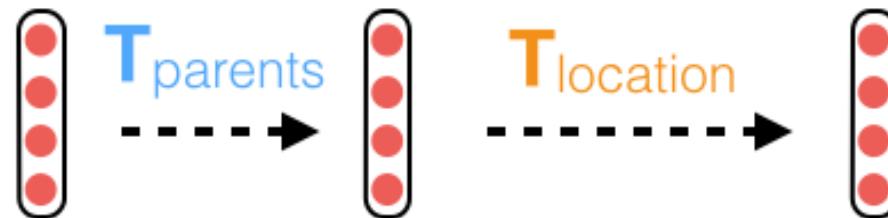
# Path queries in vector space



# Path queries in vector space: example



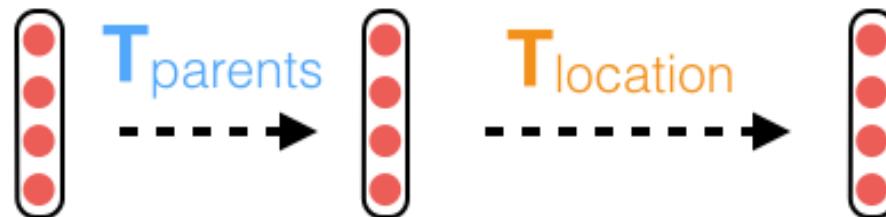
# Experimental setup: models



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

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

TransE [Bordes et al., 2013]:

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

# Experimental setup: datasets

		WordNet	Freebase
<b>Relations</b>	11	13	
	38,696	75,043	
<b>Base</b>	Train	112,581	316,232
	Test	10,544	23,733
<b>Paths</b>	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 ⇒ springfield

stephen.curry/birthdate ⇒ 1988

...

...

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... ...

tad.lincoln/parents/location ⇒ springfield  
stephen.curry/wife/birthdate ⇒ 1989

... ...

# Experiments: knowledge base completion

abraham.lincoln/location  $\Rightarrow$  springfield

		Bilinear			Bilinear-Diag			TransE		
Path query task		SINGLE	COMP	(%red)	SINGLE	COMP	(%red)	SINGLE	COMP	(%red)
WordNet	MQ	84.7	89.4	<b>30.7</b>	59.7	90.4	<b>76.2</b>	83.7	93.3	<b>58.9</b>
	H@10	43.6	54.3	<b>19.0</b>	7.9	31.1	<b>25.4</b>	13.8	43.5	<b>34.5</b>
Freebase	MQ	58.0	83.5	<b>60.7</b>	57.9	84.8	<b>63.9</b>	86.2	88	<b>13.0</b>
	H@10	25.9	42.1	<b>21.9</b>	23.1	38.6	<b>20.2</b>	45.4	50.5	<b>9.3</b>
KBC task		SINGLE	COMP	(%red)	SINGLE	COMP	(%red)	SINGLE	COMP	(%red)
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Freebase	MQ	85.3	91.0	<b>38.8</b>	84.6	89.1	<b>29.2</b>	92.7	92.8	<b>1.37</b>
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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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- Multiple levels of compositionality (think  $n$ -gram backoff)

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

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

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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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## Code and data



[worksheets.codalab.org](https://worksheets.codalab.org)

## Collaborators

Panupong Pasupat

Kelvin Guu

John Miller

## Funding

Google

Microsoft

DARPA

**Thank you!**