From Data Fusion to Knowledge Fusion

Xin Luna Dong, Google Inc.

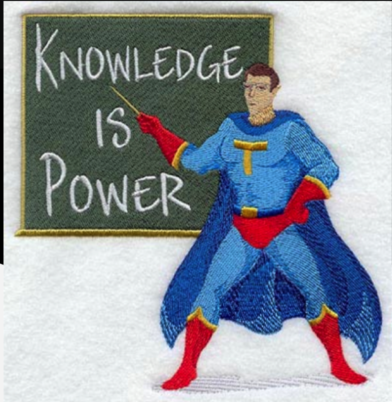
9/6/2014 @ APWeb'14

KNOWLEDGE VAULT

SONYA

SONYA: A Big Project, A Fancy Machine, And A Cute Little Girl

Knowledge Is Power



- Many Knowledge Bases (KB)

yago select knowledge

Freebase

DIADEM domain-centric intelligent automated data extraction methodology

DeepDive

NELL: Never-Ending Language Learning

ProBase

DBpedia

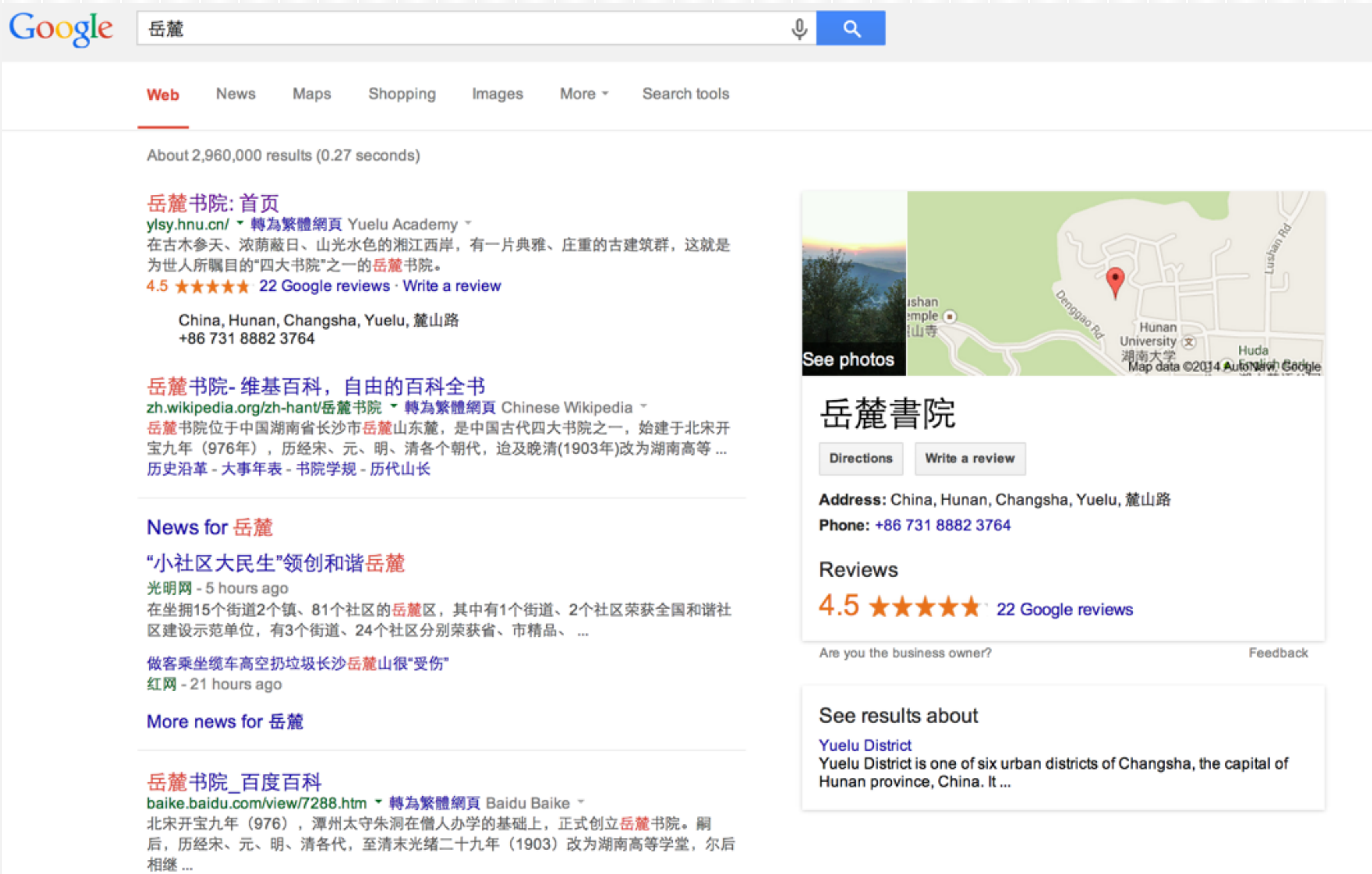
facebook

Walmart

Google Knowledge Graph

- ReadWrite 12/27/2012

Using KG in Search



Expanding KG–
Extracting Knowledge from the Web

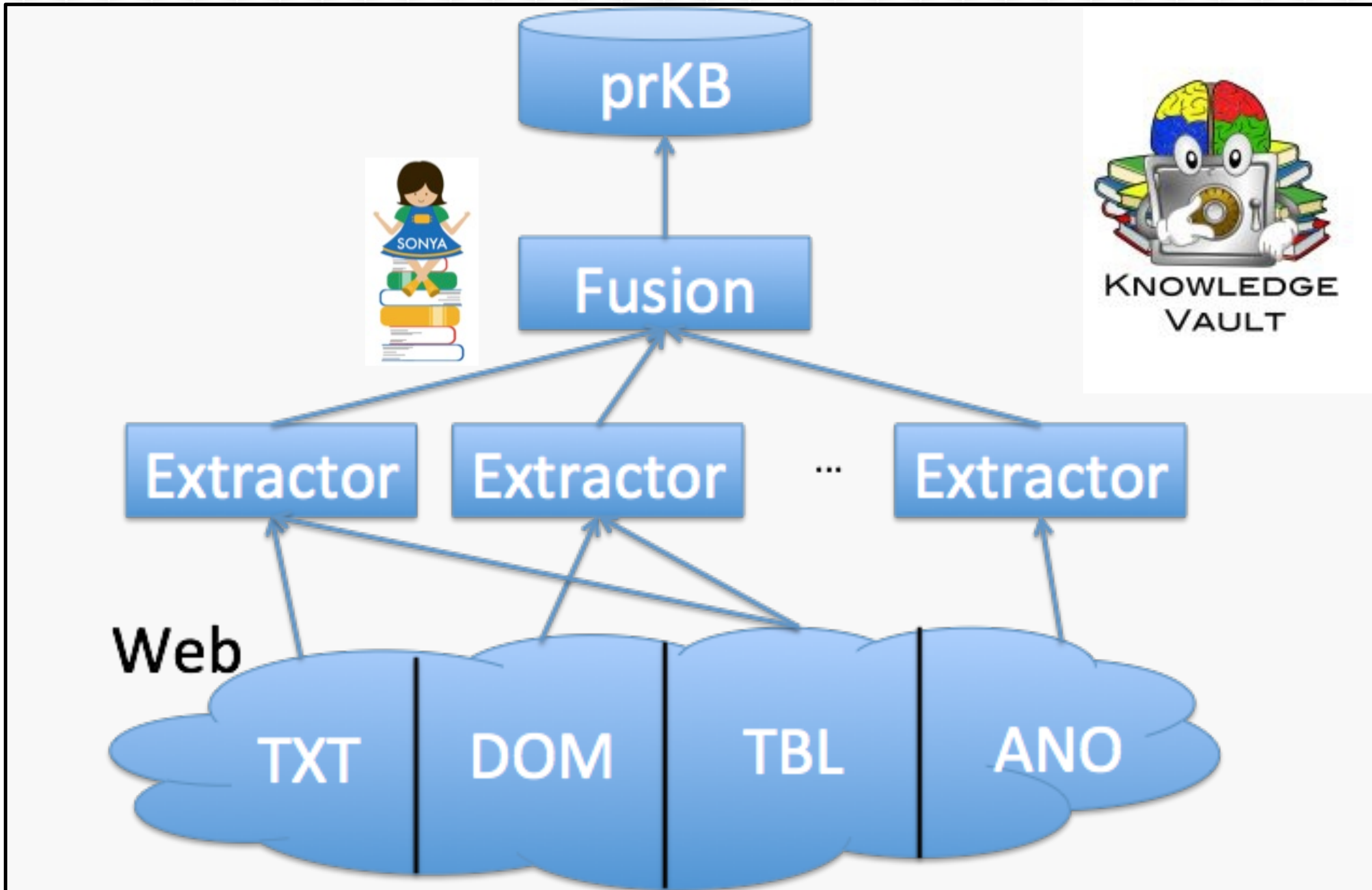
> "In the near future, the web is going to be the master copy of human knowledge. We need to figure out ways to use that knowledge."
> —Håkon Wium Lie

But–

- KG requires 99% accuracy for knowledge
- Web data is noisy and extraction is hard
- How to balance *coverage* and *accuracy*?

Knowledge Vault–
Building a Probabilistic KB

[VLDB'2014, Sigmod'2014, KDD'2014]



News

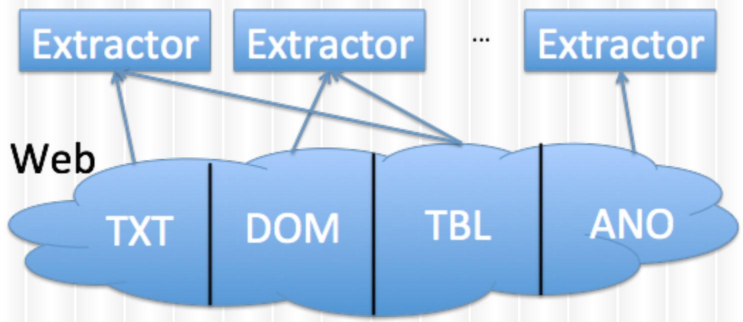
Google's Knowledge Vault already contains 1.6 billion facts

FELICITY NELSON
SATURDAY, 23 AUGUST 2014

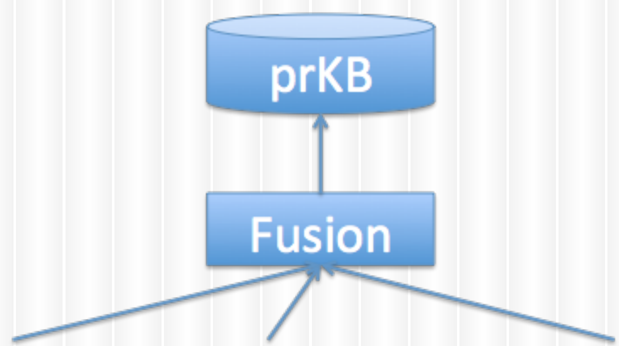
The automated, fact-harvesting bot will build up a collection of all human knowledge.

Outline

- Knowledge extraction



- Knowledge fusion



- Interesting applications
- Future directions

Knowledge Extraction I–Knowledge

- Triple: (subject, predicate, object)
  e.g., (Tom Cruise, date_of_birth, 7/3/1962)
  - Subject–a Freebase mid
    e.g., /m/07r1h
  - Predicate–predefined in Freebase; e.g., people/person/date_of_birth
  - Object–a Freebase mid, a string, a number, or a date.

Statistics for Extracted Triples

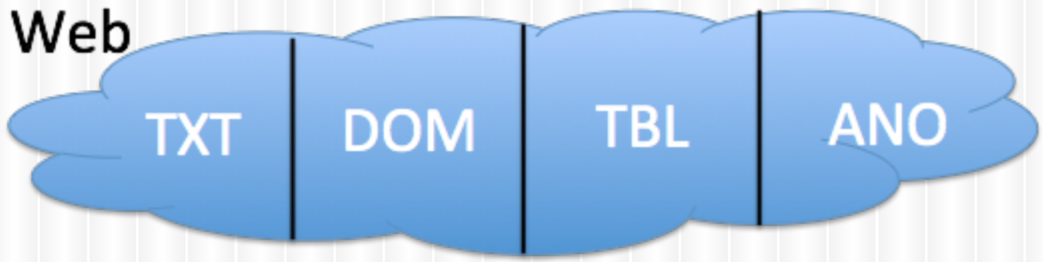
- A large knowledge base

As of 11/2013

#Triples	1.6B (now 2.8B)
#Subjects (Entities)	43M
#Types	1.1K
#Predicates	4.5K
#Objects	102M

- Highly skewed data–fat heads, long tail
  - #Triples/type: 1–14M (*location, organization, business*)
  - #Triples/entity: 1–2M (*USA, UK, CA, NYC, TX*)

Knowledge Extraction II–Sources



Free texts

Synopsis Print Cite This

Born on April 15, 1452, in Vinci, Italy, Leonardo da Vinci was concerned with the laws of science and nature, which greatly informed his work as a painter, sculpto
His ideas and body of work -- which i
The Last Supper, *Leda and the Swan* a
influenced countless artists and made d
Italian Renaissance.

Web tables & Lists

	Name and (party)[1]	Term	State of birth	Born	Died
1.	Washington (F)[3]	1789–1797	Va.	2/22/1732	12/14/
2.	J. Adams (F)	1797–1801	Mass.	10/30/1735	7/4/18
3.	Jefferson (DR)	1801–1809	Va.	4/13/1743	7/4/18
4.	Madison (DR)	1809–1817			

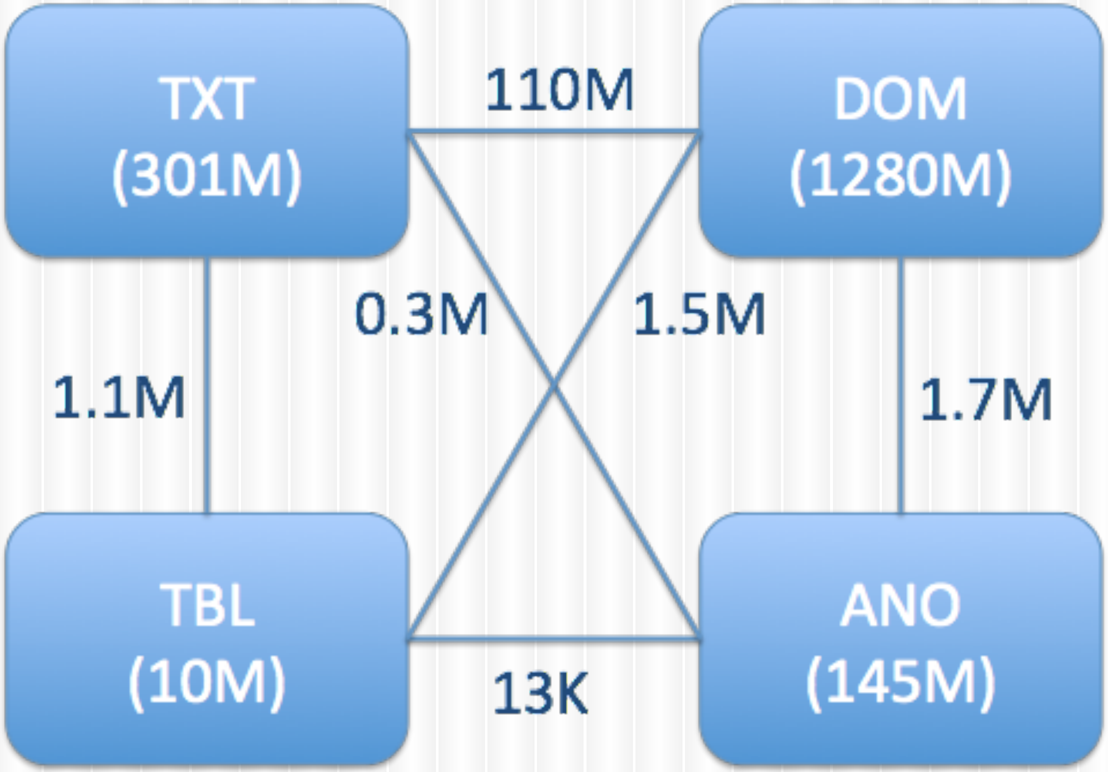
Annotations

```
<h1 itemprop="name">
Tom Cruise </h1>
<span itemprop="birthDate">
7/3/1962 </span>
<span itemprop="gender">
Male </span>
```

schema.org

Statistics for Web Sources

- 1B+ Webpages over the Web
- Contribution is skewed: 1- 50K

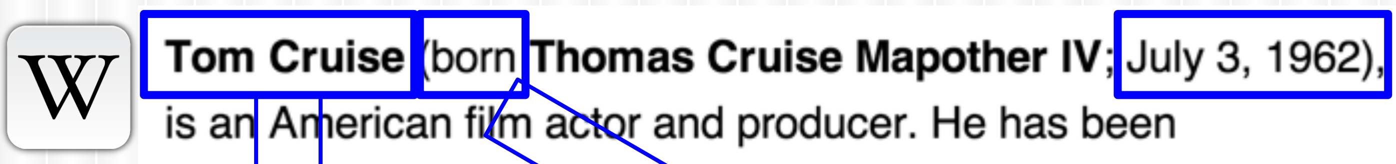


As of 11/2013

Knowledge Extraction III–Extractors

- Three tasks (any order, maybe combined)

I. Triple identification



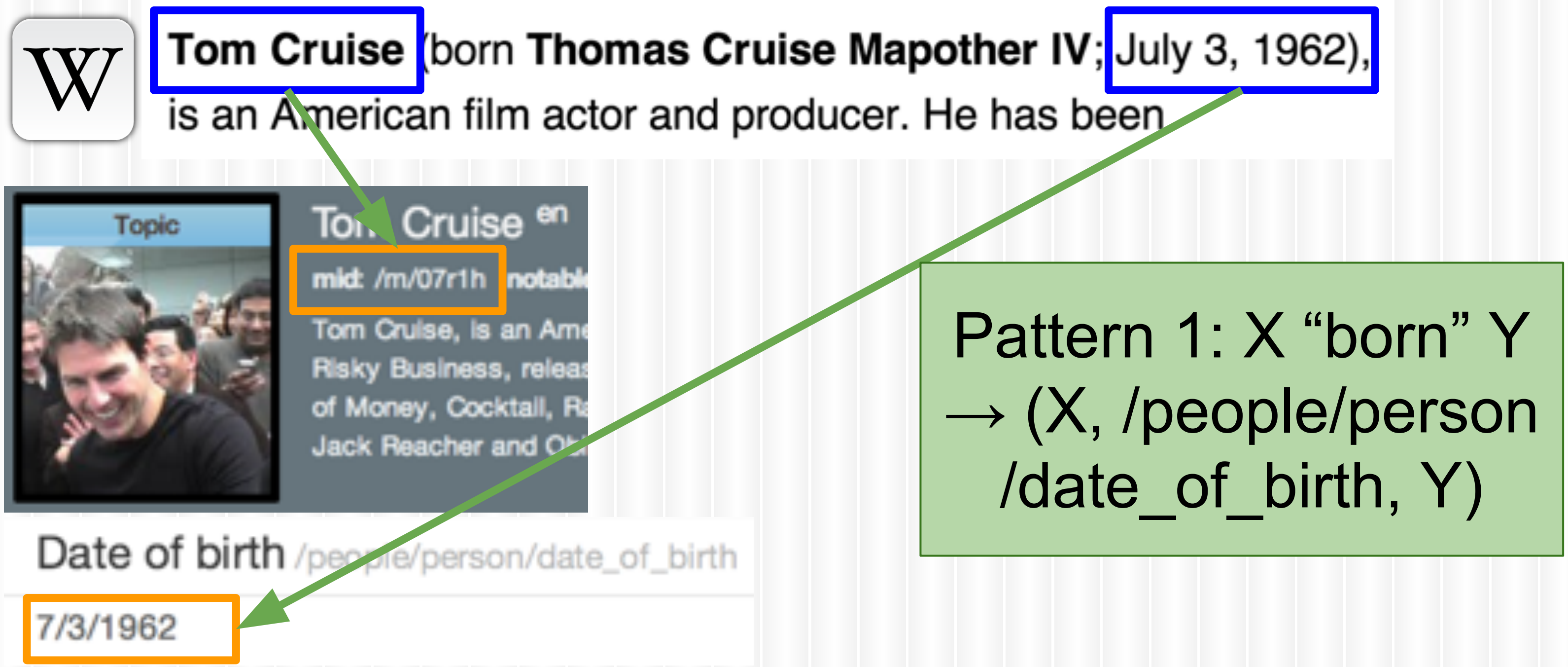
II. Entity linkage

/people/person/date_of_birth

III. Predicate linkage

Knowledge Extraction III–Extractors

- Texts/DOM: distant supervision



- Web tables/lists: schema mapping
- Annotations: semi-automatic mapping

Statistics for Extractors

- 12 extractors; high variety

	#Triples	#Webpages	#Patterns	Accu	Accu (conf $\geq$ .7)
TXT1	274M	202M	4.8M	0.36	0.52
TXT2	31M	46M	3.7M	0.18	0.80
TXT3	8.8M	16M	1.5M	0.25	0.81
TXT4	2.9M	1.2M	0.1M	0.78	0.91
DOM1	804M	344M	25.7M	0.43	0.63
DOM2	431M	925M	No pat.	0.09	0.62
DOM3	45M	N/A	No pat.	0.58	0.93
DOM4	52M	7.8M	No pat.	0.26	0.34
DOM5	0.7M	0.5M	No pat.	0.13	No conf.
TBL1	3.1M	0.4M	No pat.	0.24	0.24
TBL2	7.4M	0.1M	No pat.	0.69	No conf.
ANO	145M	53M	No pat.	0.28	0.30

As of 11/2013

Errors Can Creep in at Every Stage

Extraction error: (Obama, nationality, Chicago)

Errors Can Creep in at Every Stage

Reconciliation error:
(Obama, nationality, North America)

American
President
Barack Obama

W Donna Summer – Wikipedi ×

en.wikipedia.org/wiki/Donna_Summer

influences from all over the world. There's a touch of this, a little smidgeon of that, a dash of something else, like when you're cooking." On the song "The Queen Is Back", Summer reveals her wry and witty self-awareness of her musical legacy and her public persona. "I'm making fun of myself," she admits. "There's irony. It's poking fun at the idea of being called a queen. That's a title that has followed me, followed me and followed me. We were sitting and writing and that title kept popping up in my mind and I'm thinking, 'Am I supposed to write this? Is this too arrogant to write?' But people call me 'the queen,' so I guess it's ok to refer to myself as what everybody else refers to me as. We started writing the song and thought it was kind of cute and funny." Summer wrote "The Queen Is Back" and "Mr. Music" with J.R. Rotem and Evan Bogart, the son of Casablanca Records founder Neil Bogart.

On December 11, 2009, Summer performed at the Nobel Peace Prize Concert in Oslo, Norway in honor of American President Barack Obama. She was backed by the Norwegian Radio Orchestra.

2010–12: Final recordings [edit source | edit beta]

On July 29, 2010, Summer gave an interview with Allvoices.com wherein she was asked if she would consider doing an album of standards. She said, *I actually am, probably in September. I will begin work on a standards album. I will probably do an all-out dance album and a standards*

Errors Can Creep in at Every Stage

Source data error: (Obama, nationality, Kenya)

Obama born in Kenya

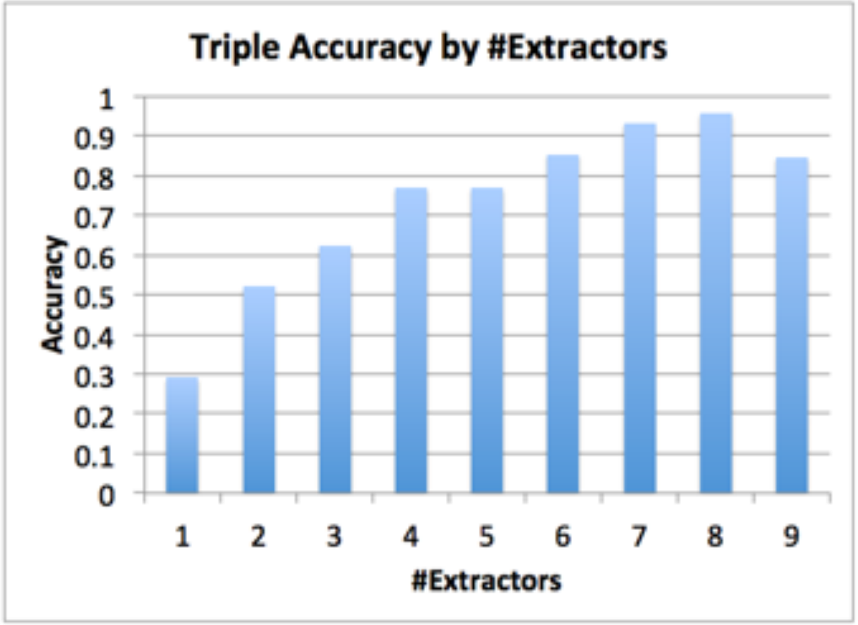
Knowledge Extraction IV–Quality

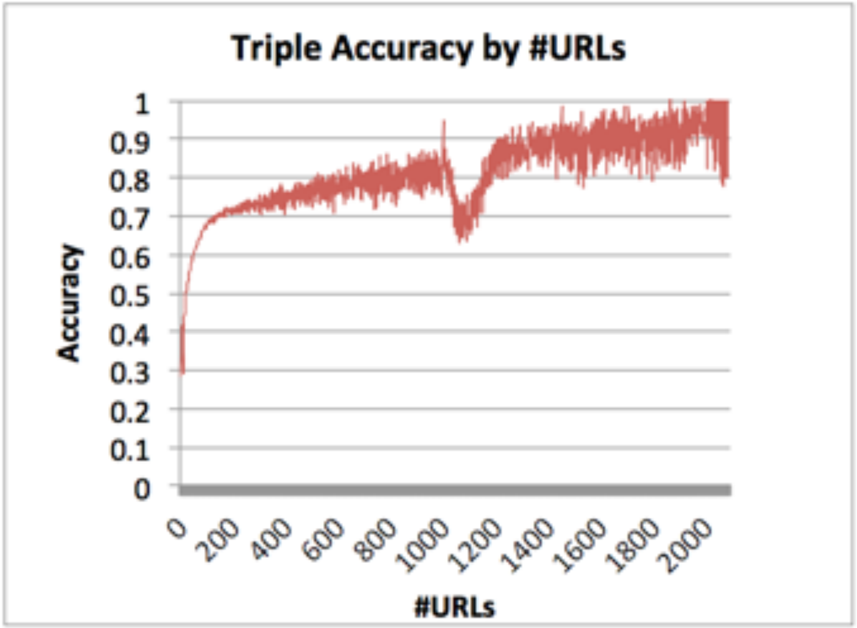
- Gold standard: Freebase
- LCWA (Local Closed-World Assumption)
  - If (s,p,o) exists in FB: true
  - Otherwise,
    - If (s,p) exists in FB: false (Freebase knowledge is locally complete)
    - Otherwise: UNKNOWN
- The gold standard contains about 40% of the triples

Statistics for Triple Correctness

- Overall accuracy: 30%
- Random sample on 25 false triples
  - Triple-identification errors: 11 (44%)
  - Entity-linkage errors: 11 (44%)
  - Predicate-linkage errors: 5 (20%)
  - Source-data errors: 1 (4%)

Statistics for Triple Correctness





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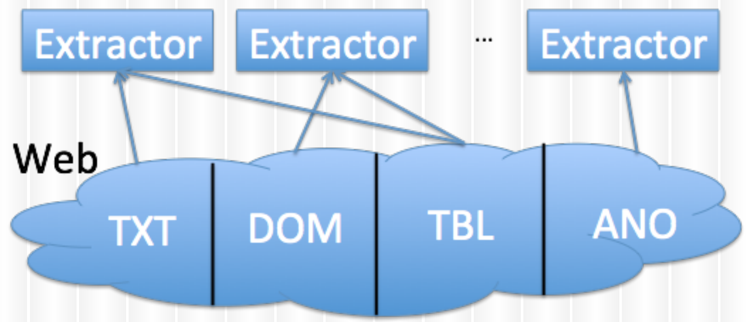
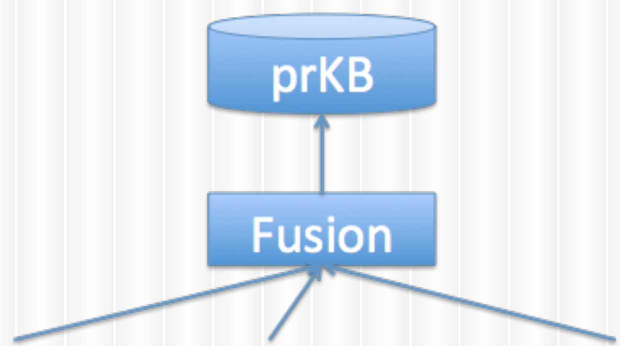
As of 11/2013

Outline

- Knowledge extraction



- Knowledge fusion

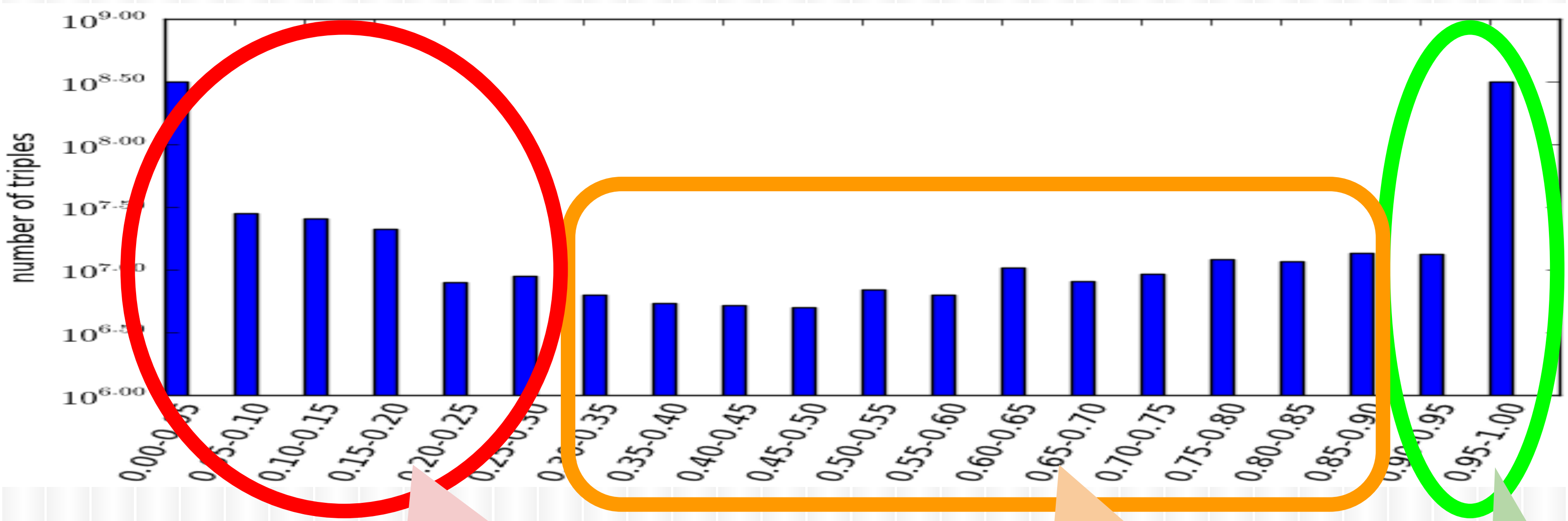


- Interesting applications
- Future directions

Goal: Judge Triple Correctness

- Input: Knowledge triples and their provenances (i.e., which extractor extracts from which source)
- Output: a probability in [0,1] for each triple
  - Probabilistic decisions vs. deterministic decisions

Usage of Probabilistic Knowledge



Negative training examples, and MANY EXCITING APPLICATIONS!!

Active learning, probabilistic inference, etc.

Upload to KG

Data Fusion–Definition

Input

Sources

Data items		S_1	S_2	…	S_N
	D_1				
	D_2				
	D_3				
	…				
	D_M				

Output

Data items		Truths
	D_1	
	D_2	
	D_3	
	…	
	D_M	

Data Fusion–Intuition

	Src1	Src2	Src3
Jagadish	UM	ATT	UM
Dewitt	MSR	MSR	UW
Bernstein	MSR	MSR	MSR
Carey	UCI	ATT	BEA
Franklin	UCB	UCB	UMD

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	Src1	Src2	Src3
Jagadish	UM	ATT	UM
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Bernstein	MSR	MSR	MSR
Carey	UCI	ATT	BEA
Franklin	UCB	UCB	UMD

Voting--Trust the majority.

Data Fusion–Intuition

	Src1	Src2	Src3
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Quality-based--Give higher votes to more accurate sources.

Data Fusion–A Bayesian Model

[Dong et al., VLDB'09]

Q1. How to compute source accuracy?

- Source Accuracy: A(S)

$$A(S) = \underset{v \in \bar{V}(S)}{Avg}\, P(v)$$

  - $\bar{V}(S)$ - values provided by S
  - $P(v)$ - pr of value v being true

Data Fusion–A Bayesian Model

[Dong et al., VLDB'09]

Q2. How to leverage accuracy in voting?

Input:

-Data item D

-Dom(D)={v_0,v_1,…,v_n}

-Observation Φ on D

Output:

Pr(v_i true|Φ) for each i=0,…, n (sum up to 1)

According to the Bayes Rule, we need to know Pr(Φ|v_i true)

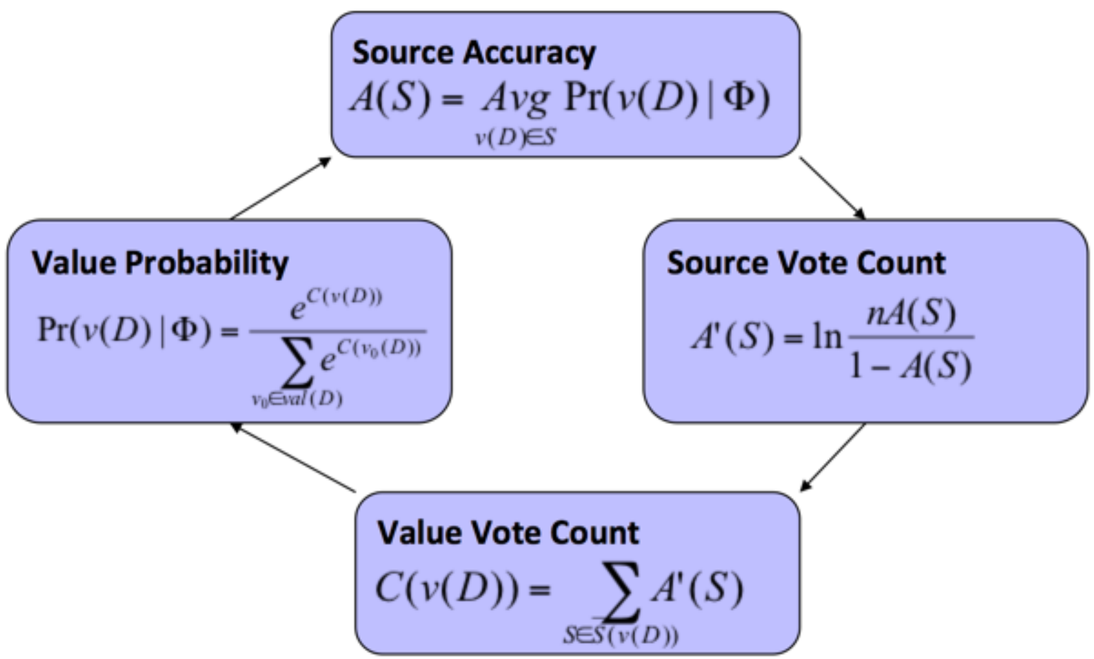
- Assuming independence of sources, we need to know Pr(Φ(S) |v_i true)
- If S provides v_i : Pr(Φ(S) |v_i true) =A(S)
- If S does not provide v_i : Pr(Φ(S) |v_i true) =(1-A(S))/n

Data Fusion–A Bayesian Model

[Dong et al., VLDB'09]

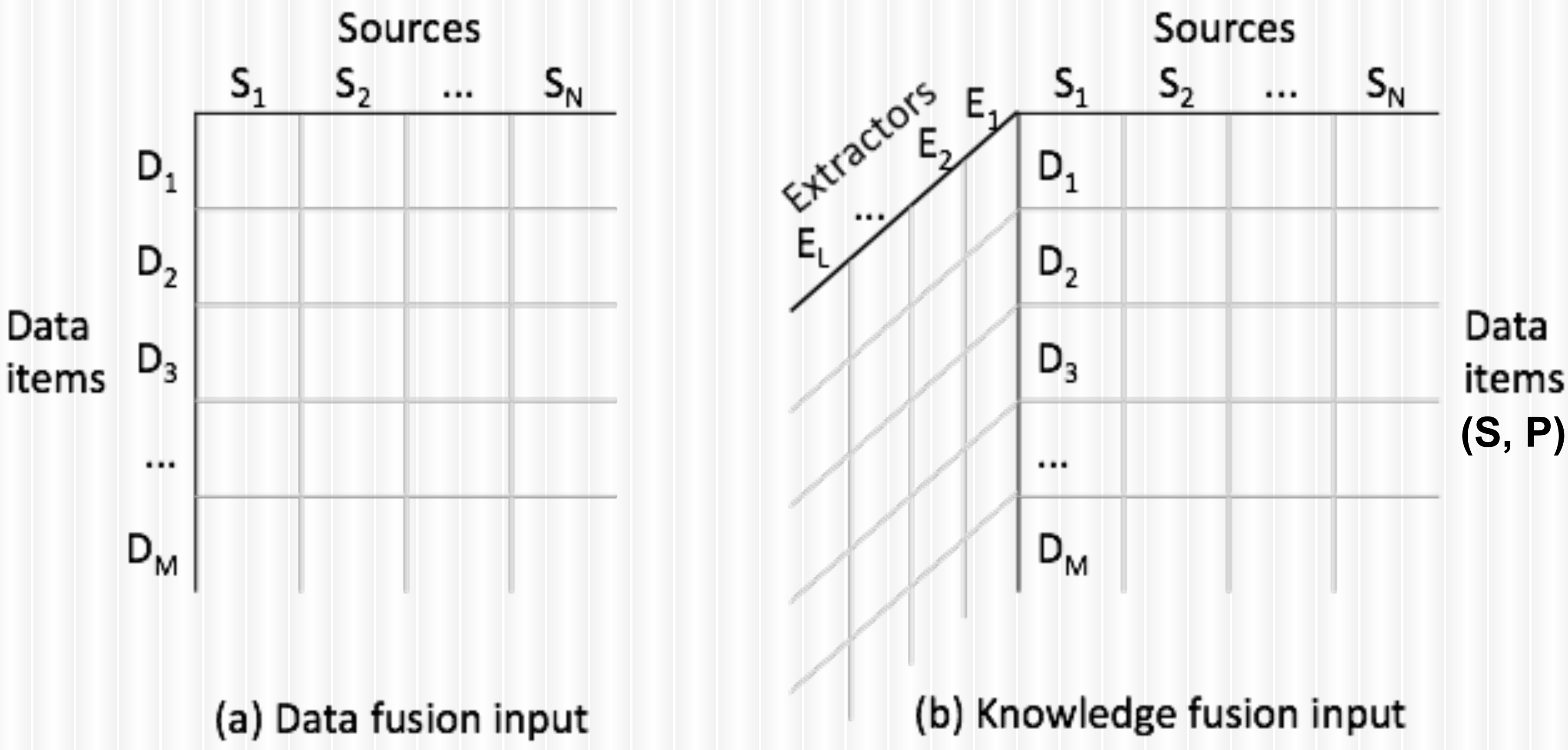
Q3. How to handle interdependence between source accuracy and value pr?

- Continue until source accuracy converges



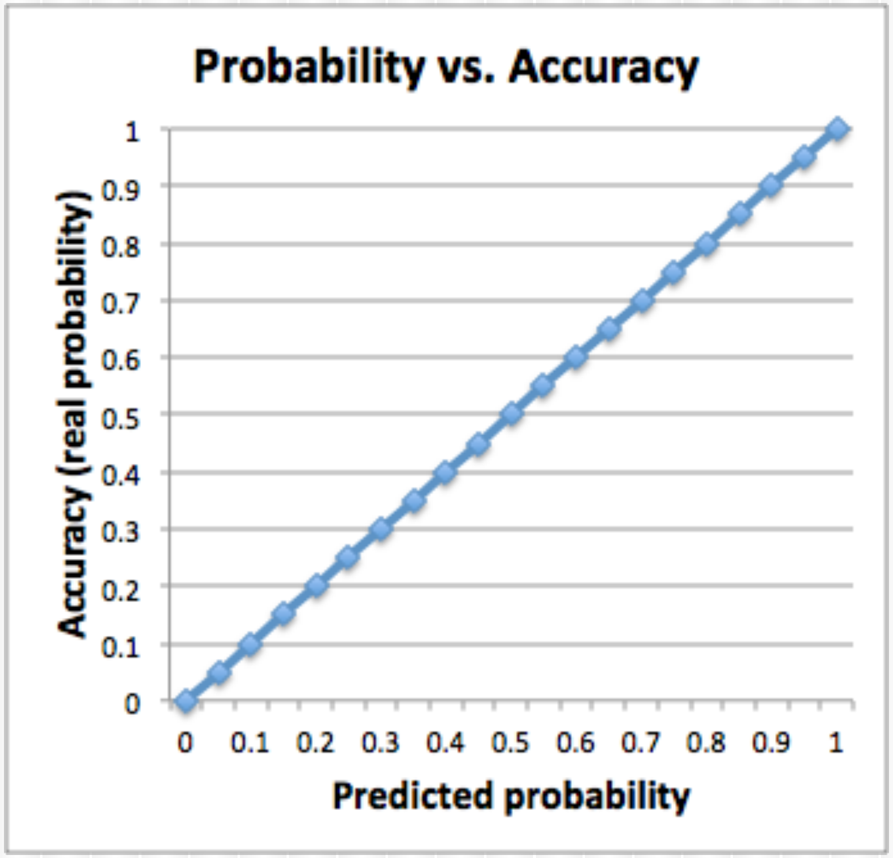
Knowledge Fusion Challenges

I. Input is ***three-dimensional***



Knowledge Fusion Challenges

II. Output prs should be ***well-calibrated***



Knowledge Fusion Challenges

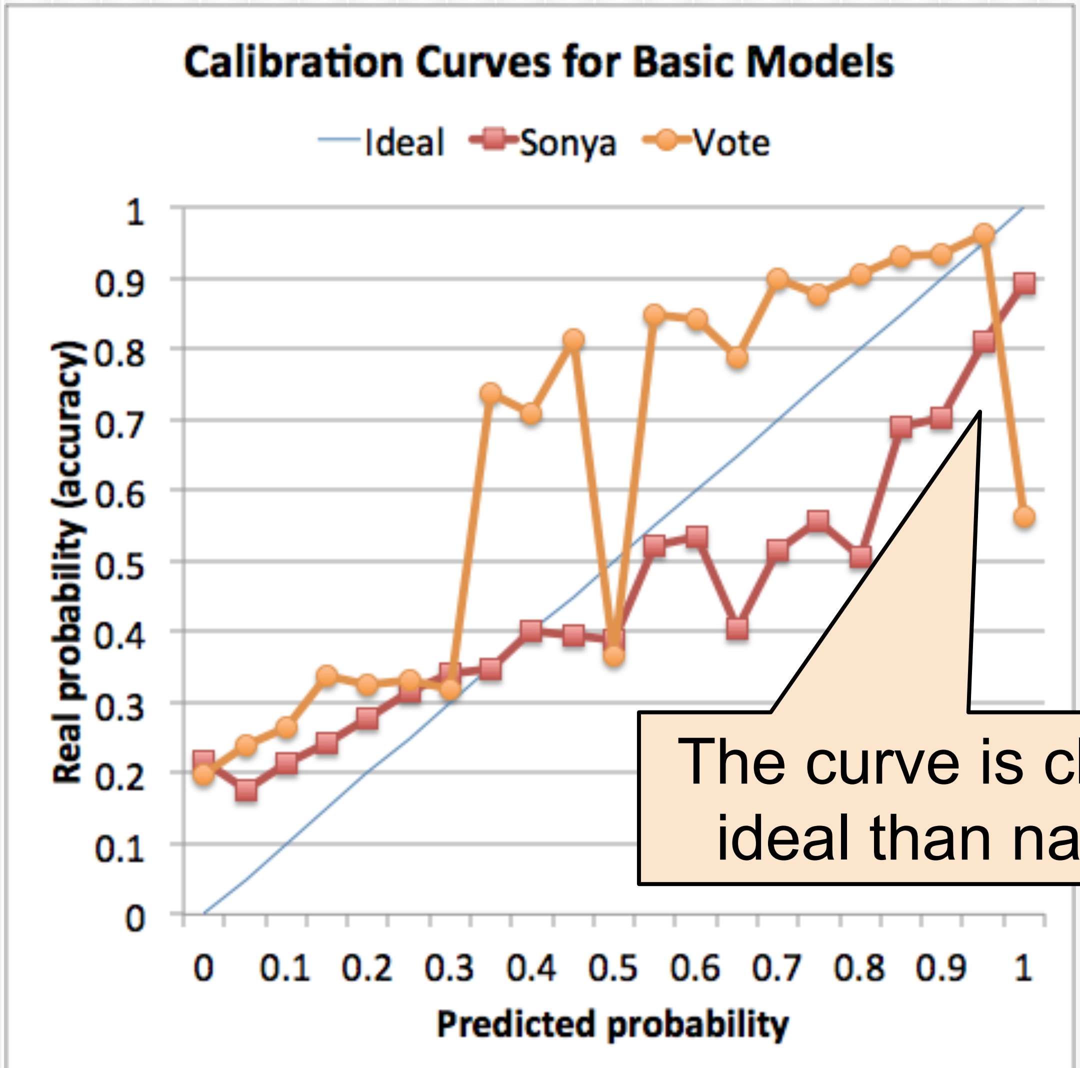
III. Data are of ***Web-scale***

- Three orders of magnitude larger than currently published data-fusion applications
  - Size: 1.1TB
  - Sources: 170K→ 1B+
  - Data items: 400K→375M
  - Values: 18M→6.4B (1.6B unique)
- Data are highly skewed
  - #Triples/Data-item: 1 - 2.7M
  - #Triples/Source: 1 - 50K

Knowledge Fusion Solutions

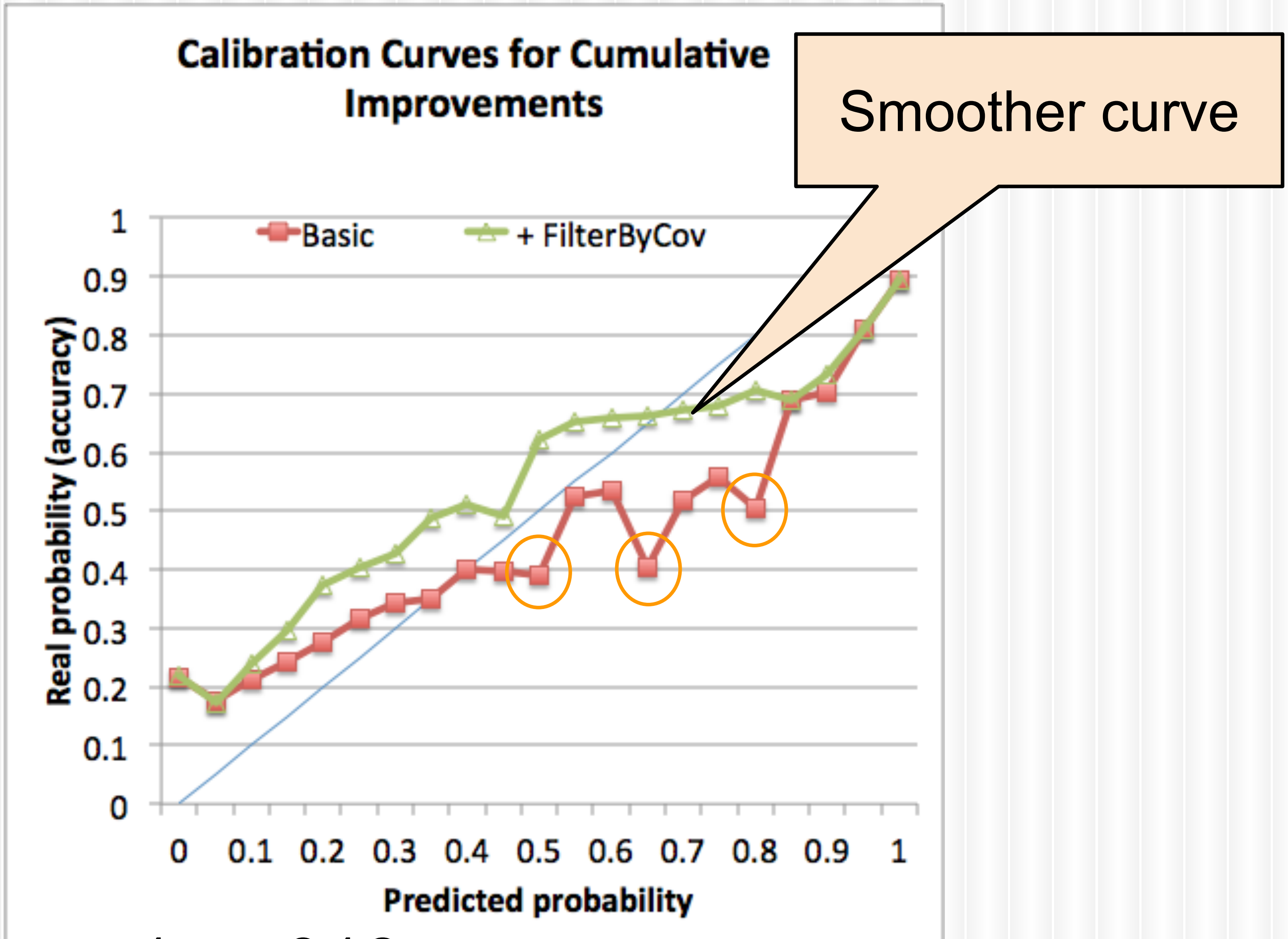
- Treat each (URL, Extractor) as a whole (*provenance)* for accuracy evaluation
- A series of refinements to improve probability calibration
- MapReduce Based Framework
  - Terminate in 5 rounds
  - Sample for *too big* data items or provenances

Basic Sonya Solution vs. Voting



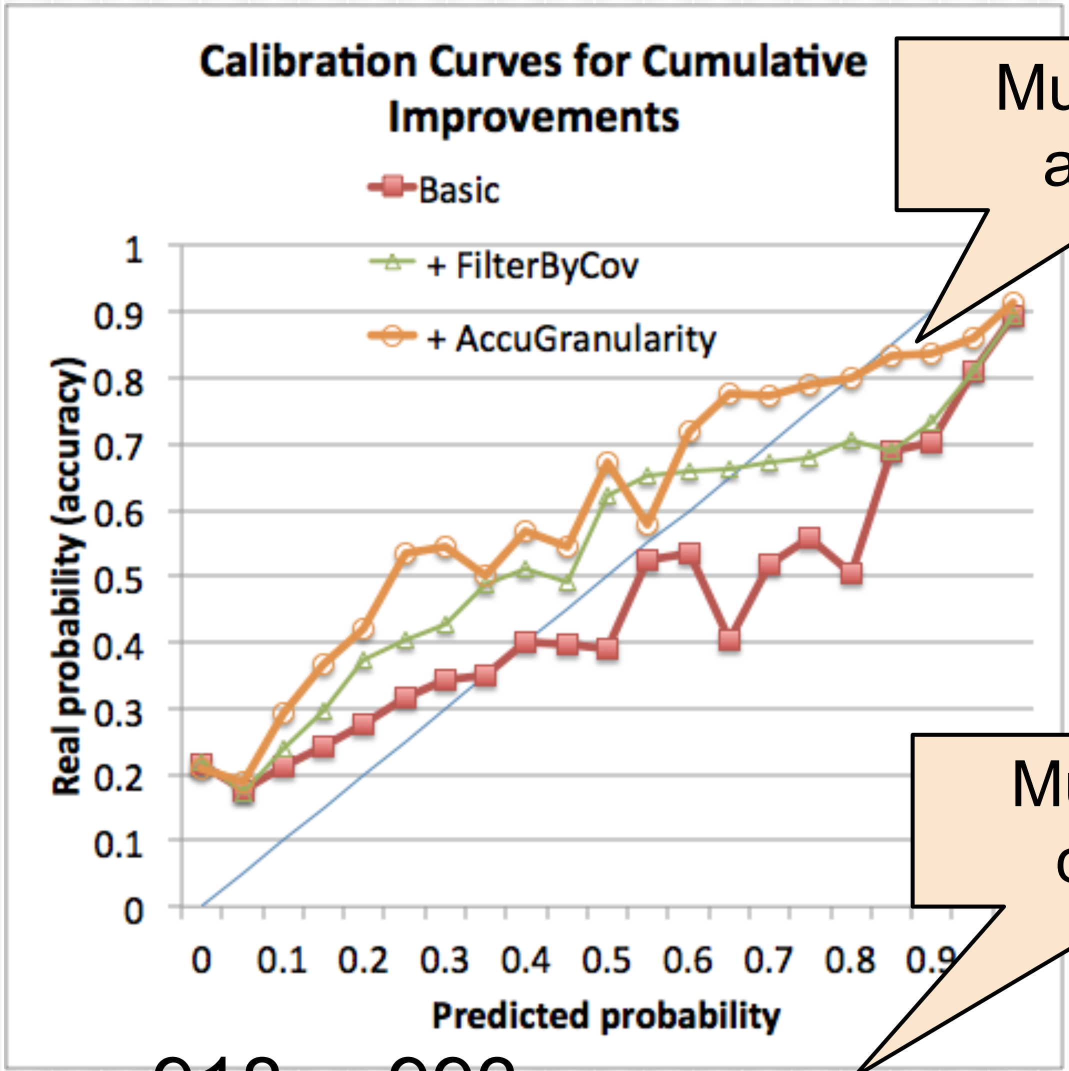
The curve is closer to the ideal than naive voting

Refinement I. Ignore Low-Coverage Provenances



Coverage: 1→ .918

Refinement II. Granularity (URL->Site, Extractor->Pattern, Predicate)

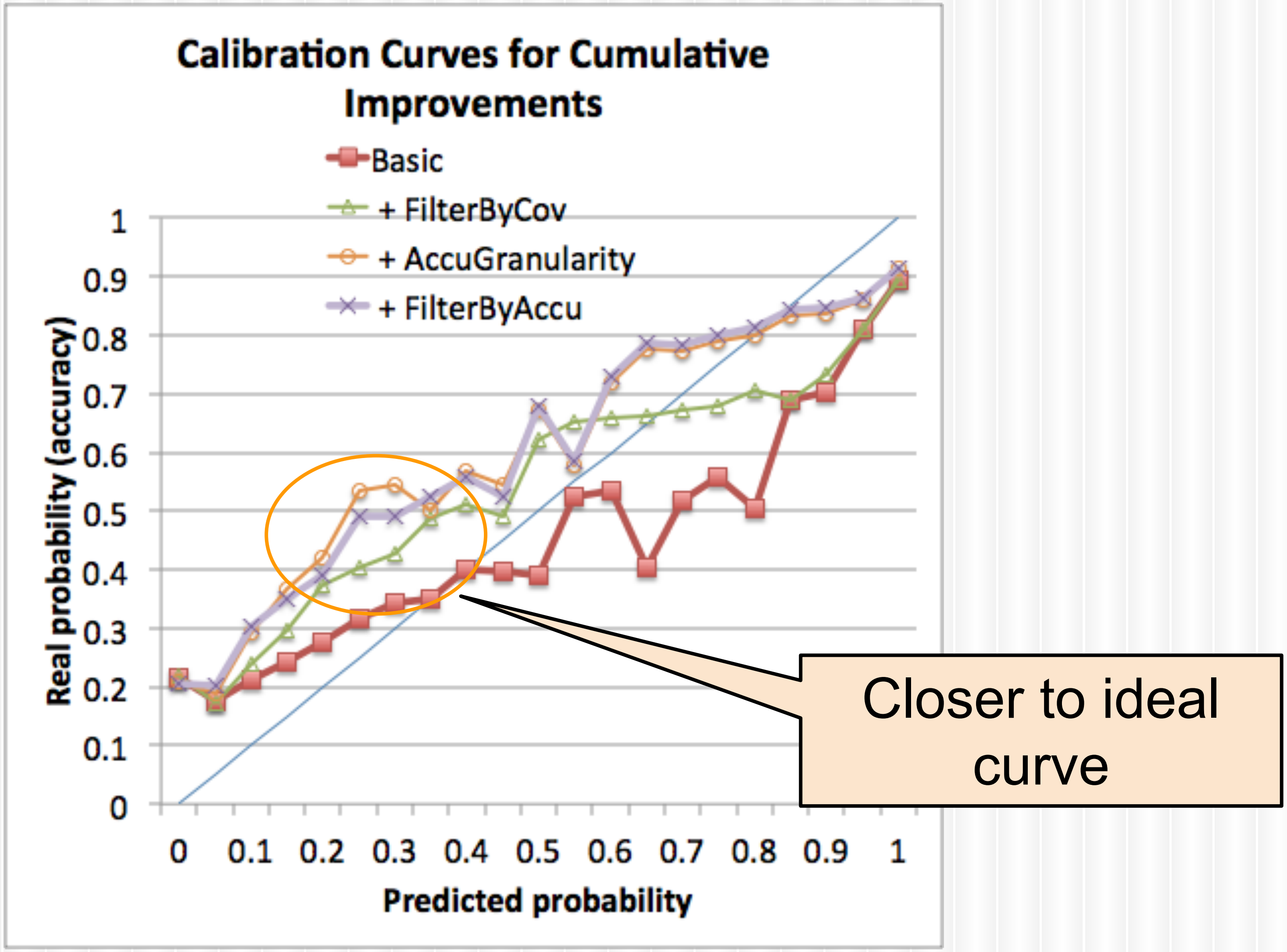


Much higher accuracy

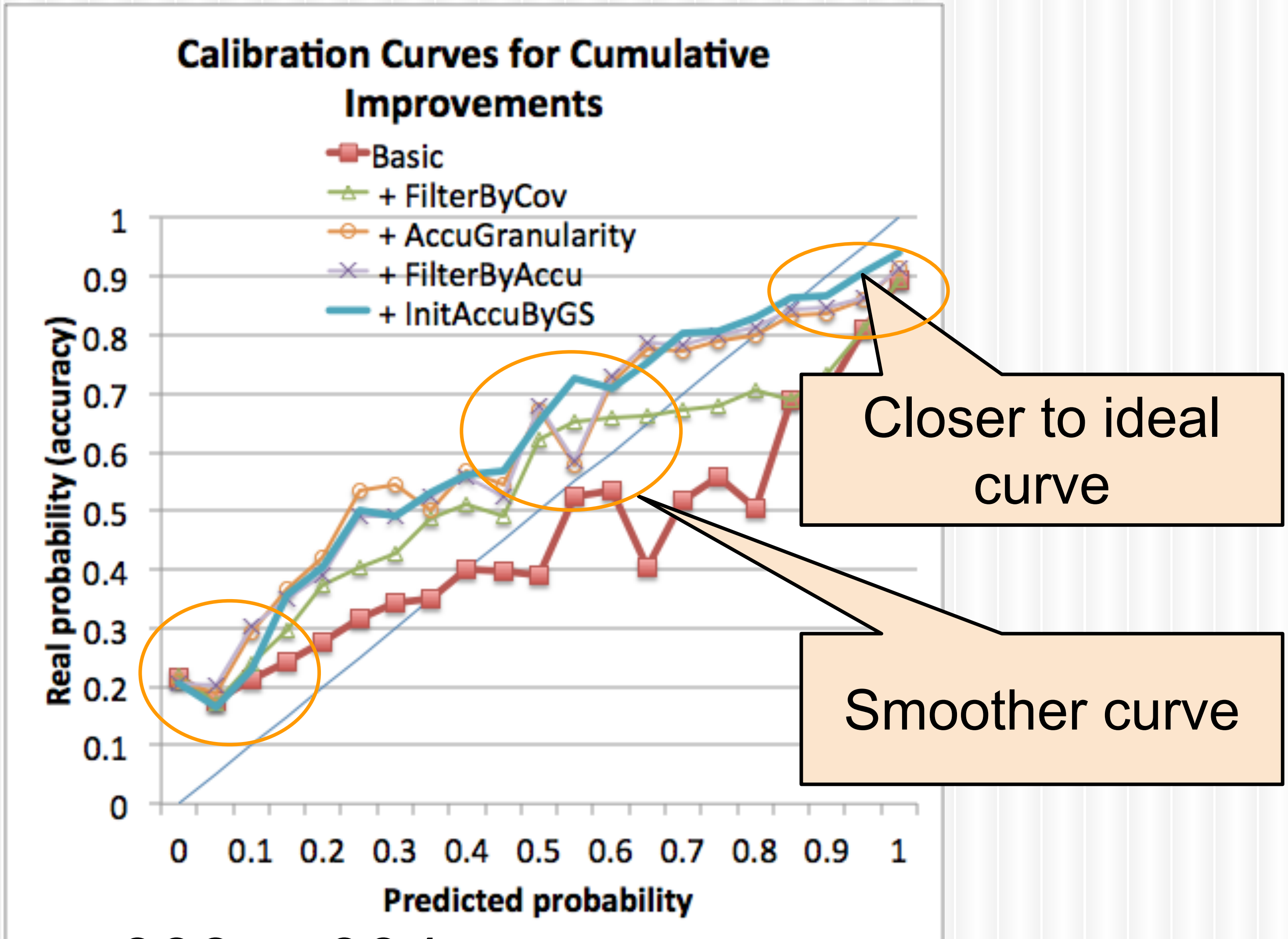
Much higher coverage

Coverage:.918→.993

Refinement III. Ignore Low-Accuracy Provenances

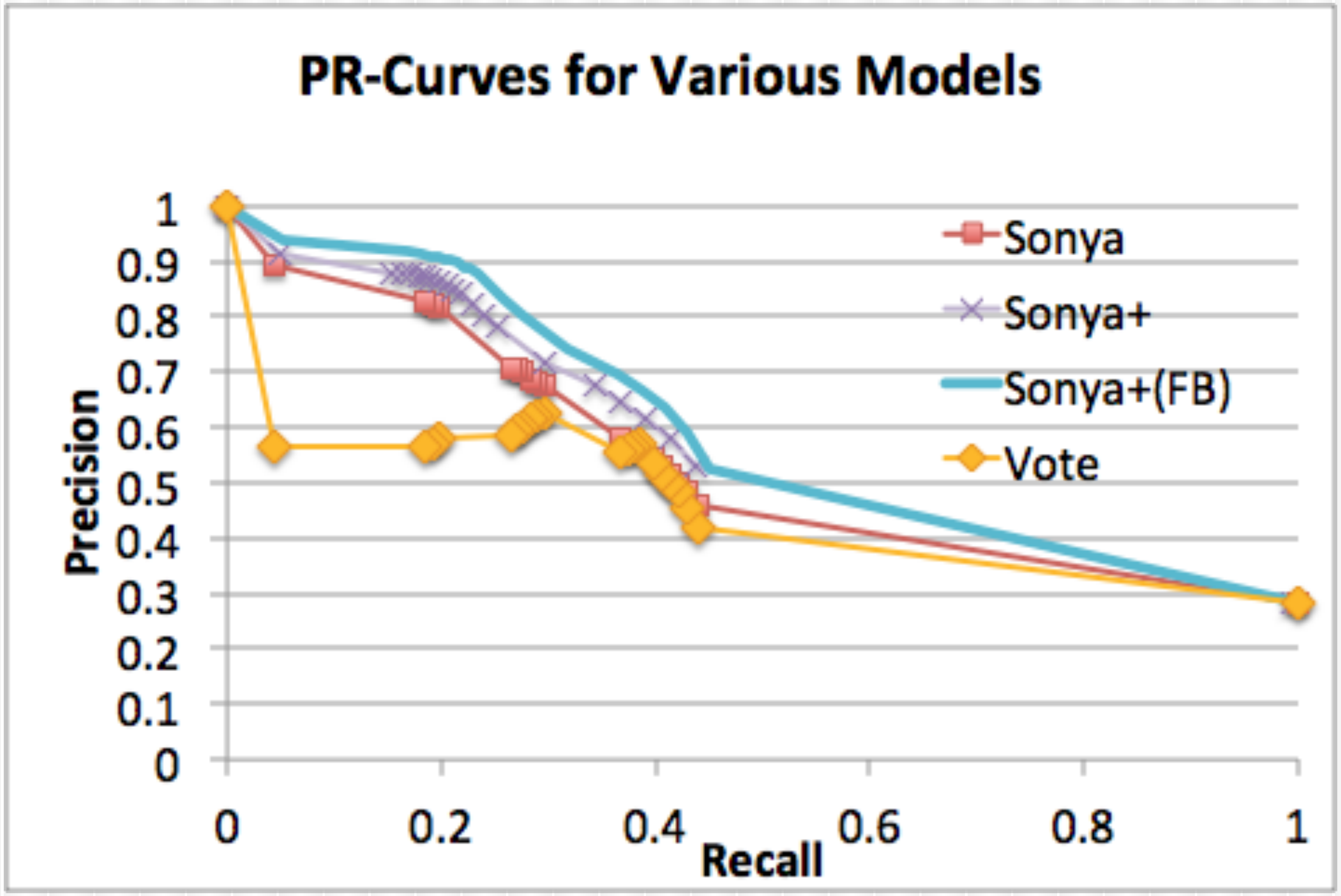


Refinement IV. Initiate Provenance Accuracy by FB

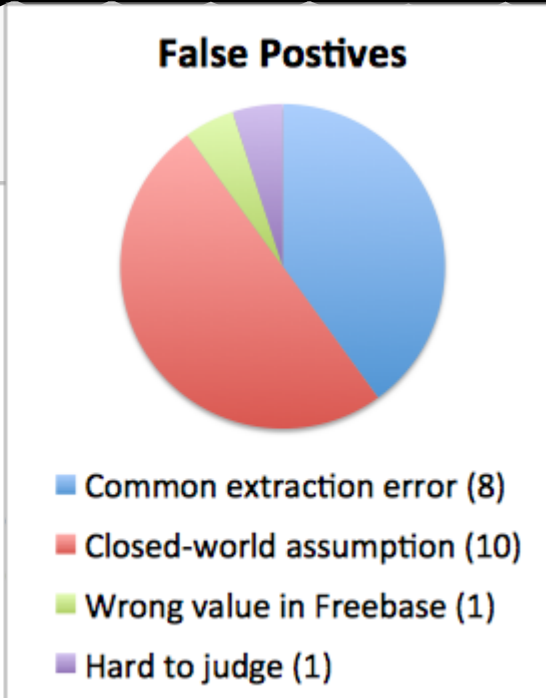


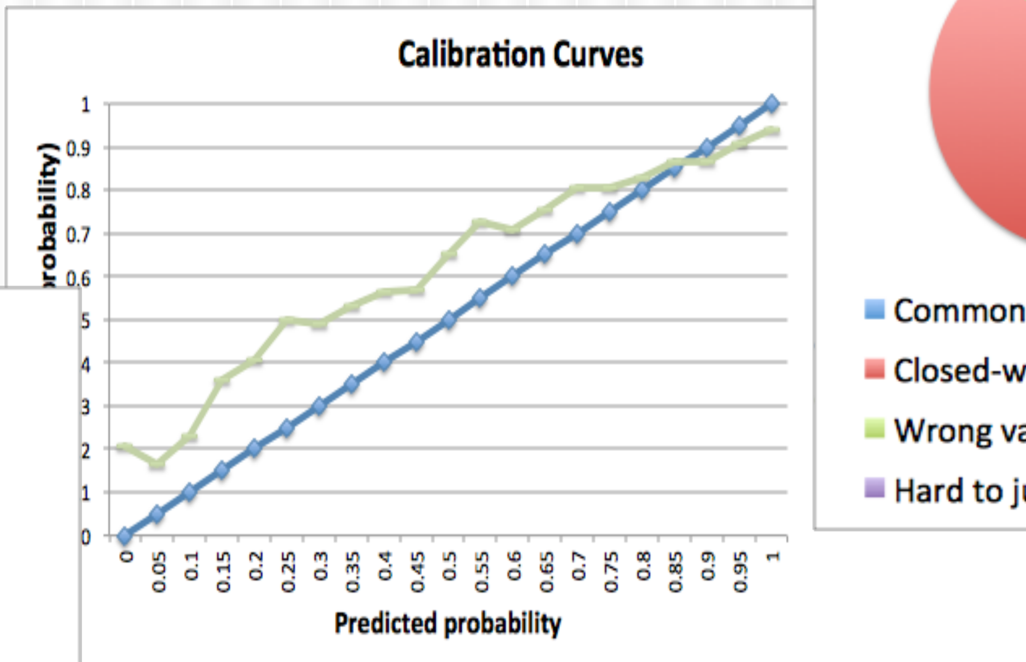
Coverage:.993→.994

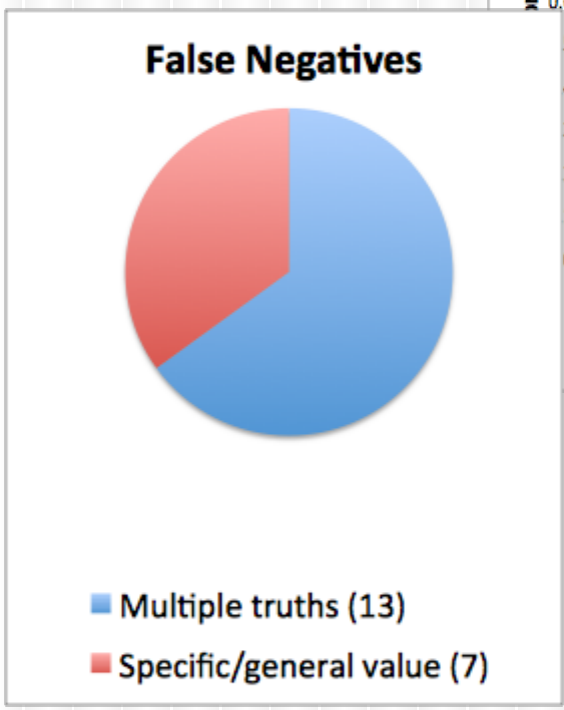
Precision-Recall Curve



Analysis of Errors



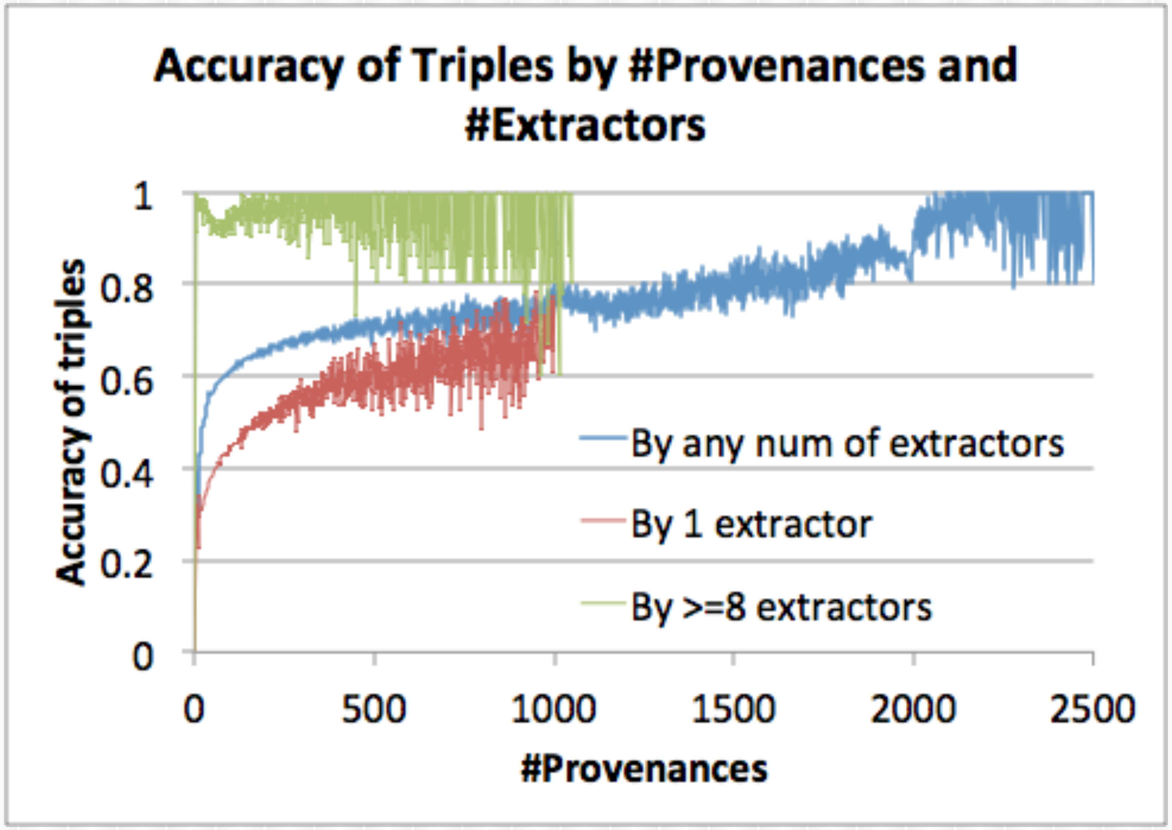




Future Directions!!!

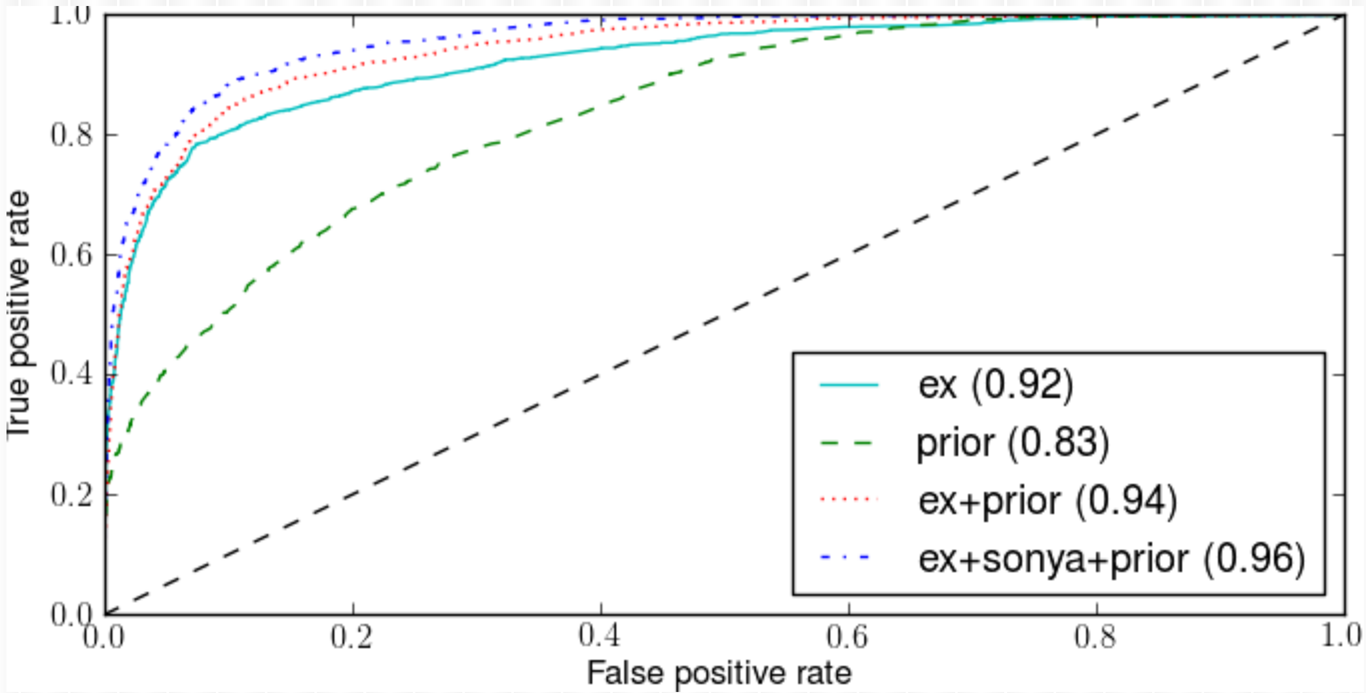
One Inherent Limitation

Cannot distinguish errors from extractors and from sources



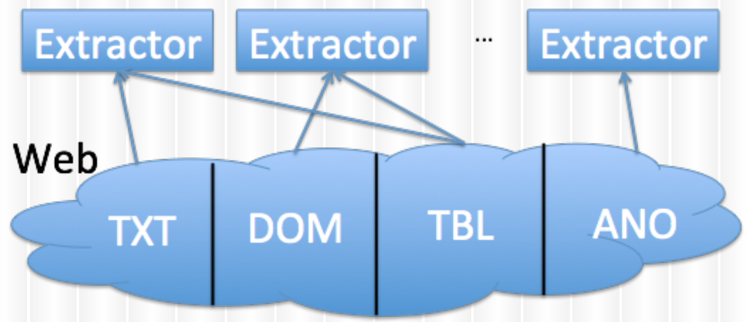
Other Fusion Techniques

- Ex: Adaboost learning from extractions
- Prior: (A, parent_of, C), (B, parent_of, C)
  → (A, spouse_of, B)

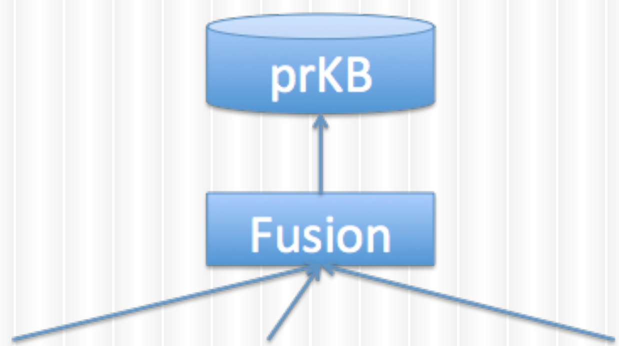


Outline

Knowledge extraction



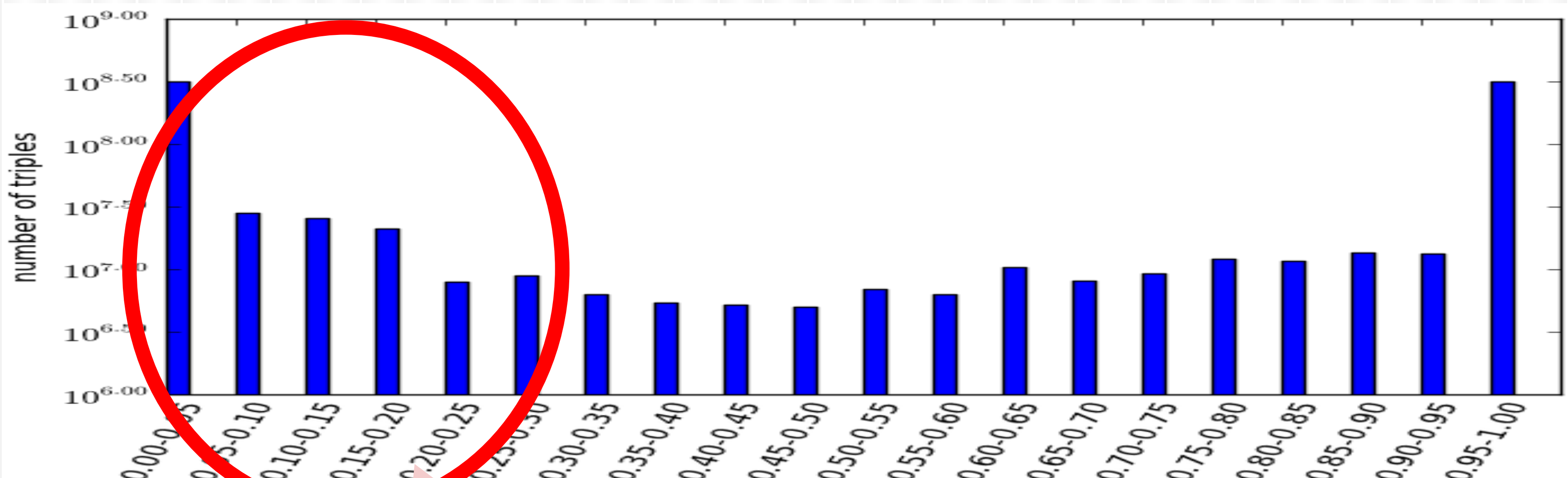
Knowledge fusion



Interesting applications

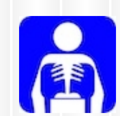
Future directions

Usage of Probabilistic Knowledge



Negative training examples, and MANY EXCITING APPLICATIONS!!

- Source errors: trustworthiness evaluation 

- Extraction errors: data abnormality diagnosis 

Application I. A New Angle to Evaluate Web Source Quality

- What we have now
  - Page Rank: links between Websites/Webpages
  - Log based: search log and click-through rate
  - Web spam
  - etc.

Popular Sources w. High Page Rank May Spread Gossip

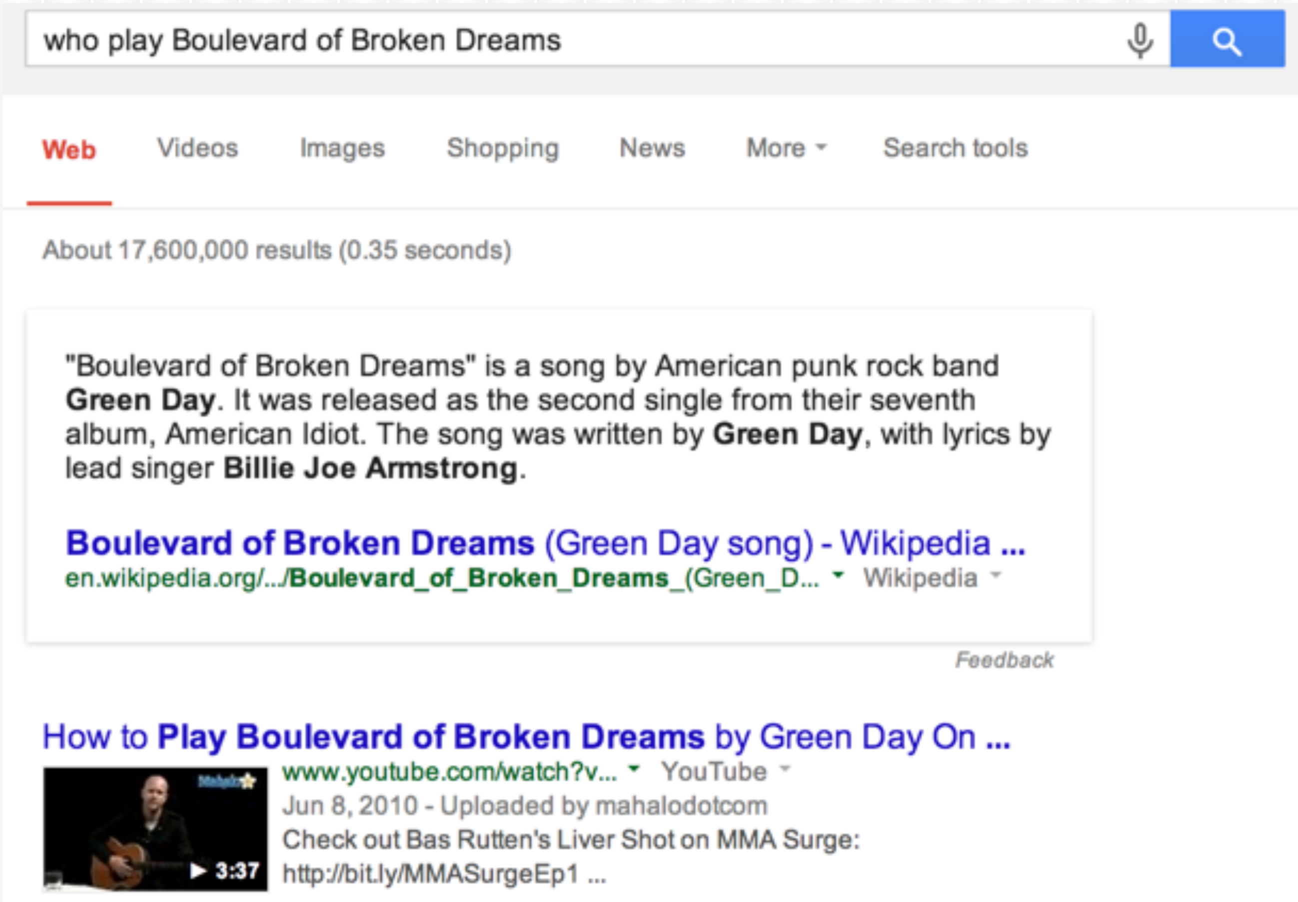
14 out of 15 Gossip Websites have high page rank

http://www.ebizmba.com/articles/gossip-websites

Domain
www.eonline.com
perezhilton.com
radaronline.com
www.zimbio.com
mediatakeout.com
gawker.com
www.popsugar.com
www.people.com
www.tmz.com
www.fishwrapper.com
celebrity.yahoo.com
wonderwall.msn.com
hollywoodlife.com
www.wetpaint.com

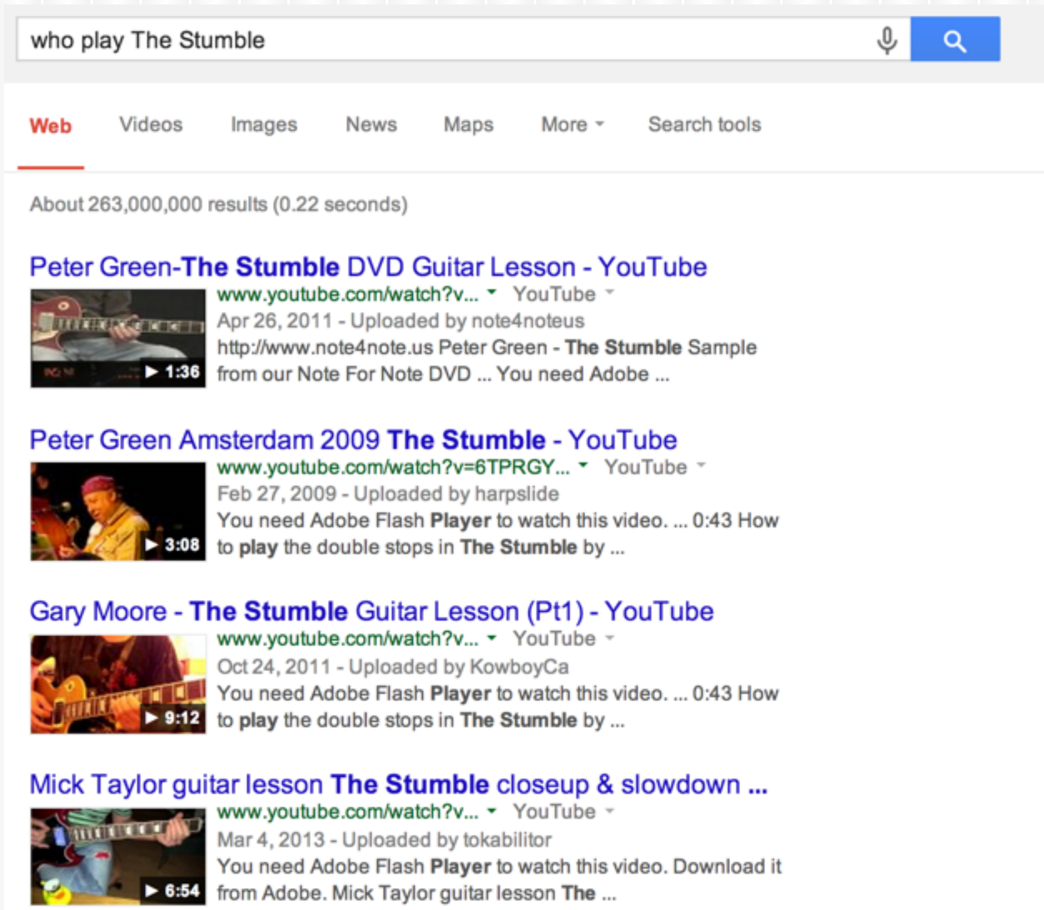
Tale Sources w. Low Page Rank May Provide Valuable Info

Tale Sources w. Low Page Rank May Provide Valuable Info



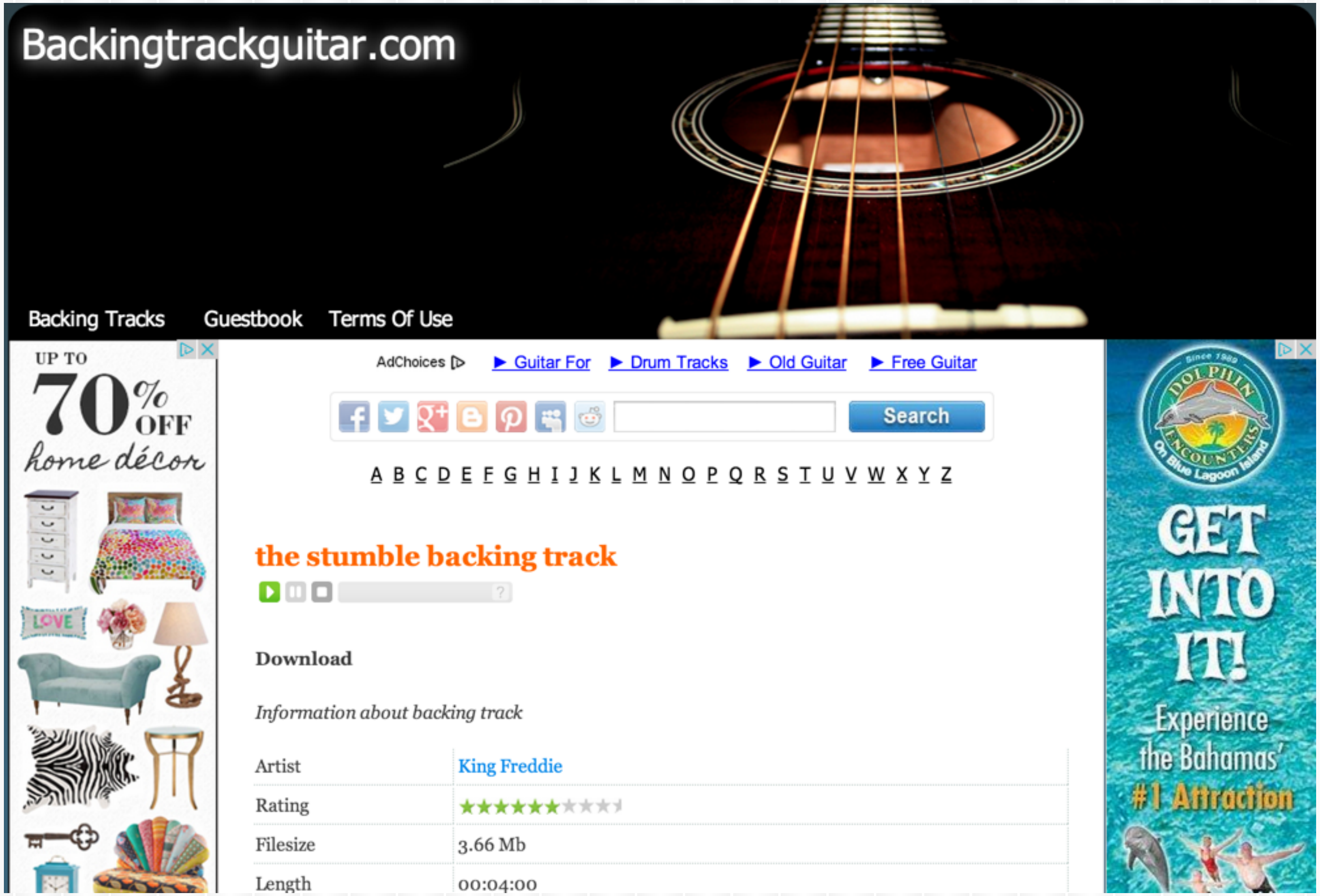
Good WebAnswer for an award-winning song

Tale Sources w. Low Page Rank May Provide Valuable Info



Missing WebAnswer for a not-so-popular song

Tale Sources w. Low Page Rank May Provide Valuable Info



Very precise info on guitar players but low Page Rank

Application I. A New Angle to Evaluate Web Source Quality

Fact 1	✓
Fact 2	✓
Fact 3	✗
Fact 4	✓
Fact 5	✗
Fact 6	✓
Fact 7	✓
Fact 8	✓
Fact 9	✓
Fact 10	✗
…	…
Accu	**0.7**

Application I. A New Angle to Evaluate Web Source Quality

How to decide if a triple is indeed claimed by the source instead of an *extraction error*?

Tr...4	0.8
Triple 5	0.4
Triple 6	0.8
Triple 7	0.9
Triple 8	1.0
Triple 9	0.7
Triple 10	0.2
…	…
Accu	**0.7**

Application I. A New Angle to Evaluate Web Source Quality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The Free Encyclopedia

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Random article
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Acèh
Адыгэбзэ
Afrikaans
Alemannisch
አማርኛ
Ænglisc
Аҧсшәа
العربية
Aragonés

United States

From Wikipedia, the free encyclopedia
(Redirected from USA)

For other uses, see US (disambiguation), USA (disambiguation), and United States (disambiguation).

The **United States of America** (**USA**), commonly referred to as the **United States** (**US**), **America** or simply **the States**, is a federal republic[10][11] consisting of 50 states and a federal district. The 48 contiguous states and the federal district of Washington, D.C., are in central North America between Canada and Mexico. The state of Alaska is the northwestern part of North America and the state of Hawaii is an archipelago in the mid-Pacific. The country also has five populated and nine unpopulated territories in the Pacific and the Caribbean. At 3.79 million square miles (9.83 million km^2) in total and with around 317

United States of America

Flag Great Seal

Motto:
"In God we trust" (official)[1][2][3]
"E pluribus unum" (Latin) (traditional)
"Out of many, one"

Anthem: "The Star-Spangled Banner"
0:00 MENU

	Triple Corr	Extraction Corr
Triple 1	1.0	1.0
Triple 2	0.9	1.0
Triple 3	0.3	1.0
Triple 4	0.8	1.0
Triple 5	0.4	0.9
Triple 6	0.8	0.9
Triple 7	0.9	0.8
Triple 8	1.0	0.2
Triple 9	0.7	0.1
Triple 10	0.2	0.1
…	…	…
Accu	**0.73**	

Extraction and Triple Correctness Example. (Obama, nationality, ?)

(Obama, nationality, Bolivarianism) (many many such objects)

- 3 extractions (Pr_extCorr=0.01)
  http://mathaba.net/news/?x=631316
  http://www.laht.com/article.asp?ArticleId=329187&CategoryId=10717
  http://www.iamericas.org/en/about-ioa/presidents-corner

Chávez Calls on Obama to Join Him in the Socialist Revolution

"Come on, Obama, align yourself with us on the way to socialism!" said the Venezuelan leader who this week also expropriated plants and lands of Venezuela's Polar, US firm Cargill, and Irish firm Smurfit. "Come on, it's the only way!"

By Jeremy Morgan
Latin American Herald Tribune staff

CARACAS – President Hugo Chávez invited President Barack

- Pr_tripleCorr=0

Extraction and Triple Correctness Example. (Obama, nationality, ?)

(Obama, nationality, Kenya)

- 2087 extractions:
  - Example of a correct extraction (Pr_extCorr=0.792):

    http://beforeitsnews.com/obama-birthplace-controversy/2013/04/alabama-supreme-court-chief-justice-roy-moore-to-preside-over-obama-eligibility-case-2458624.html

    2006: Obama In Kenya: I Am So Proud To Come Back Home - VIDEO HERE.
    2007: Michelle Obama Declares Obama Is Kenyan And America Is Mean - VIDEO HERE.
    2008: Michelle Obama Declares Barack Obama's Home Country Is Kenya - VIDEO HERE.
    FLASHBACK: Obama Is The Original Birther! Obama In 1991 Stated In His Own Bio He Was Born In Kenya. DETAILS HERE.

  - Example of a wrong extraction (Pr_extCorr=0.130):

    http://www.monitor.co.ug/News/National/US+will+respect+winner+of+Kenya+election++Obama+says/-/688334/1685814/-/ksxagx/-/index.html

    US will respect winner of Kenya election, Obama says

    SHARE BOOKMARK PRINT RATING

- Pr_tripleCorr=0 (not enough support)

Extraction and Triple Correctness Example. (Obama, nationality, ?)

(Obama, nationality, USA)

- 2481 extractions:
  - Example of a correct extraction (Pr_extCorr=0.999):
    http://www.dogonews.com/2009/10/9/a-nobel-prize-for-our-awesome-president
  - Example of a wrong extraction (Pr_extCorr=0.261):
    http://blogs.telegraph.co.uk/news/timstanley/100169248/barack-obamas-life-story-contains-myth-not-truth-says-biographer-so-why-did-the-media-report-it-as-truth/

Tim Stanley

Dr Tim Stanley is a historian of the United States. His new book about Hollywood politics is out in May. His personal website is www.timothystanley.co.uk and you can follow him on Twitter @timothy_stanley.

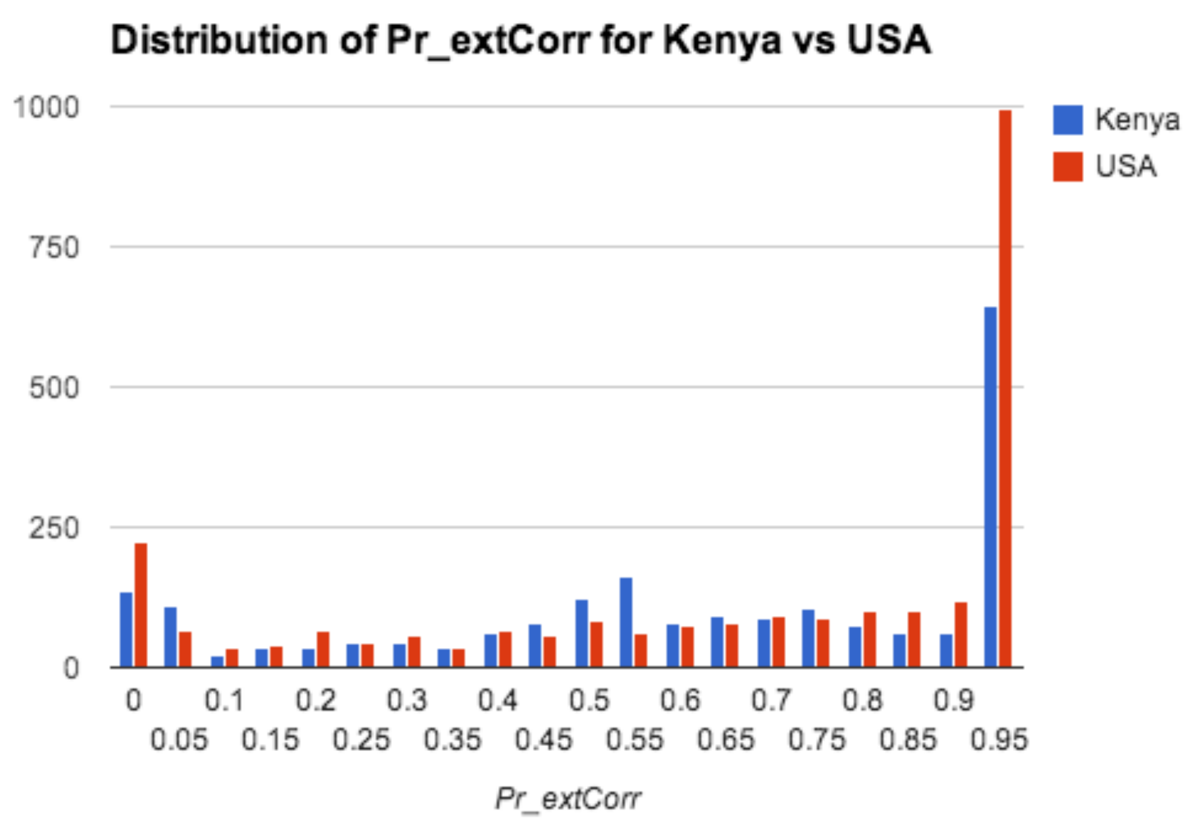
Follow 15.6K followers

Barack Obama's life story contains 'myth, not truth', says biographer. So why did the media report it as truth?

- Pr_tripleCorr=1 (Higher support)

Extraction and Triple Correctness Example. (Obama, nationality, ?)

Distribution of providers for Kenya and USA



Sonya Trustworthiness Score

Domain	#Triples	Sonya Score
www.eonline.com	12,871	0.363
perezhilton.com	46,912	0.427
radaronline.com	3,530	0.489
www.zimbio.com	2,464,452	0.530
mediatakeout.com	131	0.531
gawker.com	6,055	0.567
www.popsugar.com	1,805	0.576
www.people.com	16,886	0.585
www.tmz.com	8,149	0.621
www.fishwrapper.com	14	0.622
celebrity.yahoo.com	11,187	0.677
wonderwall.msn.com	2,524	0.684
hollywoodlife.com	4,536	0.689
www.wetpaint.com	19,284	0.730

Many gossip Web sites DO provide quite a lot of wrong factual information

Sonya Trustworthiness Score

- Example for (URL, Predicate)

  URL: https://ibirthdayworld.blogspot.com/2010/03/celebrity-birthdays-on-march-22.html

  Predicate: date_of_birth

  - #Facts = 42; Trustworthiness = 0.95

Source: http://ibirthdayworld.blogspot.com/2010/03/celebrity-birthdays-on-march-22.html e.g., http://en.wikipedia.org/wiki/World_Chess_Championship_2013 or en.wikipedia.org

Pred: /people/person/date_of_birth e.g., /people/person/place_of_birth

Max results to display: 100

Support threshold: 0.0

Query Sonya

Source	Pred	Num_of_Triples	Accuracy
http://ibirthdayworld.blogspot.com/2010/03/celebrity-birthdays-on-march-22.html	/people/person/date_of_birth	42	0.953

Sonya Trustworthiness Score

Celebrity Birthdays On March 22

<-Marcel Marceau

Below are 124 famous people born on March 22.

Browse Gift Ideas - Browse Ecards

The names in brackets below are duplicate entries.

Aaron North was born on March 22, 1979. American guitarist.

Amy Stud was born on March 22, 1986. English singer-songwriter and musician.

Andreas Johnson was born on March 22, 1970. Swedish pop and rock singer-songwriter and musician.

Andrew Lloyd Webber was born on March 22, 1948. British composer of musicals.

Angelo Badalamenti was born on March 22, 1937. American composer.

Anja Kling was born on March 22, 1970. German actress.

Annabelle Apsion was born on March 22, 1963. English actress.

Anne Hyde was born on March 22, 1638. Wife of James II of England.

Anthony van Dyck was born on March 1599. Flemish Baroque artist.

Armin Hary was born on March 22, 1937. German athlete.

Avraham Fried was born on March 22, 1959. American singer-songwriter and musical entertainer.

Sonya Trustworthiness Score

- Example for (URL, Predicate)

  URL: https://ibirthdayworld.blogspot.com/2010/03/celebrity-birthdays-on-march-22.html

  Predicate: date_of_birth

  - #Facts = 42; Trustworthiness = 0.95

  - Mistake: Anne Hyde (the URL says: 3/22/1638; Wiki/KG says: 3/12/1637)

Anne Hyde

Anne Hyde was Duchess of York and Albany as the first wife of James, Duke of York, later King James II and VII. Originally Anglican, her father was a lawyer. Wikipedia

Born: March 12, 1637, Windsor, United Kingdom

Died: March 31, 1671, London, United Kingdom

Spouse: James II of England (m. 1660–1671)

Children: Anne, Queen of Great Britain, Mary II of England, More

Parents: Edward Hyde, 1st Earl of Clarendon, Frances Hyde, Countess of Clarendon

Siblings: Laurence Hyde, 1st Earl of Rochester, Henry Hyde, 2nd Earl of Clarendon

Application II. Provide An X-Ray for Extracted Data

- Goal: Help users analyze errors, changes and abnormalities in data

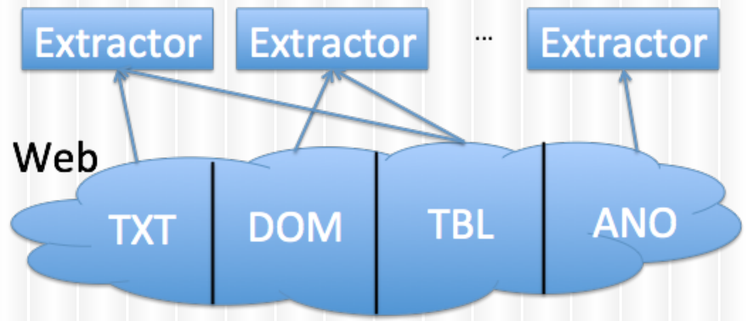
- Intuitions: cluster errors by features and return clusters with top error rates

Application II. Provide An X-Ray for Extracted Data

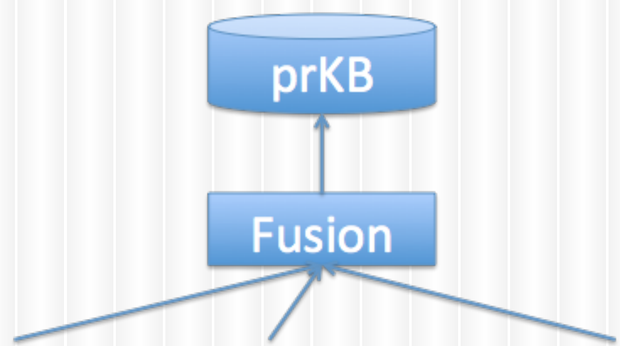
- Cluster I.
  - Feature: (besoccor.com, date_of_birth, 1986_02_18)
  - #Triples: 630; Errs: 100%
  - Reason: default value
- Cluster 2.
  - Feature: (ExtractorX, pred: namesakes, obj:the county)
  - #Triples: 4878; Errs: 99.8%
  - E.g., [Salmon P. Chase, namesakes, The County]
  - Contexts: *The county* was named for Salmon P. Chase, former senator and govenor of Ohio
  - Reason: Unresolved coreference

Outline

Knowledge extraction



Knowledge fusion

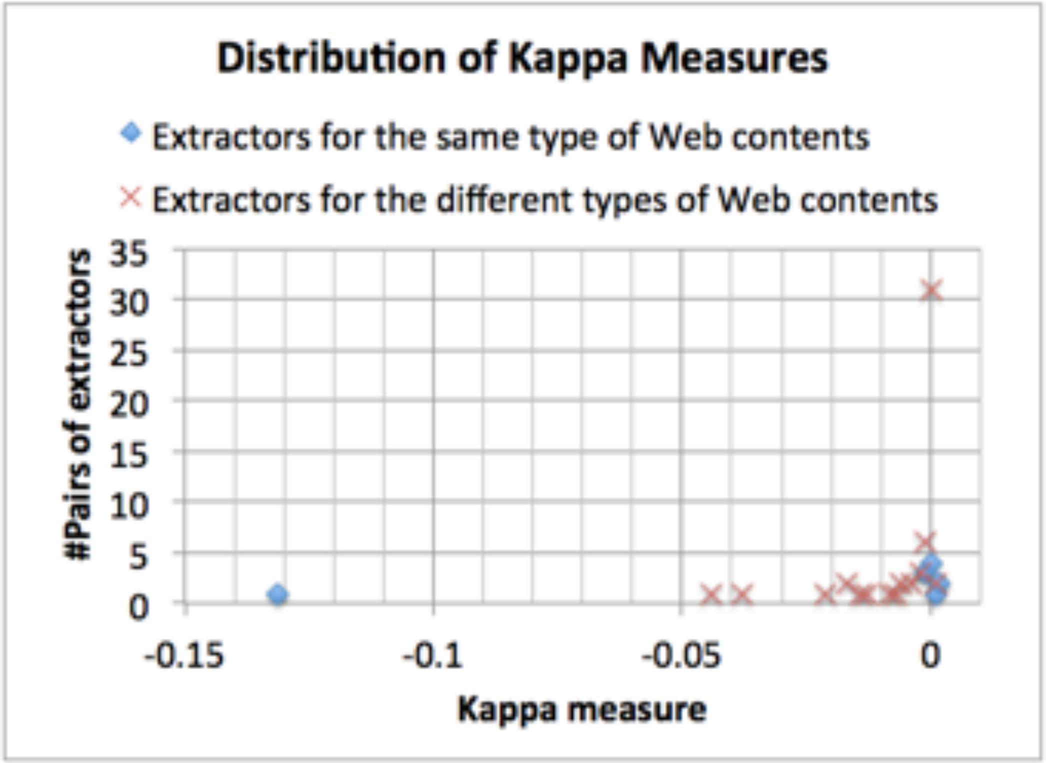


Interesting applications

Future directions

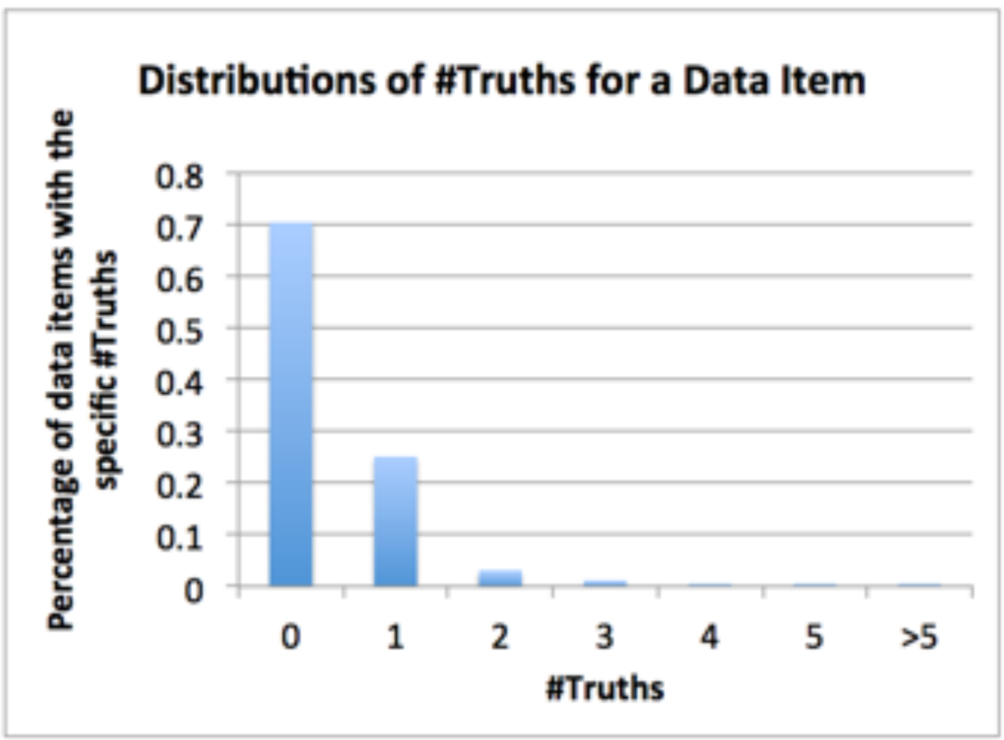
Future Directions: Remove the Assumptions One by One

Assumption I. Independence between pairs of provenances (i.e., (URL, extractor))



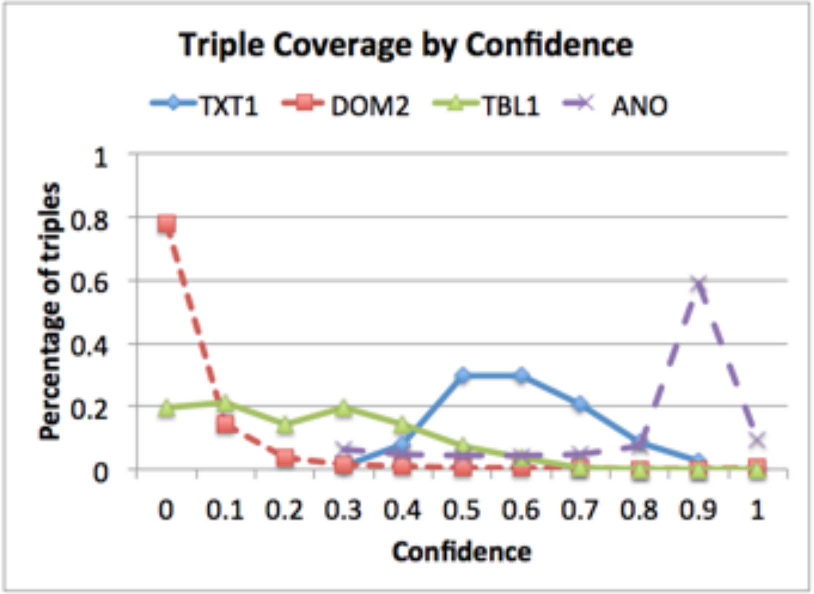
Future Directions: Remove the Assumptions One by One

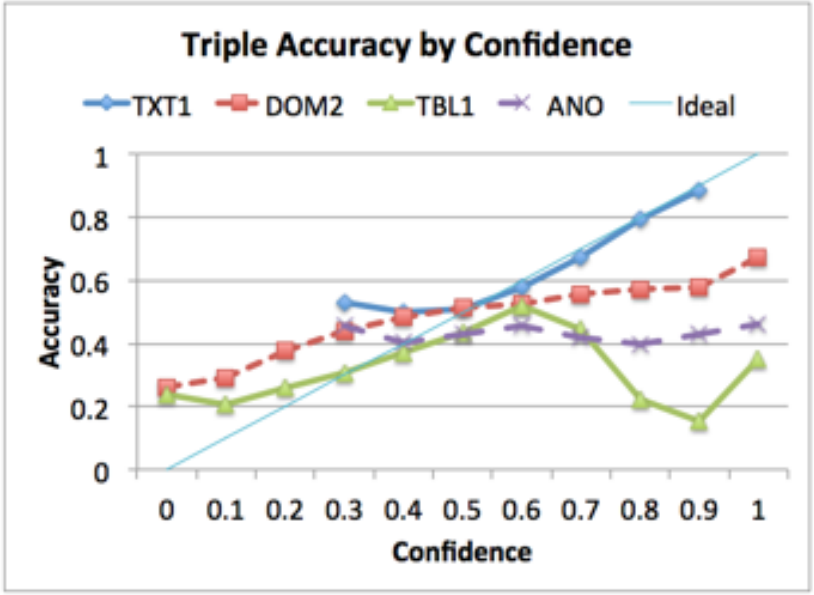
Assumption II. Single true object for each (sub, pred)



Future Directions: Remove the Assumptions One by One

Assumption III. Extractions are deterministic





Future Directions: Remove the Assumptions One by One

Assumption IV. Values (objects) are categorical

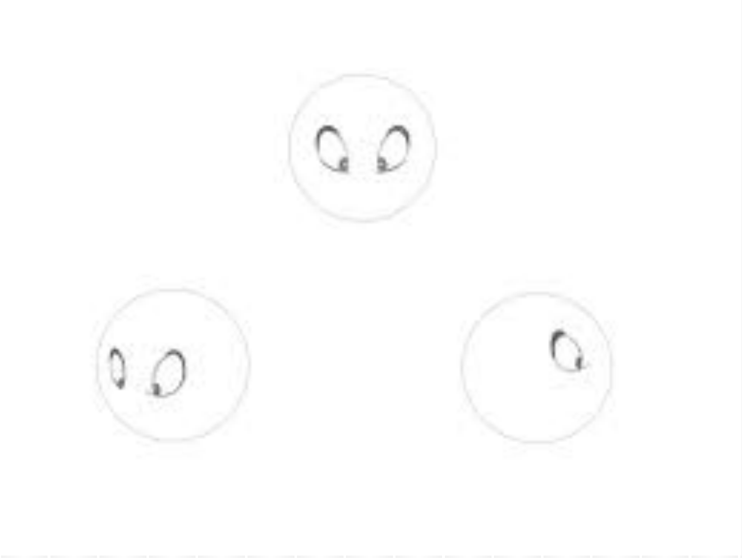
Assumption V. We have enough data to judge accuracy of each source

Assumption VI. Local closed-world assumption in evaluation

Future Directions: Remove the Assumptions One by One

Assumption VII. Global closed-world assumption--consider only existing entities and predicates in FB

WE NEED SOMETHING NEW!!!

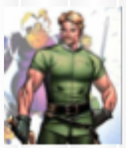


TAKE AWAYS

- A new area--Knowledge Fusion
- We can solve KF problem fairly well by adapting DF methods
- Many interesting future directions for KF!
- Many exciting applications for the prKB!!

Acknowledgement


Evgeniy Gabrilovich (Manager, need to say anything?)


Geremy Heitz (Strongest supporter)


Wilko Horn (Strictest code reviewer)


Kevin Murphy (Intelligent consultant)


Shaohua Sun (Critical representer to the outside world)


Wei Zhang (Fearless explorer of new ideas)

THANK YOU!

Questions?