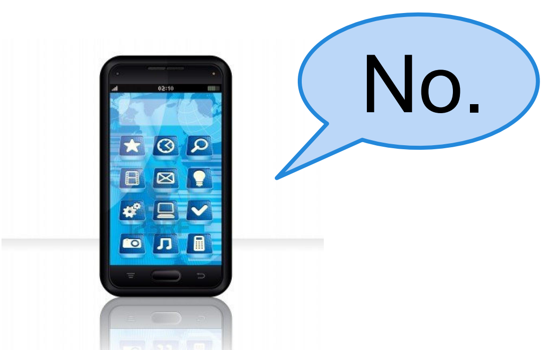
Combined Distributional and Logical Semantics

Mike Lewis and **Mark Steedman**
University of Edinburgh

Semantics

Was Obama born in Kenya?

Obama's birthplace is not Kenya



Distributional Semantics

- Induce the meanings of words from corpora

Distributional Semantics

- Induce the meanings of words from corpora

X was born in Y
(Obama, Hawaii)
(Shakespeare, Stratford)
(Obama, 1961)
...

X's birthplace is Y
(Obama, Hawaii)
(Shakespeare, Stratford)
(Jesus, Bethlehem)
...

(e.g. Lin & Pantel, 2001)

Distributional Semantics

sim(*X was born in Y***,** *X's birthplace is Y***) > t**

Obama was born in Hawaii
⇒ *Obama's birthplace is Hawaii*

Distributional Semantics

Was Obama born in Kenya?

Obama's birthplace is not Kenya

Formal Semantics

Obama	was	born in	Hawaii
NP	**(S\NP)/(S\NP)**	**(S\NP)/NP**	**NP**

S\NP

S\NP

S

Formal Semantics

Obama	was	born in	Hawaii
NP	**(S\NP)/(S\NP)**	**(S\NP)/NP**	**NP**
obama	$\lambda p \lambda x \, . \, p(x)$	$\lambda y \lambda x \, . \, born\_in'(x, y)$	*hawaii*

S\NP

S\NP

S

Formal Semantics

Obama	was	born in	Hawaii
NP	**(S\NP)/(S\NP)**	**(S\NP)/NP**	**NP**
obama	$\lambda p \lambda x \, . \, p(x)$	$\lambda y \lambda x \, . \, born\_in'(x, y)$	*hawaii*

S\NP

$\lambda x \, . \, born\_in'(x, hawaii)$

S\NP

$\lambda x \, . \, born\_in'(x, hawaii)$

S

$born\_in'(obama, hawaii)$

Formal Semantics

Obama	wasn't	born in	Kenya
NP	**(S\NP)/(S\NP)**	**(S\NP)/NP**	**NP**
obama	$\lambda p \lambda x . \neg p(x)$	$\lambda y \lambda x . born\_in'(x, y)$	*kenya*

S\NP

$\lambda x . born\_in'(x, kenya)$

S\NP

$\lambda x . \neg born\_in'(x, kenya)$

S

$\neg born\_in'(obama, kenya)$

Formal Semantics

Obama wasn't born in Kenya

$\not\Rightarrow$

Obama was born in Kenya

Formal Semantics

Every US president was born in the United States

$\Rightarrow$

Obama wasn't born in Kenya

Formal Semantics

Nicole Kidman and Barack Obama were born in Hawaii

⇔

Nicole Kidman was born in Hawaii and Barack Obama was born in Hawaii

Formal Semantics

Was Obama born in Kenya?

Obama's birthplace is not Kenya

Formal Semantics

$\neg$*birthplace'(obama, kenya)*

$\Rightarrow$?

born_in'(obama, kenya)

Formal Semantics

+ Models semantic operators ("not", "every", etc.)

+ Abstracts away from syntax (conjunctions, passive voice, relative clauses, etc)

- Doesn't model meaning of content words

Combining Formal and Distributional Semantics

Existing approaches:

- Compositional vector space models
  - (e.g. Coecke et al., 2011, Baroni et al., 2012, Grefenstette 2013)

- Learn inference rules as logical axioms
  - (e.g. Garrette et al., 2011, Beltagy et at., 2013)

Combining Formal and Distributional Semantics

Obama was born in Hawaii

⇩

born_in'(obama, hawaii)

Hawaii is Obama's birthplace

⇩

birth_place'(obama, hawaii)

Combining Formal and Distributional Semantics

Obama was born in Hawaii

↓

relation53(obama, hawaii)

Hawaii is Obama's birthplace

↓

relation53(obama, hawaii)

Combining Formal and Distributional Semantics

Learn lexical entries such that:

born	$\vdash$ **(S\NP)/PP[in]**	:	*λxλy . relation53(x,y)*
birthplace	$\vdash$ **N/PP[of]**	:	*λxλy . relation53(x,y)*

Formal Semantics

Obama	was	born in	Hawaii
NP	**(S\NP)/(S\NP)**	**(S\NP)/NP**	**NP**
obama	$\lambda p \lambda x \,.\, p(x)$	$\lambda y \lambda x \,.\, relation53(x, y)$	*hawaii*

S\NP

$\lambda x \,.\, relation53(x, hawaii)$

S\NP

$\lambda x \,.\, relation53(x, hawaii)$

S

relation53(obama, hawaii)

Combining Formal and Distributional Semantics

Gather statistics on predicates in large corpus:

born_in'(X, Y)
(Obama, Hawaii)
(Shakespeare, Stratford)
(Obama, 1961)
...

birthplace_of'(X, Y)
(Obama, Hawaii)
(Shakespeare, Stratford)
(Jesus, Bethlehem)
...

Combining Formal and Distributional Semantics

born_in'(X, Y)

birth_place(X,Y)

employeeOf'(X, Y)

workFor'(X, Y)

buy'(X, Y)

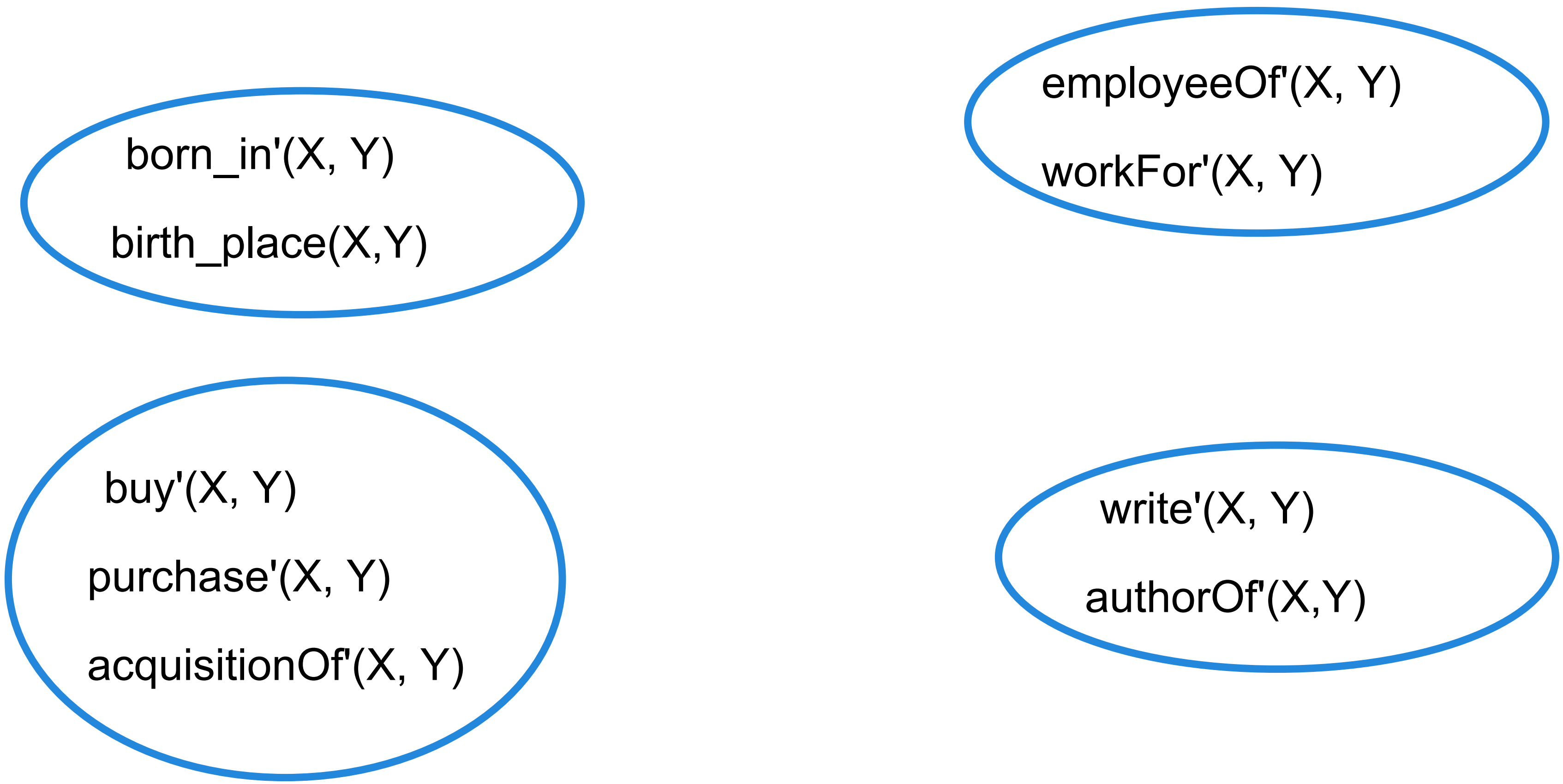
purchase'(X, Y)

acquisitionOf'(X, Y)

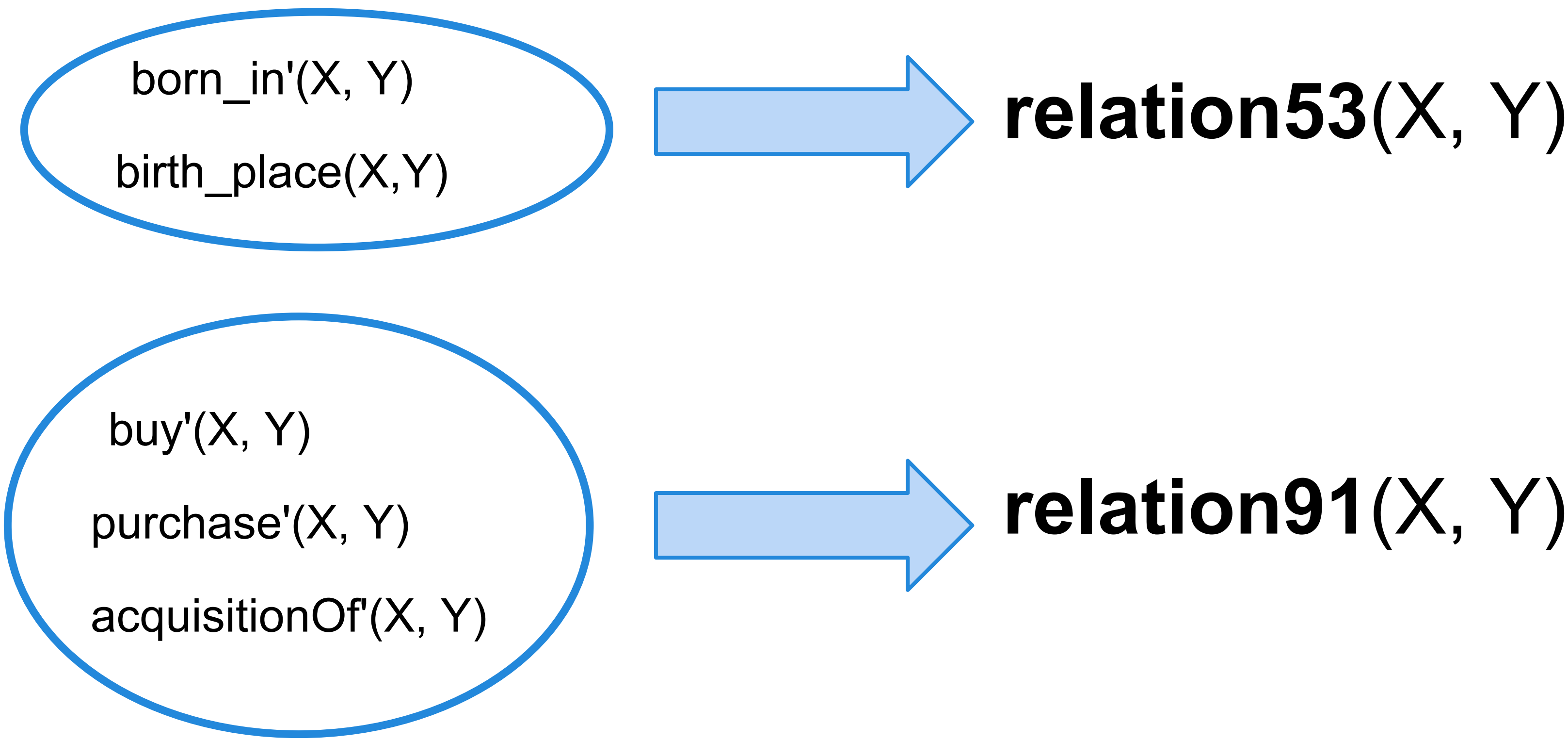
write'(X, Y)

authorOf'(X,Y)

Combining Formal and Distributional Semantics



Combining Formal and Distributional Semantics



Cluster using Chinese Whispers (Biemann, 2006)

Combining Formal and Distributional Semantics

Was Obama born in Kenya?

Obama's birthplace is not Kenya

Ambiguity

Obama was born in Hawaii
Obama was born in 1961

Ambiguity

Obama was born in 1961

$\not\Rightarrow$

Obama's birthplace is 1961

Ambiguity

Create multiple typed lexical entries:

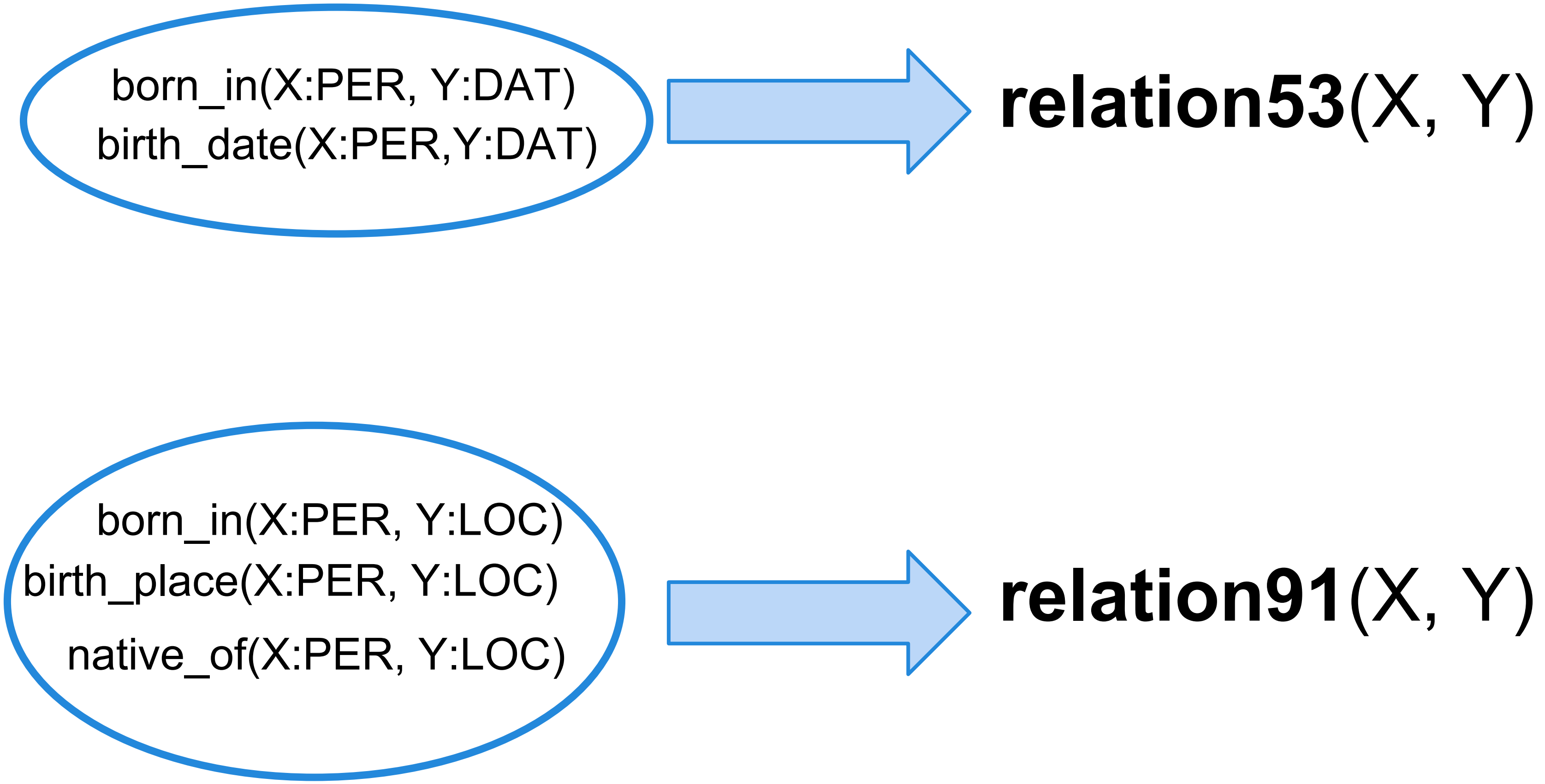
born ⊢(S\NP)/PP[in] : $\boldsymbol{\lambda y_{LOC} \lambda x_{PER}}$ **. birthPlace(x,y)**

born ⊢(S\NP)/PP[in] : $\boldsymbol{\lambda y_{DAT} \lambda x_{PER}}$ **. birthDate(x,y)**

(similar to: Schoenmackers et al., 2010; Berant et al., 2011)

Clustering Typed Predicates

Only cluster predicates with the same type



Topic Model

One 'document' per predicate

One 'word' per argument

lives in X
Hawaii
London
France

year of X
1564
2001
1945

born in X
Hawaii
2001
London
1564

Topic Model

One 'document' per predicate

One 'word' per argument

lives in X
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year of X
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born in X
Hawaii
2001
London
1564

(see also: Melamud et al., 2013)

Example Types

suspect, assailant, fugitive, accomplice, ...
author, singer, actress, actor, dad, ...
city, area, country, region, town, capital, ...
subsidiary, automaker, airline, Co., GM, ...
musical, thriller, sequel, special, ...
...

Combining types

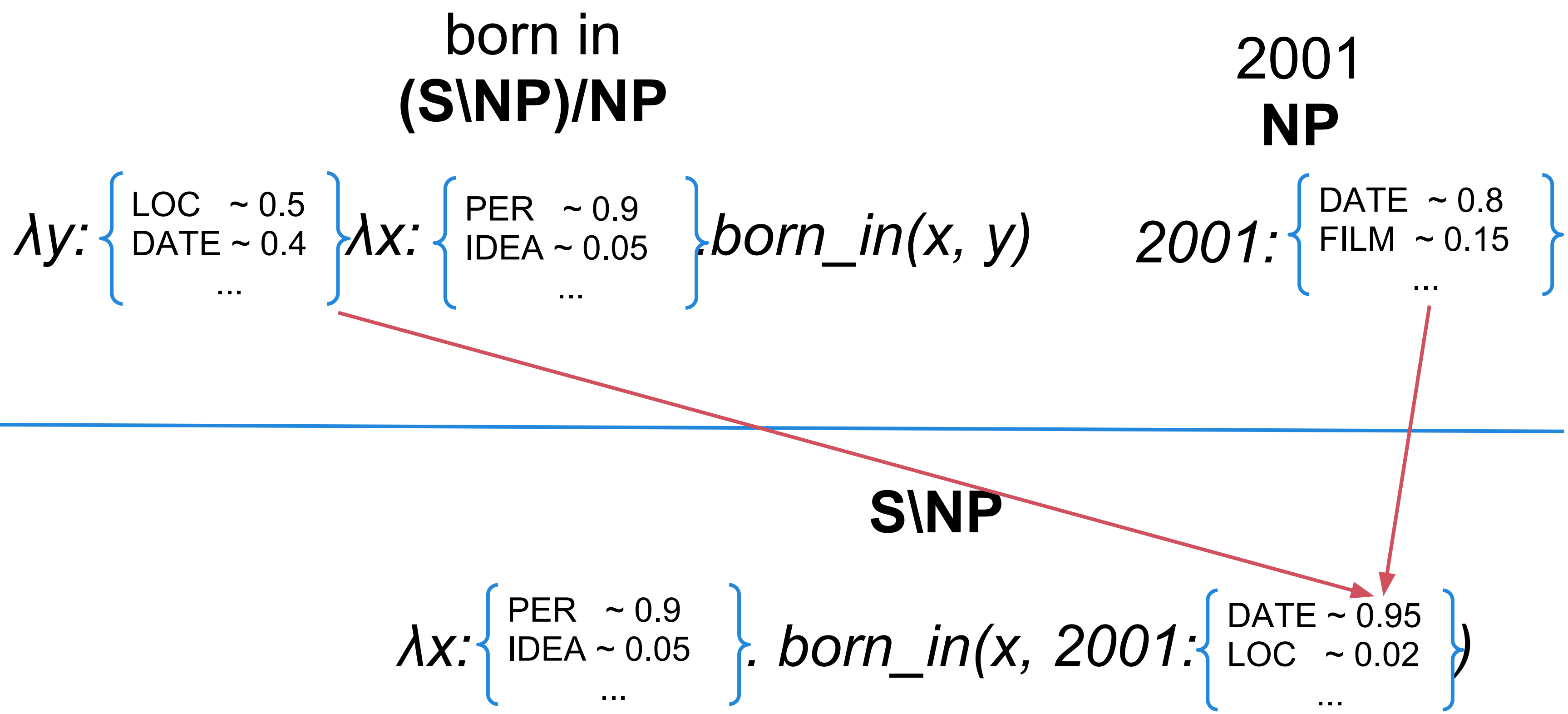
born in
(S\NP)/NP

$\lambda y{:}\left\{\begin{array}{l}\text{LOC} \sim 0.5 \\ \text{DATE} \sim 0.4 \\ \dots\end{array}\right\}\lambda x{:}\left\{\begin{array}{l}\text{PER} \sim 0.9 \\ \text{IDEA} \sim 0.05 \\ \dots\end{array}\right\}.born\_in(x, y)$

2001
NP

$2001{:}\left\{\begin{array}{l}\text{DATE} \sim 0.8 \\ \text{FILM} \sim 0.15 \\ \dots\end{array}\right\}$

Combining types



Combining types

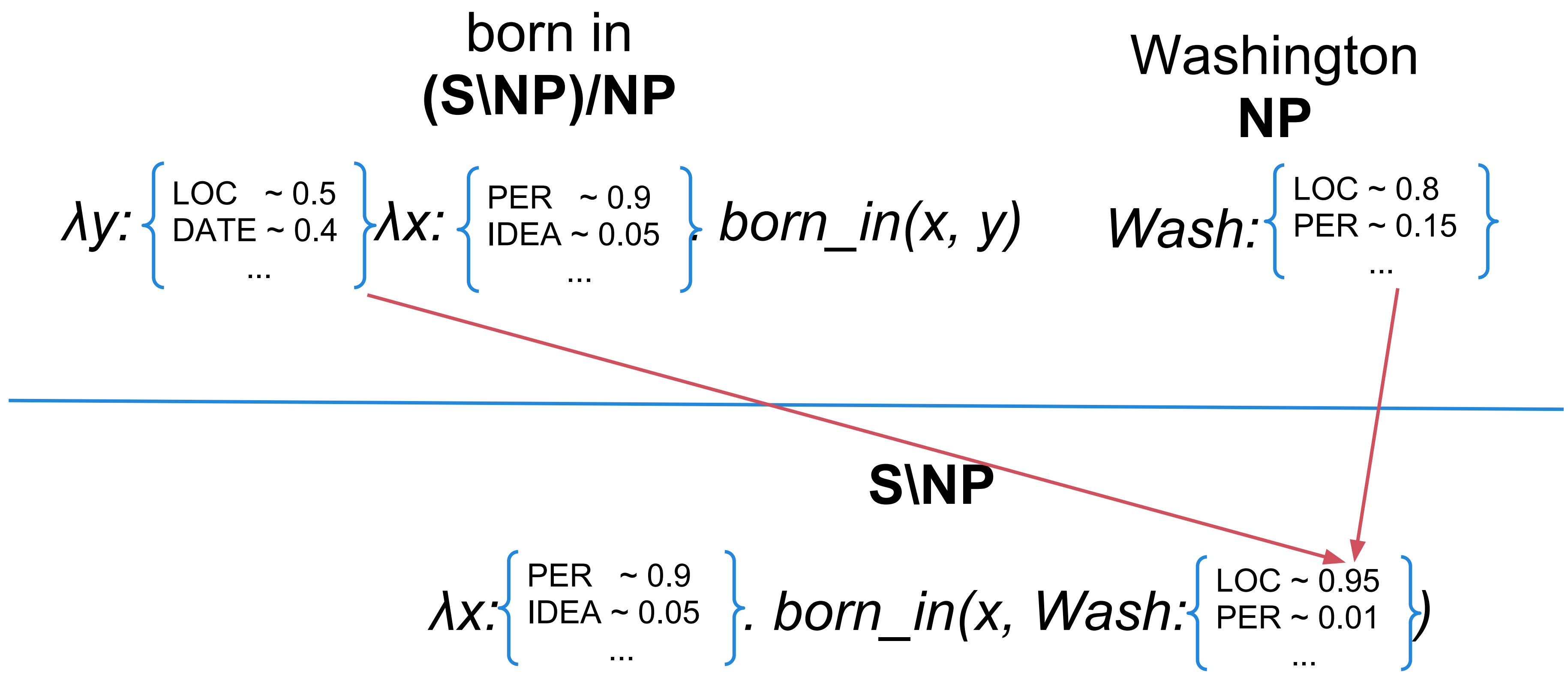
born in
(S\NP)/NP

$$\lambda y: \left\{ \begin{array}{l} \text{LOC} \sim 0.5 \\ \text{DATE} \sim 0.4 \\ \quad \ldots \end{array} \right\} \lambda x: \left\{ \begin{array}{l} \text{PER} \sim 0.9 \\ \text{IDEA} \sim 0.05 \\ \quad \ldots \end{array} \right\} .\ born\_in(x, y)$$

Washington
NP

$$Wash: \left\{ \begin{array}{l} \text{LOC} \sim 0.8 \\ \text{PER} \sim 0.15 \\ \quad \ldots \end{array} \right\}$$

Combining types



Compositional Semantics

born $\vdash$ **(S\NP)/PP[in]** : $\lambda y_{\mathbf{LOC}} \lambda x_{\mathbf{PER}} \,.\, birthPlace(x,y)$

born $\vdash$ **(S\NP)/PP[in]** : $\lambda y_{\mathbf{DAT}} \lambda x_{\mathbf{PER}} \,.\, birthDate(x,y)$

Compositional Semantics

born ⊢ **(S\NP)/PP[in]** : $\lambda y_{\mathbf{LOC}} \lambda x_{\mathbf{PER}}$. *birthPlace(x,y)*

born ⊢ **(S\NP)/PP[in]** : $\lambda y_{\mathbf{DAT}} \lambda x_{\mathbf{PER}}$. *birthDate(x,y)*

⇓

born ⊢**(S\NP)/PP[in]**: $\lambda y \lambda x . \left\{ \begin{array}{l} (x{:}LOC,\ y{:}PER) \Rightarrow birthPlace(x,\ y) \\ (x{:}DAT,\ y{:}PER) \Rightarrow birthDate(x,\ y) \end{array} \right\}$

Compositional Semantics

Output packed logical form capturing joint distribution:

Obama was born in Hawaii in 1961

$$\left\{\begin{array}{l} \textit{birthPlace} \sim 0.9 \\ \textit{birthDate} \sim 0.1 \end{array}\right\}(\text{Obama, Hawaii})$$

$$\wedge \left\{\begin{array}{l} \textit{birthPlace} \sim 0.1 \\ \textit{birthDate} \sim 0.9 \end{array}\right\}(\text{Obama, 1961})$$

Training Details

- Train on English Gigaword
- Use C&C parser for syntax (Clark and Curran 2004)
- 15 entity types
- Lexicon includes manual entries for some function words ("every", "not", etc.)

Evaluation

Automatically generate question set from corpus

Google bought YouTube

↓

Who bought YouTube?

What did Google buy?

Evaluation

Automatically generate question set from corpus

Google bought YouTube

Who bought YouTube?

What did Google buy?

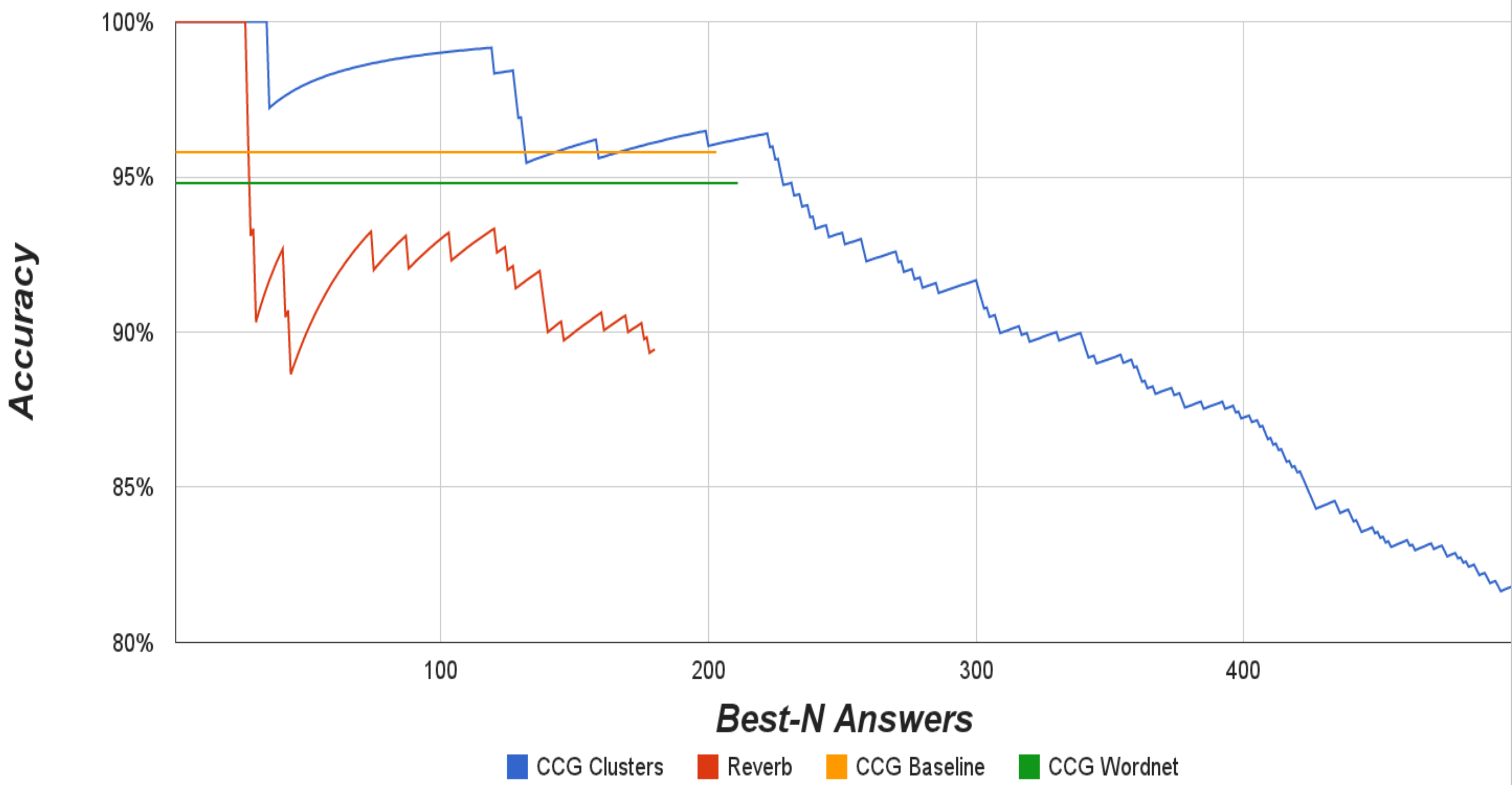
Generate 1000 questions

Manual evaluation

Comparison Systems

- Reverb (Fader et al., 2011)
- Relational LDA (Yao et al., 2011)
- CCG Baseline
- CCG + WordNet
- **CCG using Distributional Clusters**

QA Results



100%
95%
90%
85%
80%
Accuracy
100
200
300
400
Best-N Answers
CCG Clusters
Reverb
CCG Baseline
CCG Wordnet

Examples

Question: What did Delta merge with?

Sentence: The 747 freighters came with Delta's acquisition of Northwest

Answer: Northwest

Evaluating Formal Semantics

Problems involving inference using quantifiers from the FraCaS Suite (Section 1):

Premises:
Every European has the right to live in Europe.
Every European is a person.
Every person who has the right to live in Europe can travel freely within Europe.

Hypothesis:
Every European can travel freely within Europe

Evaluating Formal Semantics

	Single Premise Sentence	Multiple Premise Sentences
Natural Logic 2007	84%	-
Natural Logic 2008	98%	-
CCG-Dist (parser)	70%	50%
CCG-Dist (gold syntax)	89%	80%

Conclusions

- Formal and distributional semantics complement each other
- Modelling content words using cluster identifiers gives the benefits of both

Thanks!

Any questions?