Combining Axiom Injection and Knowledge Base Completion for Efficient Natural Language Inference

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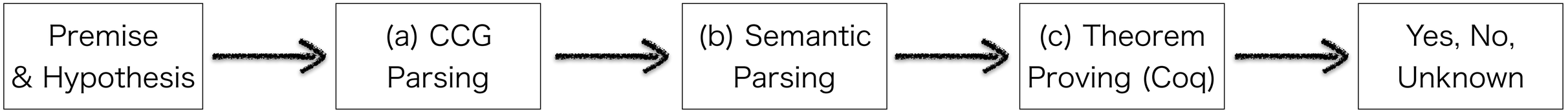
Today's Talk

- Goal:
  - Developing **Accurate** & **Efficient** RTE system based on higher-order logic
  - Proof Assistant Coq: Automated higher-order theorem proving
- Issue: How to deal the massive amount of knowledge (axioms) ??

$$\forall x.\texttt{hike}(x) \to \texttt{walk}(x)$$
$$\forall x.\texttt{walk}(x) \to \neg\texttt{ride}(x)$$
$$\vdots$$

  - **Extending knowledge base** & **efficient reasoning** lie in a strained relation
- We solve the issue by combining logic-based RTE system with **knowledge base completion**!
  - We develop a **Coq plugin** for the further efficiency

Background: ccg2lambda (Mineshima+, 2015)

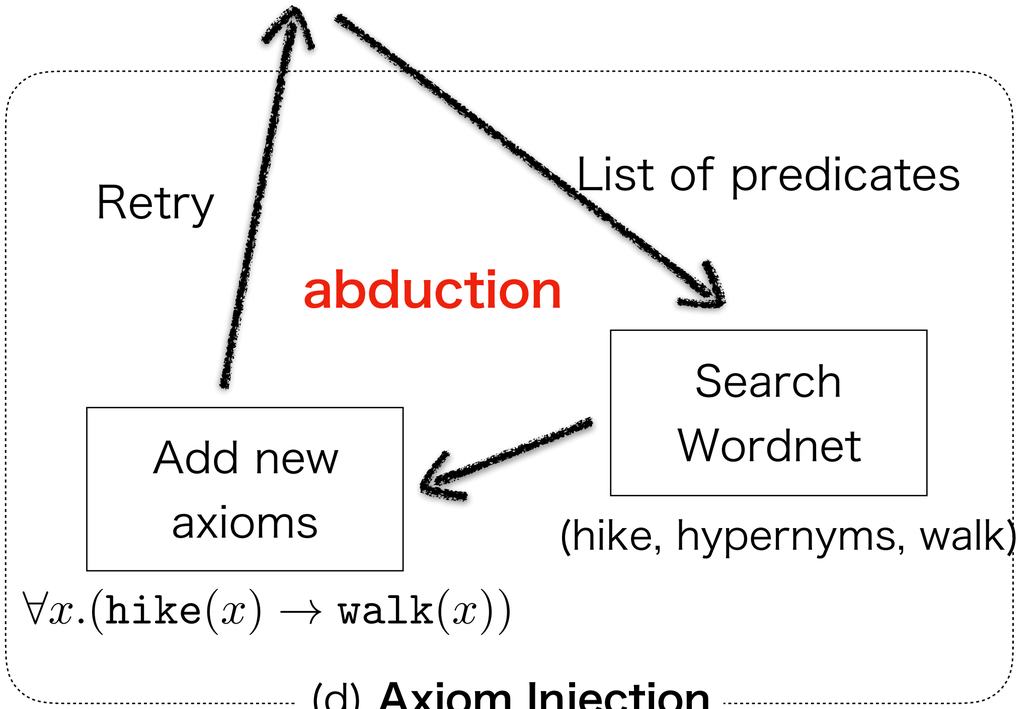


Premise

$$\dfrac{\dfrac{\dfrac{\text{A}}{\underset{\lambda F.\lambda G.\exists x.F(x)\wedge G(x)}{NP/N}} \quad \dfrac{\text{man}}{\underset{\lambda x.\mathtt{man}(x)}{N}}}{\underset{\lambda G.\exists x.\mathtt{man}(x)\wedge G(x)}{NP}}> \quad \dfrac{\text{hikes}}{\underset{\lambda Q.Q(\lambda x.\exists e.\mathtt{hike}(e)\wedge \mathtt{subj}(e,x))}{S\backslash NP}}}{\underset{\exists x.\mathtt{man}(x)\wedge\exists e.\mathtt{hike}(e)\wedge\mathtt{subj}(e,x)}{S}}<$$

Hypothesis

$$\dfrac{\dfrac{\dfrac{\text{A}}{\underset{\lambda F.\lambda G.\exists x.F(x)\wedge G(x)}{NP/N}} \quad \dfrac{\text{man}}{\underset{\lambda x.\mathtt{man}(x)}{N}}}{\underset{\lambda G.\exists x.\mathtt{man}(x)\wedge G(x)}{NP}}> \quad \dfrac{\text{walks}}{\underset{\lambda Q.Q(\lambda x.\exists e.\mathtt{walk}(e)\wedge \mathtt{subj}(e,x))}{S\backslash NP}}}{\underset{\exists x.\mathtt{man}(x)\wedge\exists e.\mathtt{walk}(e)\wedge\mathtt{subj}(e,x)}{S}}<$$



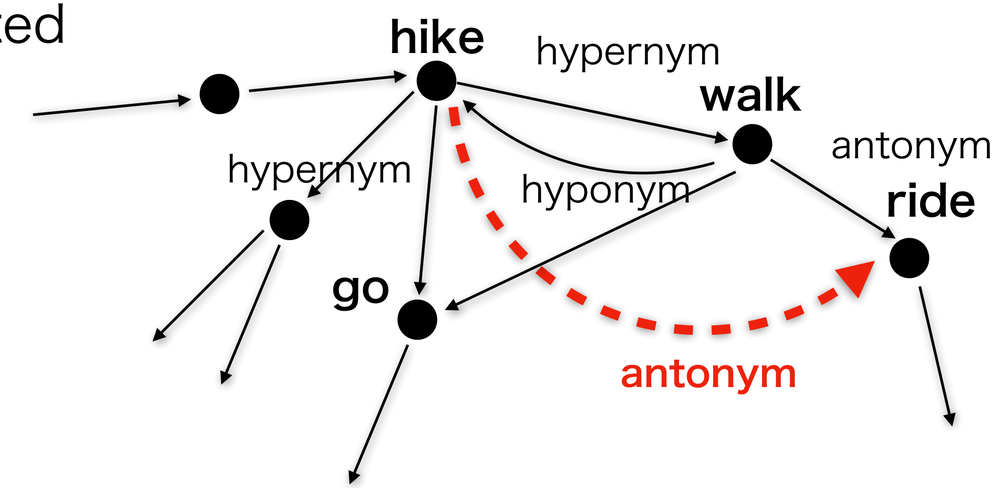
- **1st Issue**: Tensed relation between extending knowledge and efficient reasoning
- **2nd ssue**: Needs to exit a Coq proving session to run abduction

Knowledge Base Completion

- Wordnet
  - 0.1 million nodes, 0.5 million edges
- Freebase
  - 2 billion edges
- Knowledge base is not complete
  - Not all true facts (relations) are annotated

  → Infer missing knowledge using ML

(hike, hypernym, walk)
(walk, antonym, ride)
(hike, hypernym, go)
…



Knowledge Base Completion

- Design a function f to evaluate a triplet (s, r, o) is true or false
  - Simple models with the efficiency in mind (e.g. use of diagnoal matrices)
  - Higher-order relations (e.g. transitivity) are modeled with loss function (Bouchard+, 2015)
  - Achieves high scores on WordNet benchmark datasets(WN18, more than 94% in Hits@1)
- TransE (Bordes+, 2013)

$$f(s, r, o) = ||\mathbf{e}_s + \mathbf{e}_r - \mathbf{e}_o||_2^2, \mathbf{e}_i \in \mathbb{R}^n$$

Very simple additive model

- ComplEx (Trouillon+, 2016)

$$f(s, r, o) = \sigma(Re(\langle \boldsymbol{e}_s, \boldsymbol{e}_r, \overline{\boldsymbol{e}_o} \rangle)), \boldsymbol{e}_s, \boldsymbol{e}_r, \boldsymbol{e}_o \in \mathbb{C}^n$$

Models anti-symmetricity in complex vector space

Proposed: Axiom Injection using Knowledge Base Completion

- We replace abduction method based on search on KBs (Martínez-Gómez+, 2017)
- Instead, our method uses a KBC function f
  - Convert triplets whose scores are above a predefined threshold
  - Conversion is defined in terms of relations r:

Relation r	Generated Axiom	Example
synonym, hypernym, derivationally-related	$\forall x.(s(x) \rightarrow o(x))$	$(\texttt{make}, r, \texttt{build}) \rightsquigarrow \forall e.(\texttt{make}(e) \rightarrow \texttt{build}(e))$
antonym	$\forall x.(s(x) \rightarrow \neg o(x))$	$(\texttt{parent}, r, \texttt{child}) \rightsquigarrow \forall x.(\texttt{parent}(x) \rightarrow \neg\texttt{child}(x))$
hyponym	$\forall x.(o(x) \rightarrow s(x))$	$(\texttt{talk}, r, \texttt{advise}) \rightsquigarrow \forall e.(\texttt{advise}(e) \rightarrow \texttt{talk}(e))$

Proposed: Axiom Injection using Knowledge Base Completion

- **Very Fast**: traversal on KB → matrix operation of $O(n)$
  - Large gap in computing transitive closure (hypernym → hypernym → ⋯)
- **Scalable**: Adding new triplets with low cost
  - KB Graph: The time of a traversal is increased as # of entities does...
  - If s, r, and o exist already, no increase of # of parameters!
    - In the experiment, we add knowledge from VerbOcean(Chklovski+, 2004)
- **Latent knowledge** obtained in KBC model is also available (e.g. (hike, antonym, ride))

ccg2lambda (Mineshima+, 2015)

Premise & Hypothesis → (a) CCG Parsing → (b) Semantic Parsing → (c) Theorem Proving (Coq) → Yes, No, Unknown

Premise

$$\dfrac{\dfrac{\dfrac{\text{A}}{\substack{NP/N \\ \lambda F.\lambda G.\exists x.F(x) \wedge G(x)}} \quad \dfrac{\text{man}}{\substack{N \\ \lambda x.\mathtt{man}(x)}}}{\substack{NP \\ \lambda G.\exists x.\mathtt{man}(x) \wedge G(x)}}\,> \quad \dfrac{\text{hikes}}{\substack{S\backslash NP \\ \lambda Q.Q(\lambda x.\exists e.\mathtt{hike}(e) \wedge \mathtt{subj}(e,x))}}}{\substack{S \\ \exists x.\mathtt{man}(x) \wedge \exists e.\mathtt{hike}(e) \wedge \mathtt{subj}(e,x)}}\,<$$

Hypothesis

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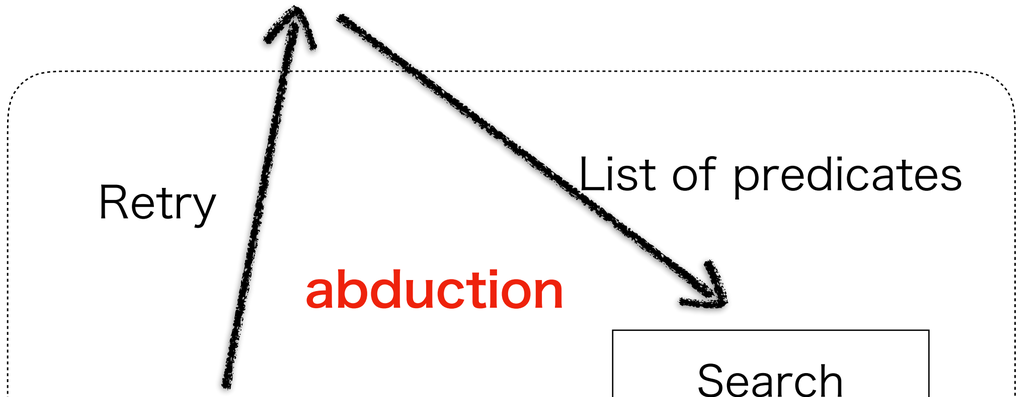

(d) **Axiom Injection** (Martínez-Gómez+, 2017)

- **1st Issue**: Tensed relation between extending knowledge and efficient reasoning
- **2nd ssue**: Needs to exit a Coq proving session to run abduction

Even Faster Reasoning with our Coq plugin (`abduction`)

```
1 subgoal

  ============================
  (exists x : Entity, man x /\ (exists e : Event, hike e /\ subj e x)) ->
  exists x : Entity, man x /\ (exists e : Event, walk e /\ subj e x)
t < intro.
1 subgoal

  H : exists x : Entity, man x /\ (exists e : Event, hike e /\ subj e x)
  ============================
  exists x : Entity, man x /\ (exists e : Event, walk e /\ subj e x)

t < abduction.
1 subgoal
  H : exists x : Entity, man x /\ (exists e : Event, hike e /\ subj e x)
  NLax1 : forall x : Event, hike x -> walk x
  ============================
  exists x : Entity, man x /\ (exists e : Event, walk e /\ subj e x)
```

(man, walk)
(man, hike)
(hike, walk)

(hike, hypernym, walk)

Construct a list of predicate pairs from context and goal

↓

Send them to Python server

↓

Evaluate all the predicate pairs using ComplEx

↓

Filter them by score

↓

Add them as axioms

Even Faster Reasoning with our Coq plugin (`abduction`)

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- No need to quit Coq
- Python server
  - DL libraries (and use of GPUs...)
- The mechanism can be extended for other problems of theorem proving
  - e.g. premise selection (Alemi+, 2016)

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Experiments

- We evaluate our model on SICK(Marelli+, 2014) dataset
  - Metrices: accuracy and processing time of an RTE problem
    - (macro average of 5 runs on trial set, timeout 100 sec.)
- We use ComplEx (Trouillon+ 2016) as our KBC model.
  - Logistic loss: $\sum_{((s,r,o),t)\in\mathcal{D}} t \log f(s,r,o) + (1-t)\log(1-f(s,r,o))$
- In this work, we create training data as well
  - by extracting triplets from WordNet: (syno-, ant-, hypo-, hyper- nyms ..)
  - VerbOcean(Chklovski+, 2004): relations among verbs

Experimental Results on SICK

	Accuracy	Speed (Sec. / Problem)
no abduction	77.30	3.79
search-based (WordNet)	83.55	9.12
search-based (+VerbOcean)	83.68	9.42
KBC-based (WordNet)	83.55	4.03
KBC-based (+VerbOcean)	83.45	3.84

- Baseline: axiom injection based on search on KBs (Martínez-Gómez+, 2017)
- **Accuracy**: comparable / slightly lower compared to baseline
- **Proccessing Speed**: greatly improve; come close to "no abduction" case
- **Augmentation with VerbOcean**: further improvement in speed

Analyzing Latent Knowledge on More Challenging LexSICK dataset

- We construct a new RTE problems to evaluate latent knowledge of KBC model in terms of RTE.
  - 60 problems of combination of syntactic & lexical phenomena

P: Someone is dropping the meat in a pan.	**P:** The man is singing and playing the guitar.
-> H: The meat is being thrown into a pan.	**-> H:** The guitar is being performed by a man.

Summary:

- A KBC-based injection method of lexical knowledge to logic-based RTE systems
  - Efficient, Scalable, Provides latent knowledge
  - `abduction` tactic enables even faster reasoning
- Future work
  - Phrase-level lexical axioms $\forall x.(\texttt{have}(x) \wedge \texttt{fun}(x)) \rightarrow \texttt{enjoy}(x)$
    - Compositionally compute their vectors from word's ones
  - Lexical axioms from multiword expressions

$$\forall x.\texttt{make\_up\_one's\_mind}(x) \rightarrow \texttt{determine}(x)$$