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

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NAIST®

Ochanomizu University

National Institute of Advanced Industrial Science and Technology AIST

Recognizing Textual Entailment

a.k.a. Natural Language Inference

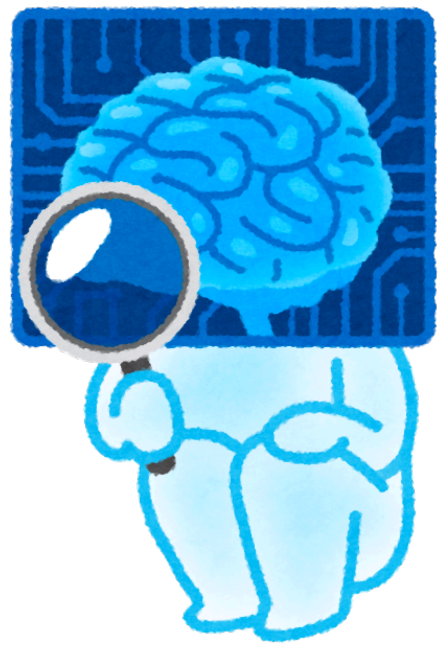
Premise(s)

P1: Clients at the demonstration were all impressed by the system's performance.

P2: Smith was a client at the demonstration.

Hypothesis

H: Smith was impressed by the system's performance.

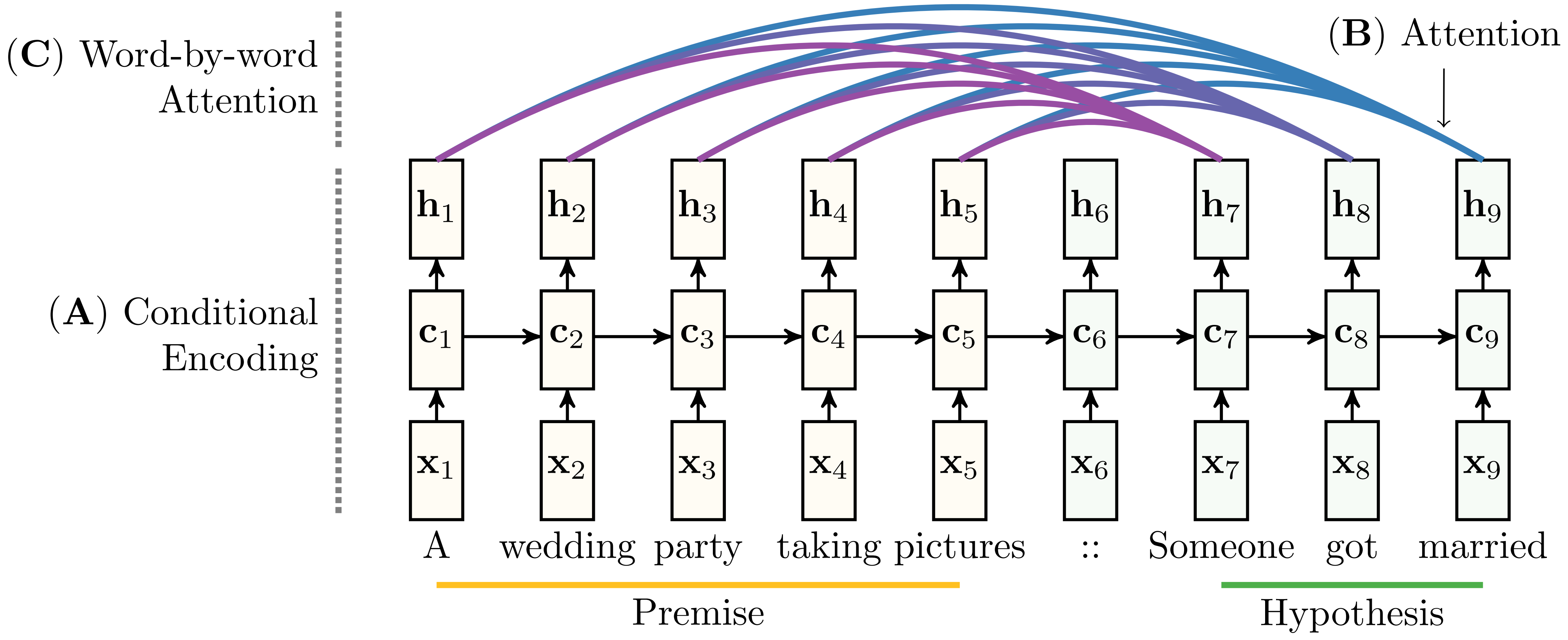


`{entailment, contradiction, unknown}`

- A testbed to evaluate if a machine can reason as we do
  - lexical, logical, syntactic phenomena, etc.
- Elemental technology for improving other NLP tasks
  - Question answering, reading comprehension, etc.

Approaches to RTE

- Machine learning (Rocktäschel et al., 2016, etc.)
  - e.g. Neural Networks



Rocktäschel et al., 2016

Approaches to RTE

- Machine learning (Rocktäschel et al., 2016, etc.)
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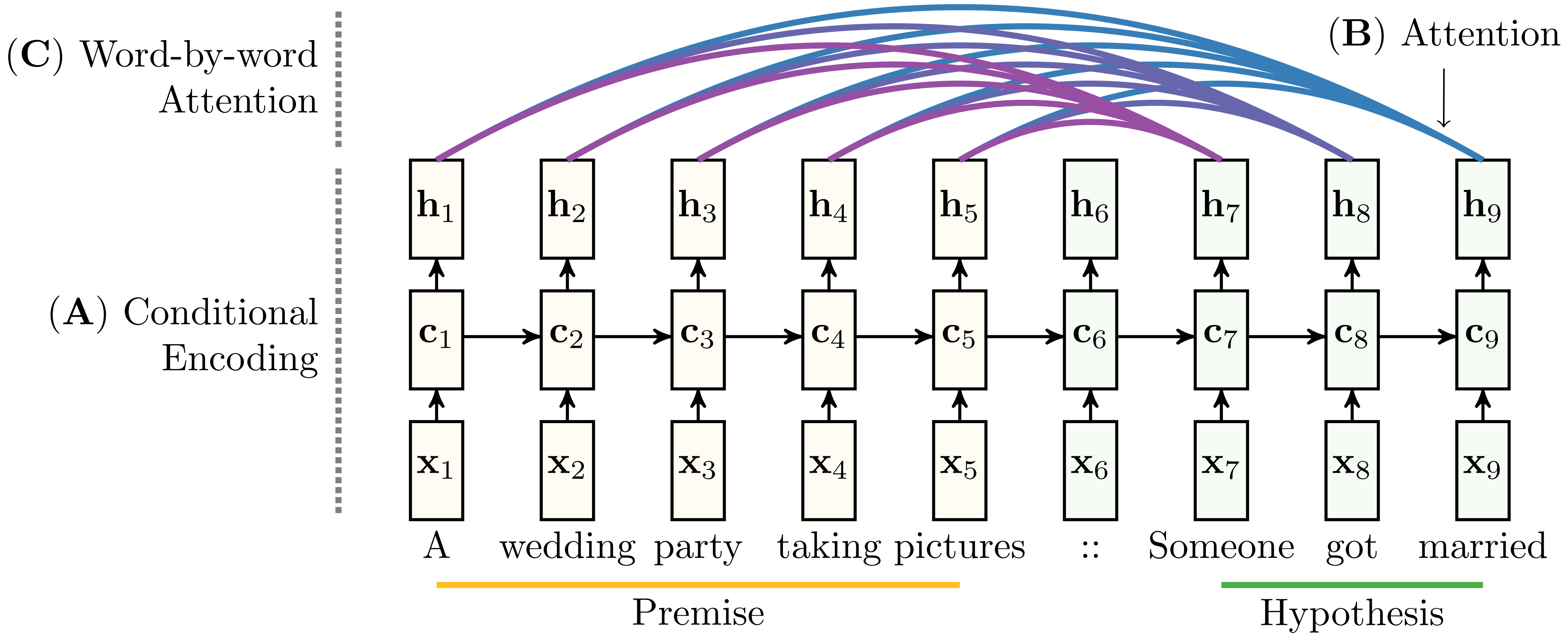
- Logic (Mineshima et al., 2015, Abzianidze 2017, etc)
  - Traditional pipeline systems
  - Theorem prover (e.g. Coq)



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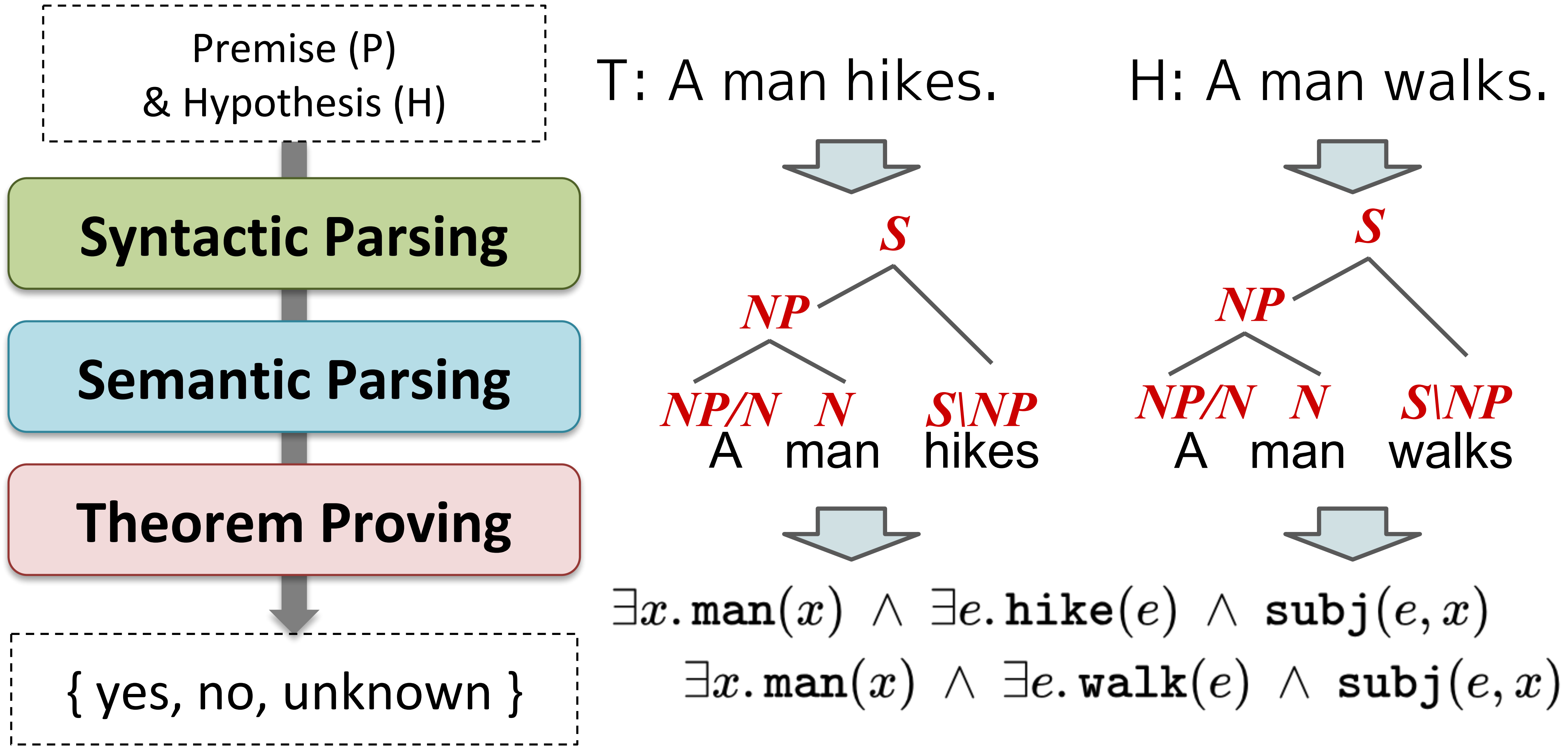

Mineshima et al., 2015

Approaches to RTE

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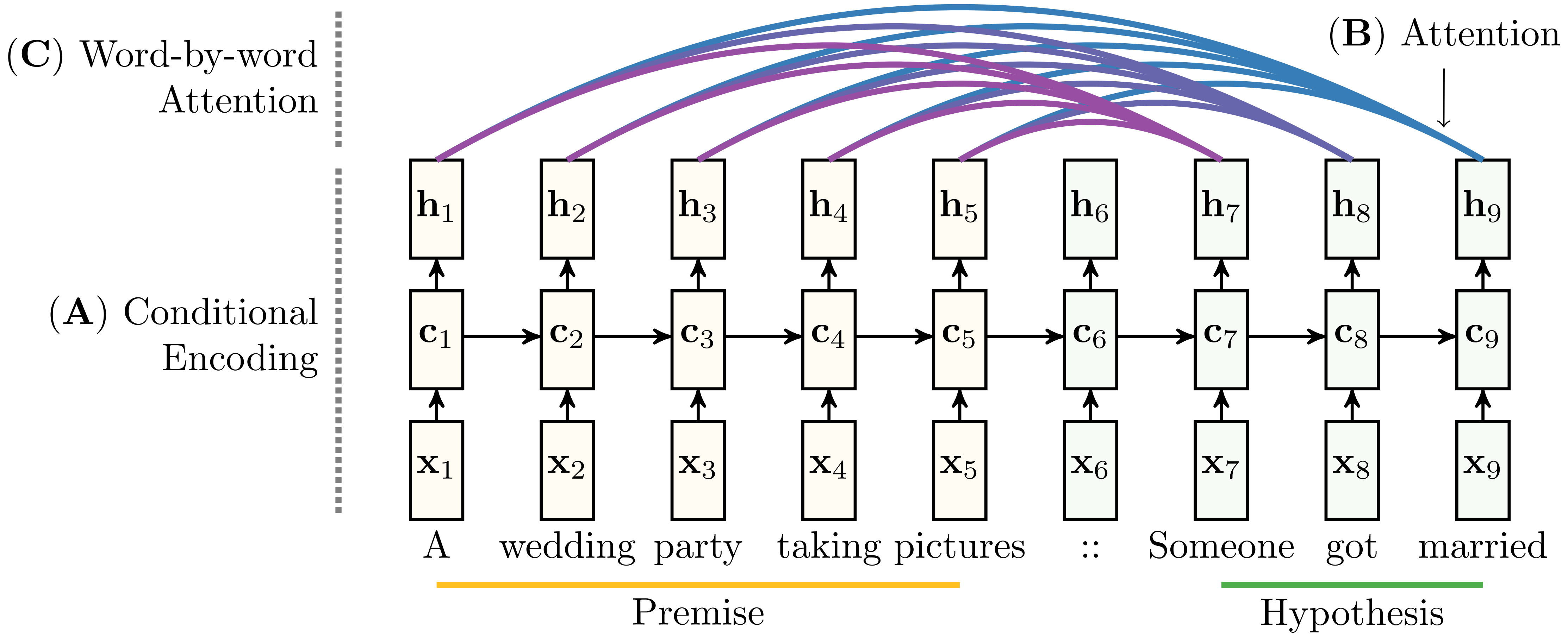
  - e.g. Neural Networks
- Logic (Mineshima et al., 2015, Abzianidze 2017, etc)
  - Traditional pipeline systems
  - Theorem prover (e.g. Coq)
- **Ours**: logic-based, extended by ML! (Hybrid)



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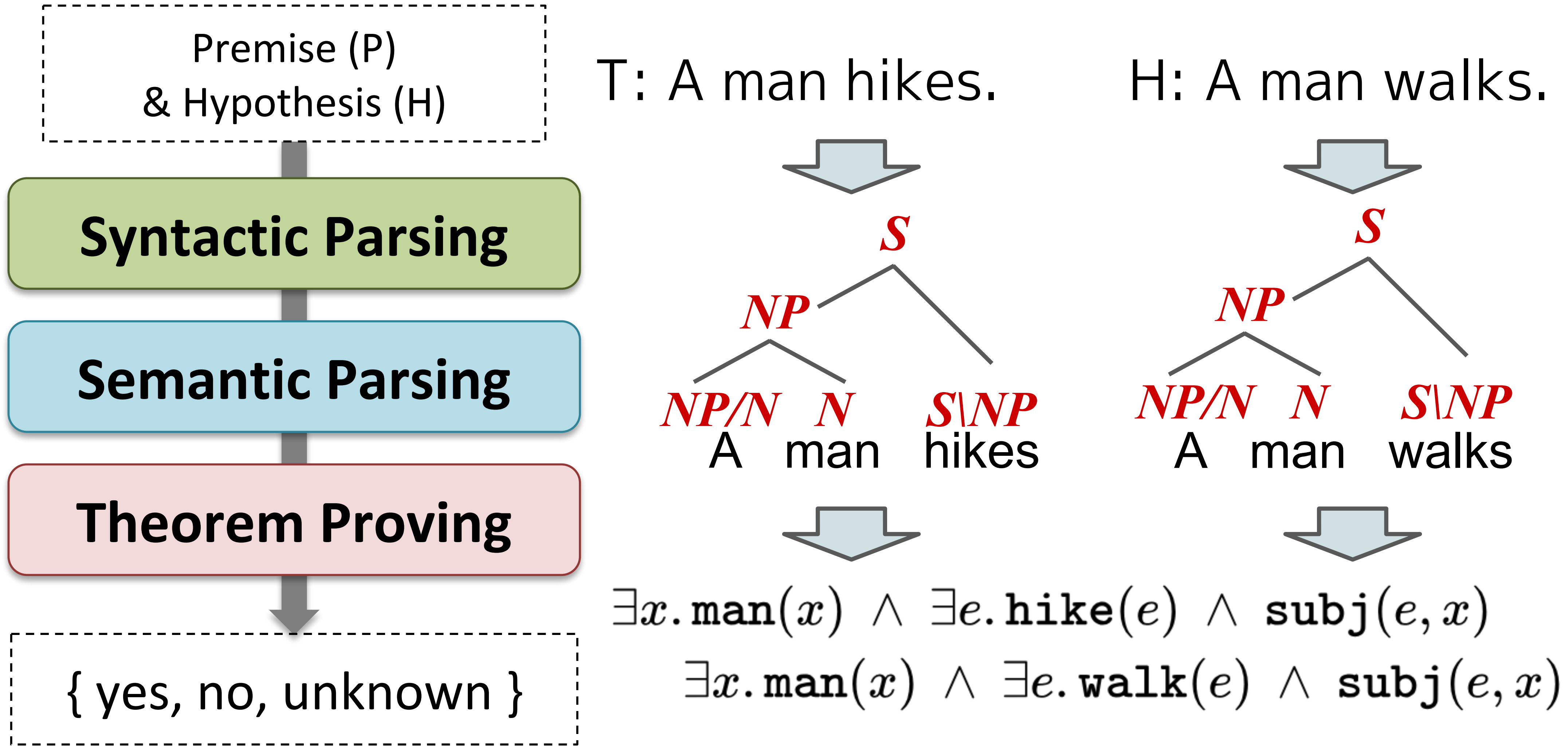
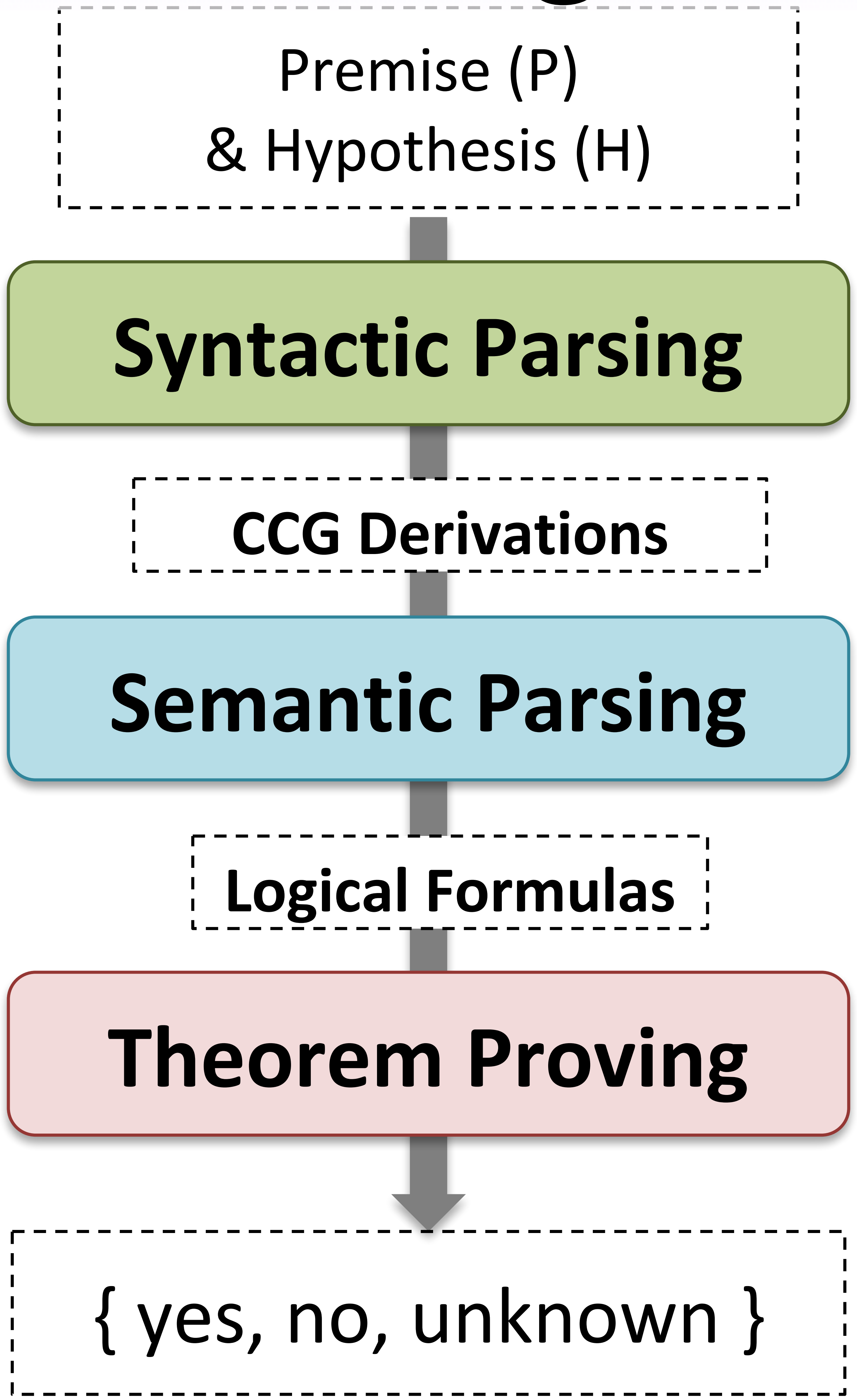
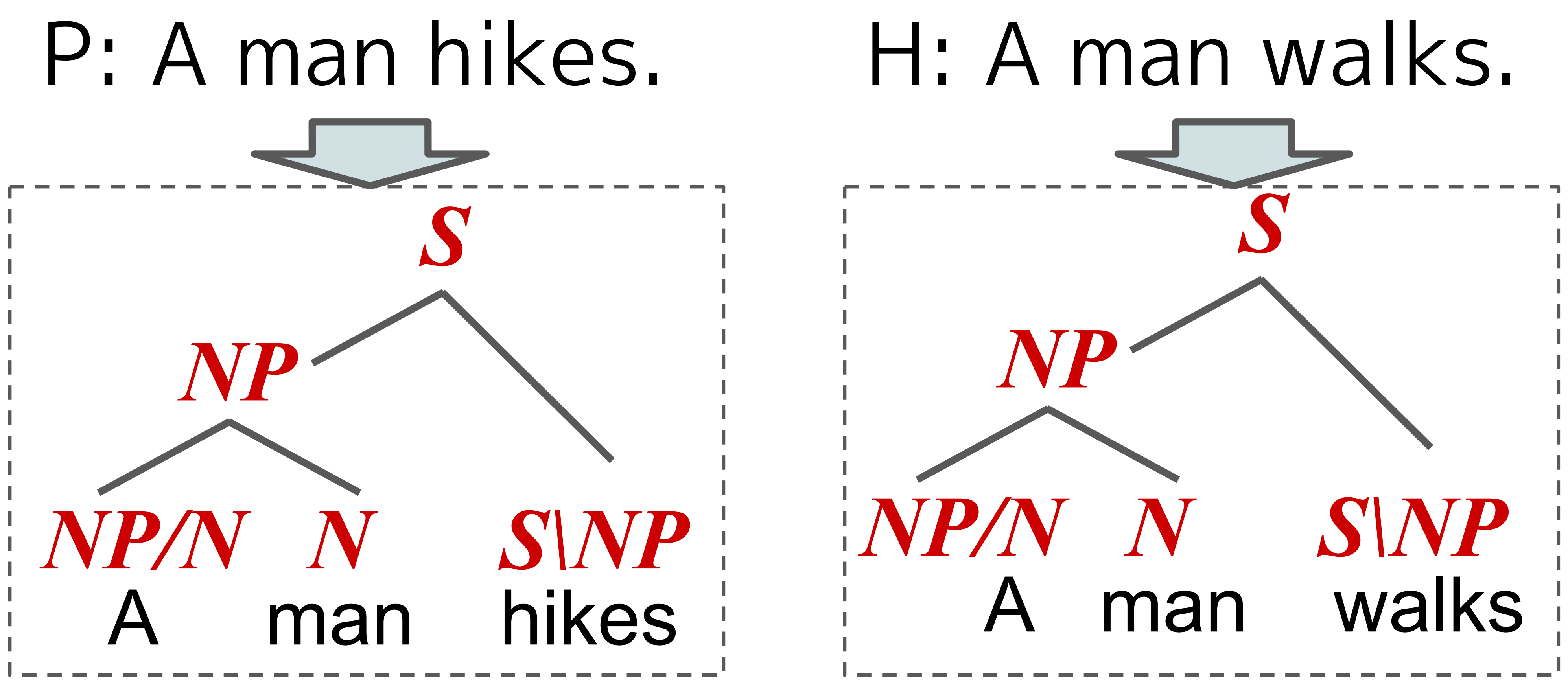


Mineshima et al., 2015

ccg2lambda (Mineshima et al., 2015)





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Coq < Proof. ccg2lambda. Qed.
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Coq theorem prover

result: unknown

ccg2lambda (Mineshima et al., 2015)

Premise (P)
& Hypothesis (H)

Syntactic Parsing

CCG Derivations

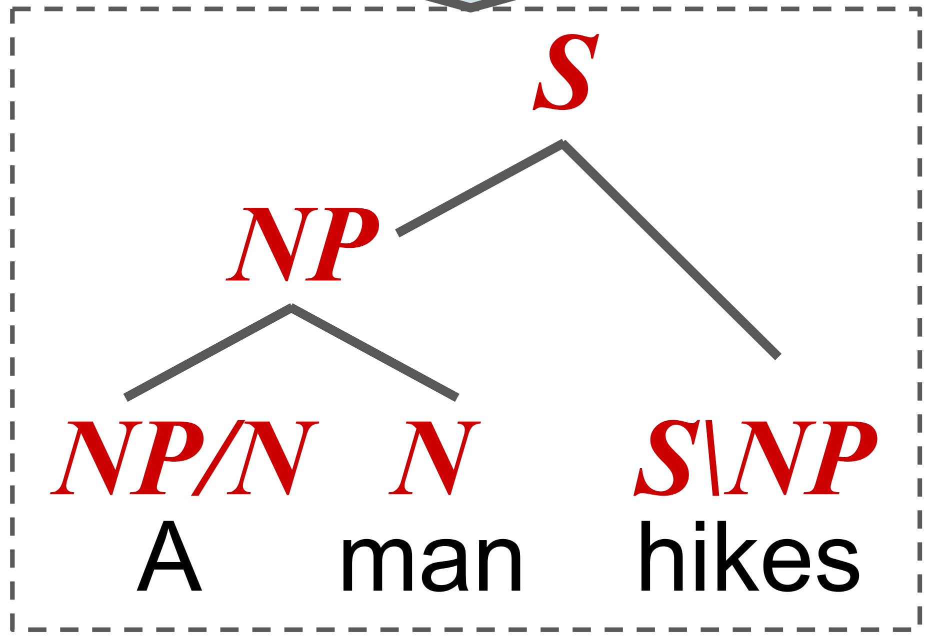
Semantic Parsing

Logical Formulas

Theorem Proving

{ yes, no, unknown }

P: A man hikes.



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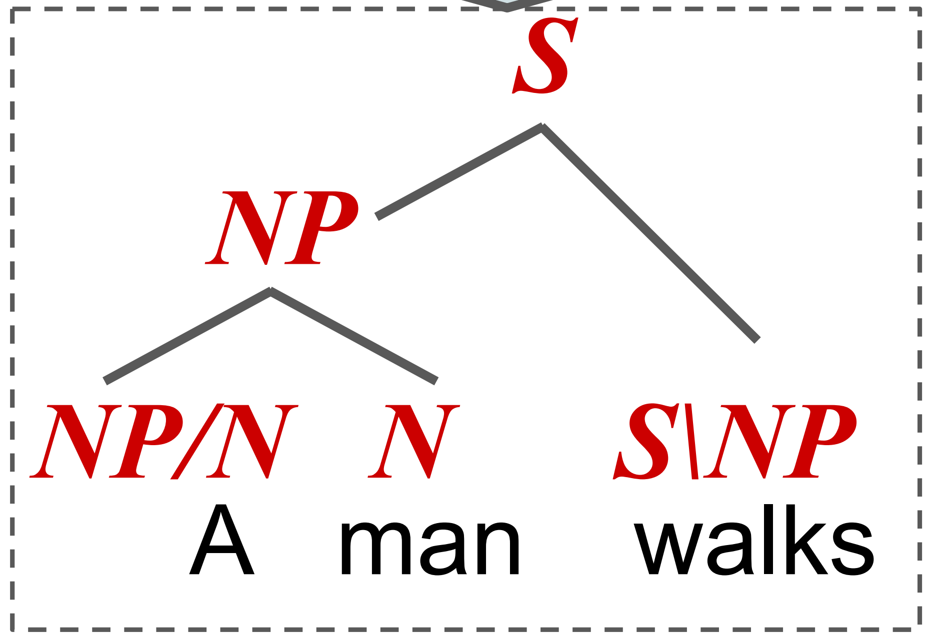

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result: unknown

👍 Unsupervised

👍 Captures linguistic phenomena
- 83.6 % accuracy in SICK

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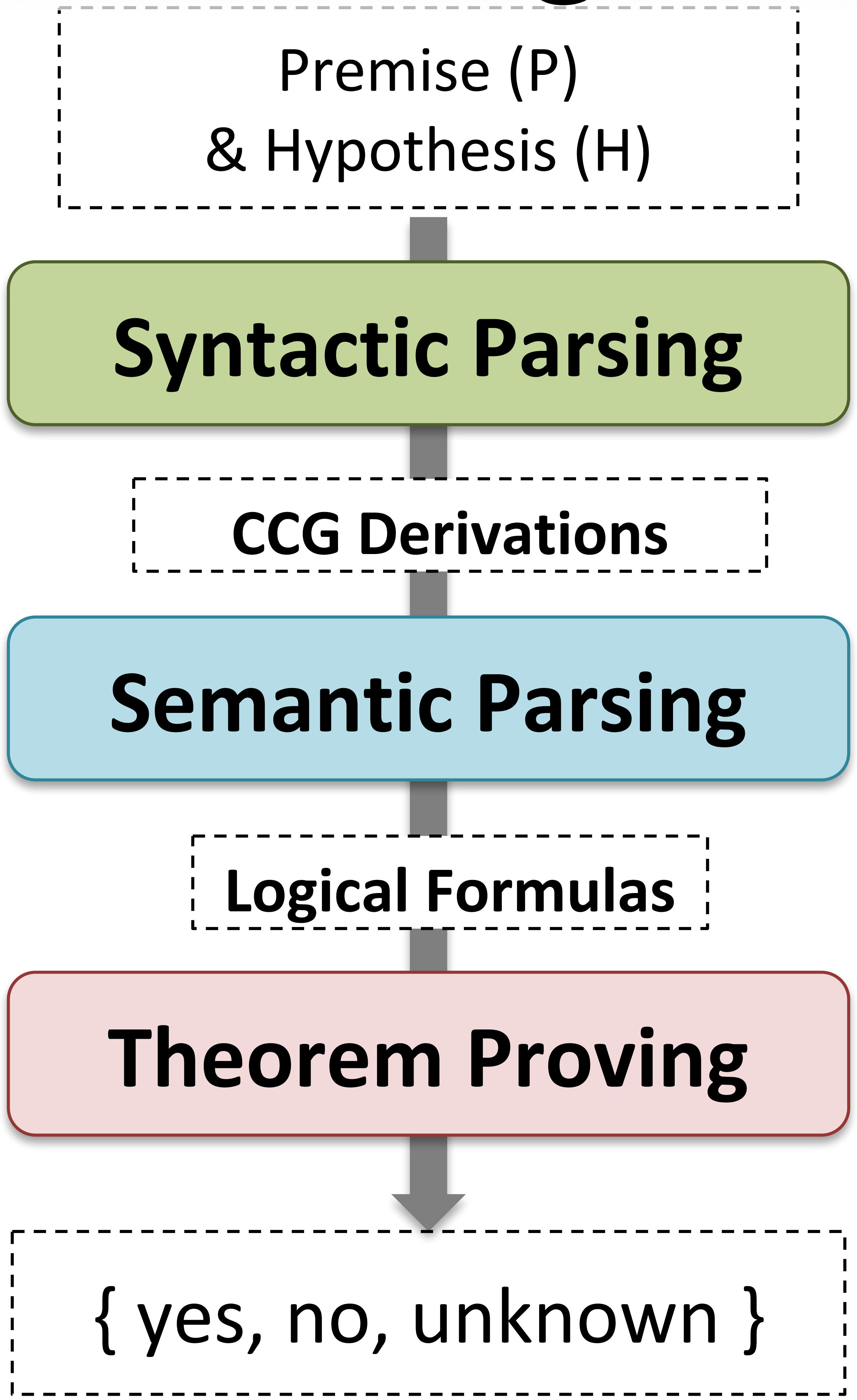
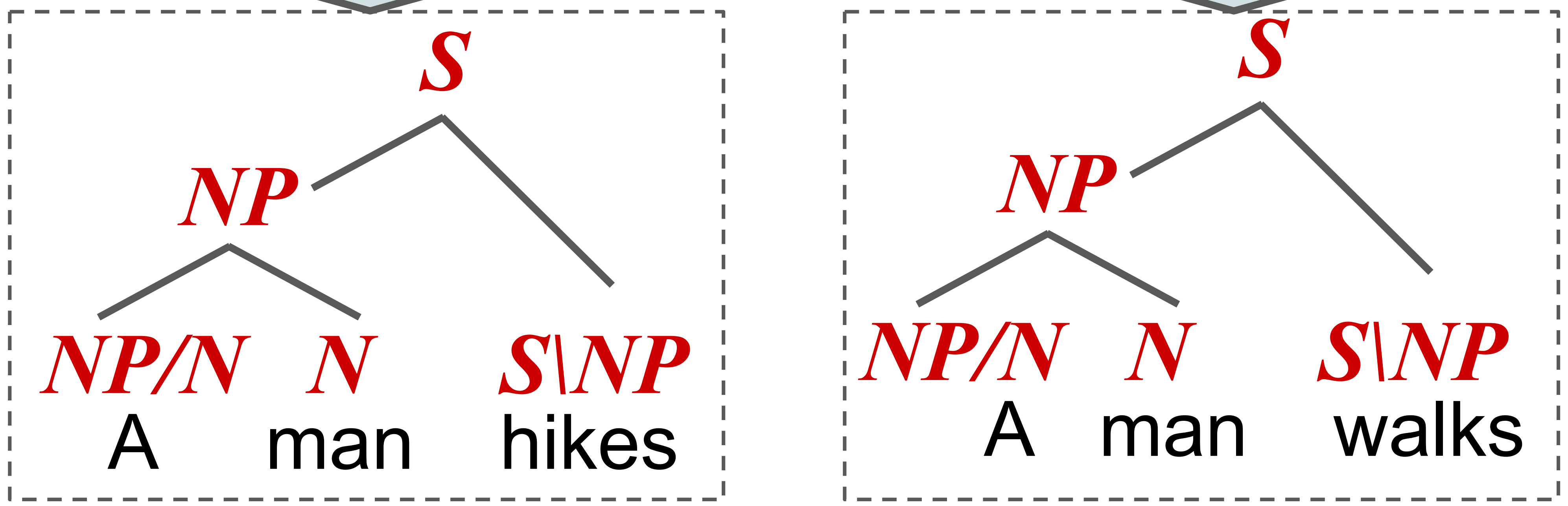


P: A man hikes. H: A man walks.



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Coq theorem prover

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🤔 How to handle external knowledge?
e.g. $\forall x\,.\,\mathbf{hike}(x) \rightarrow \mathbf{walk}(x)$
- Use WordNet as axioms blows up the search space of theorem proving!

"Abduction" Mechanism (Martínez-Gómez et al., 2017)

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Logical Formulas

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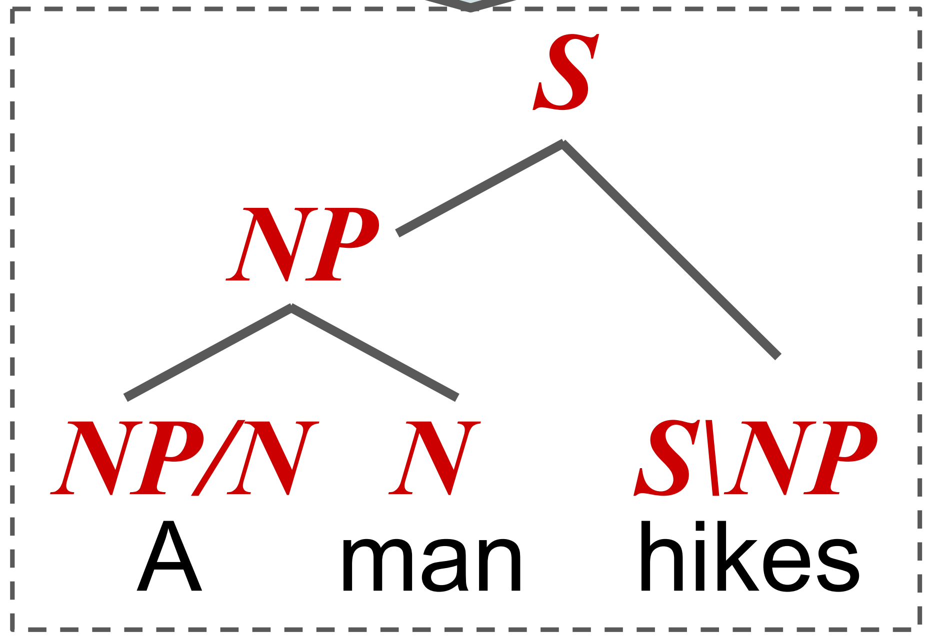

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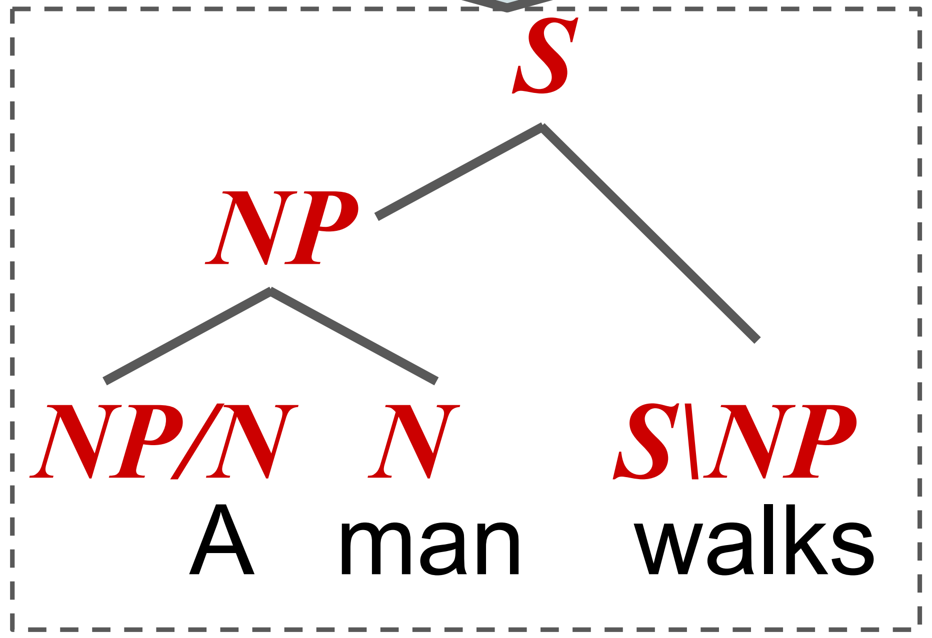

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Logical Formulas

Theorem Proving

{ yes, no, unknown }

Search on KBs

PRINCETON UNIVERSITY
WordNet
A lexical database for English

New Axioms

Theorem Proving

{ yes, no, unknown }

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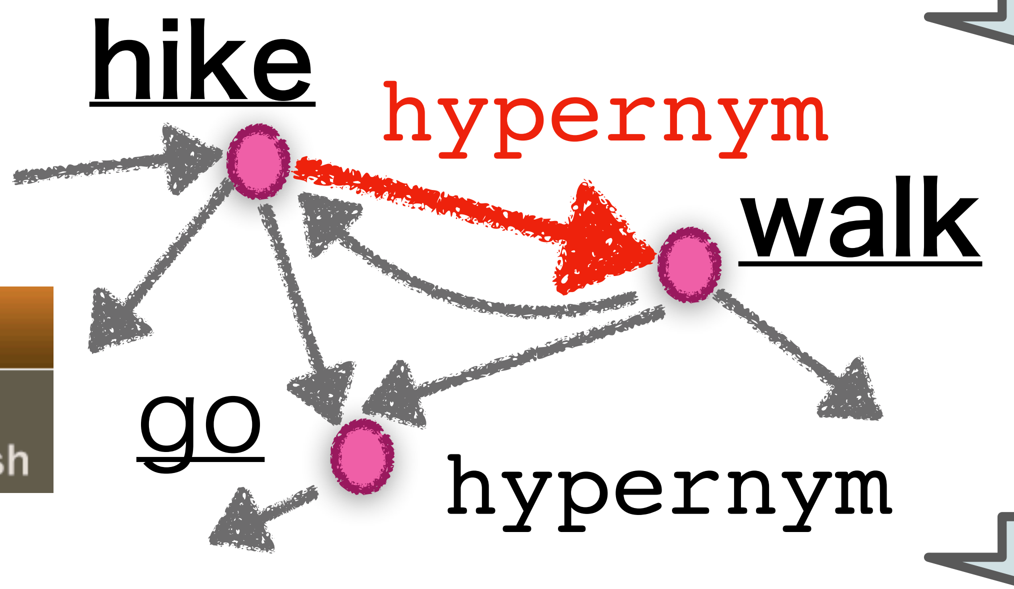

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```
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Coq theorem prover

result: yes

More steps when the 1st theorem proving is unsuccessful

1. Search KBs (e.g. WordNet) for useful lexical relations
2. Rerun Coq with additional axioms

"Abduction" Mechanism (Martínez-Gómez et al., 2017)

- Promising approach to handling external knowledge within a logic-based system

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- (However,) **Practical issues**:
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- Do not want to run Coq again and again for real applications 😣
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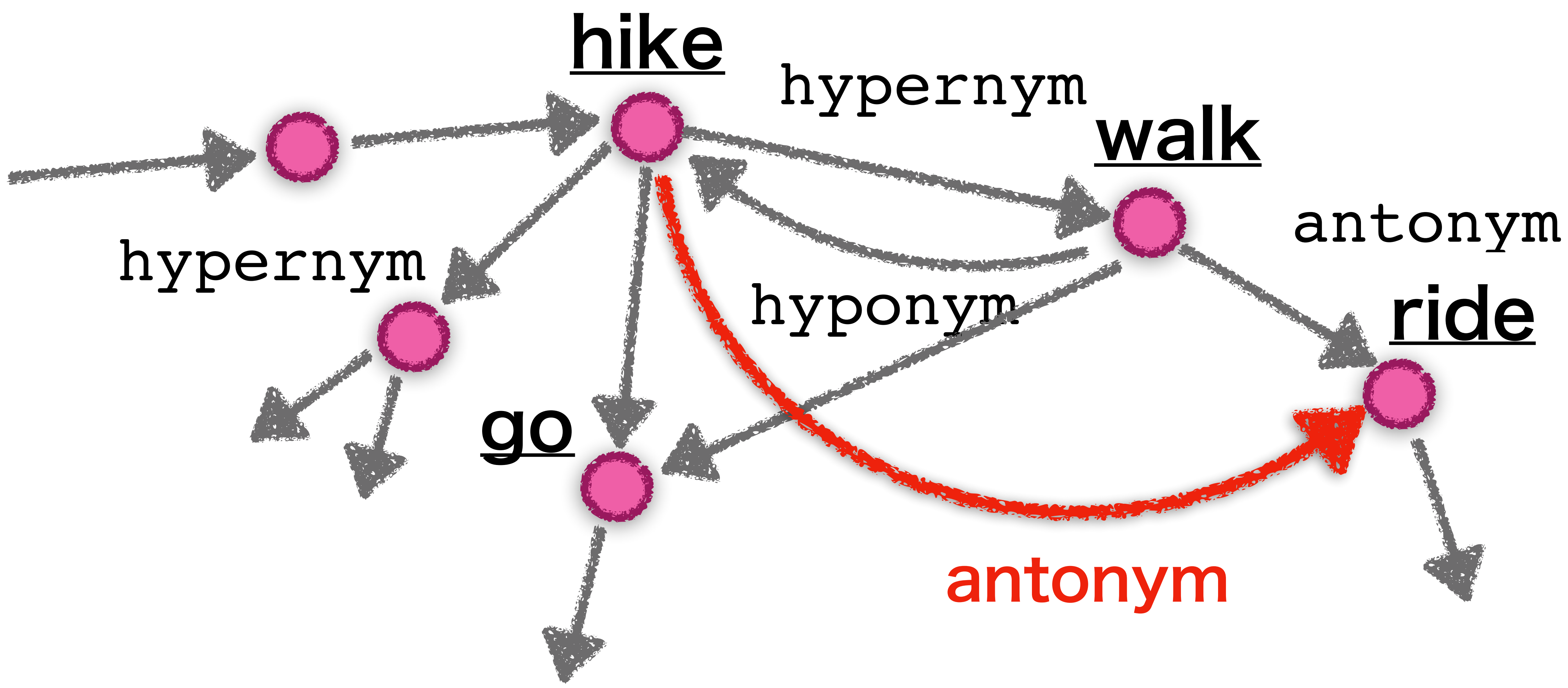
👉 **We solve these issues by:**

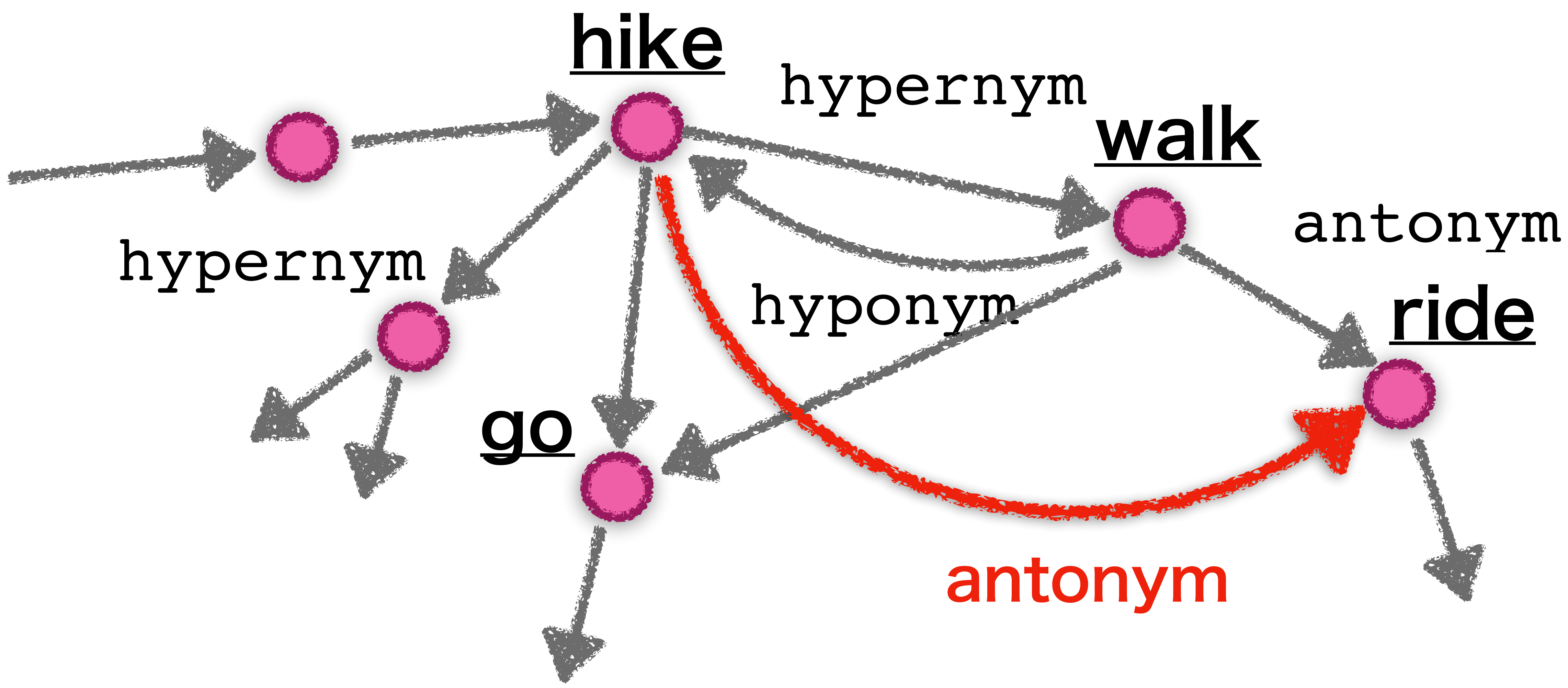
1. **Replacing search on KBs by techniques of "Knowledge Base Completion"**
2. **Developing "`abduction`" Coq plugin**

1. Extending Abduction Mechanism with KBC



1. Extending Abduction Mechanism with KBC

- **Knowledge Base Completion**:
  - A task to complement missing relations
  - recent huge advancement



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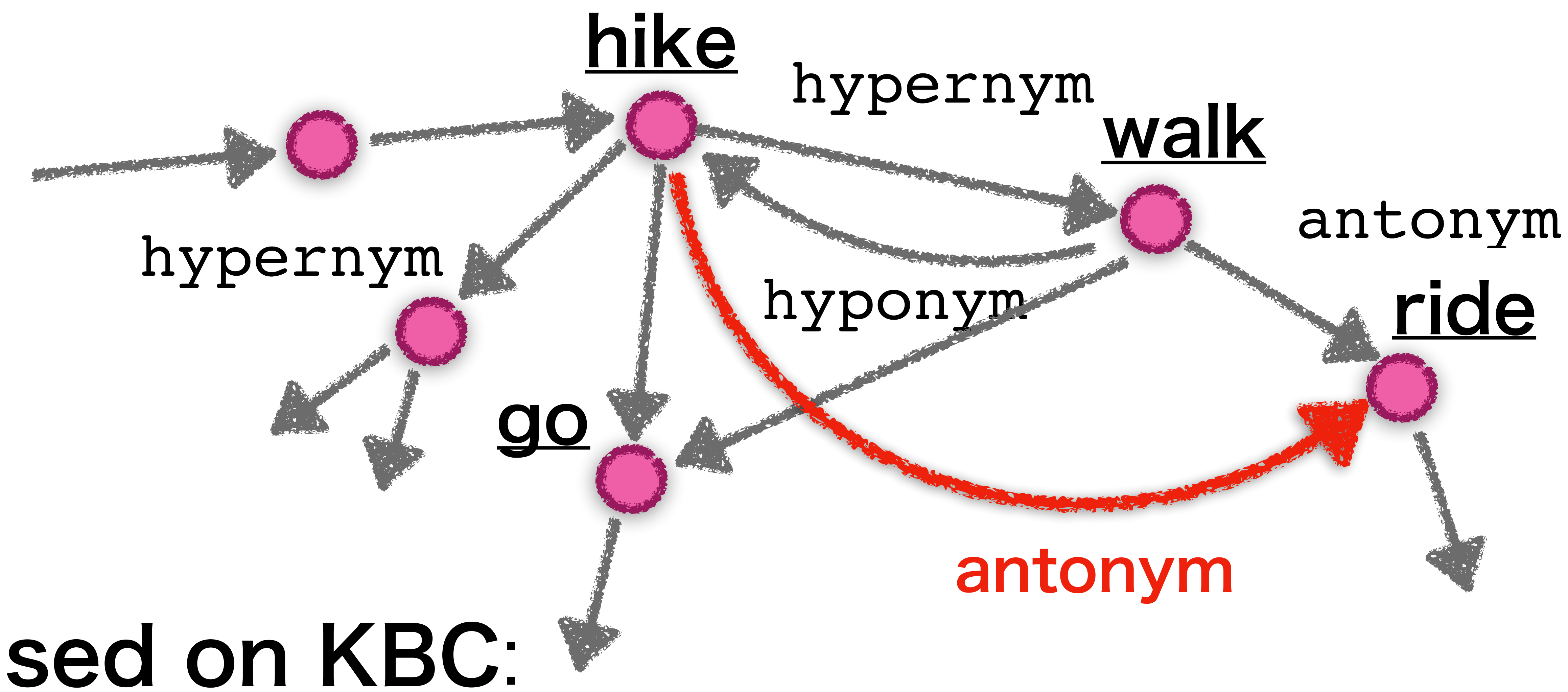
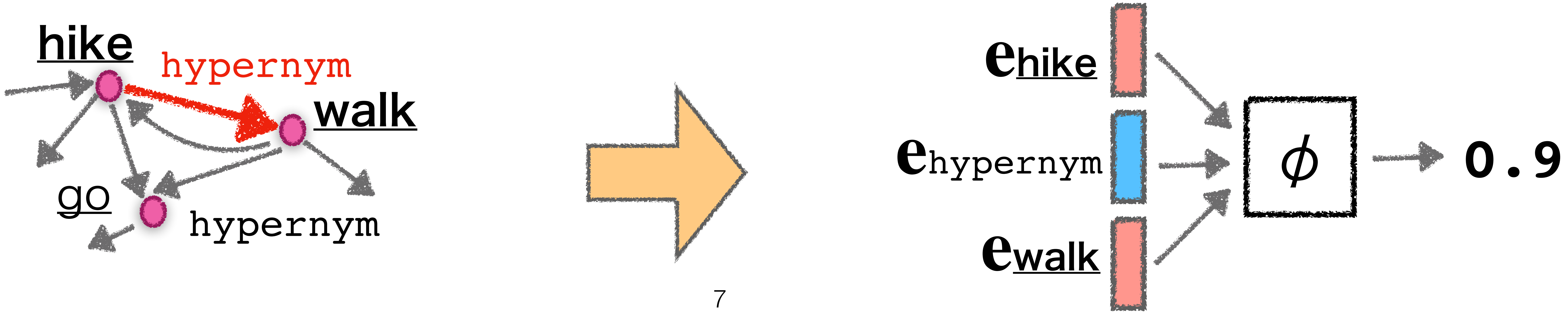
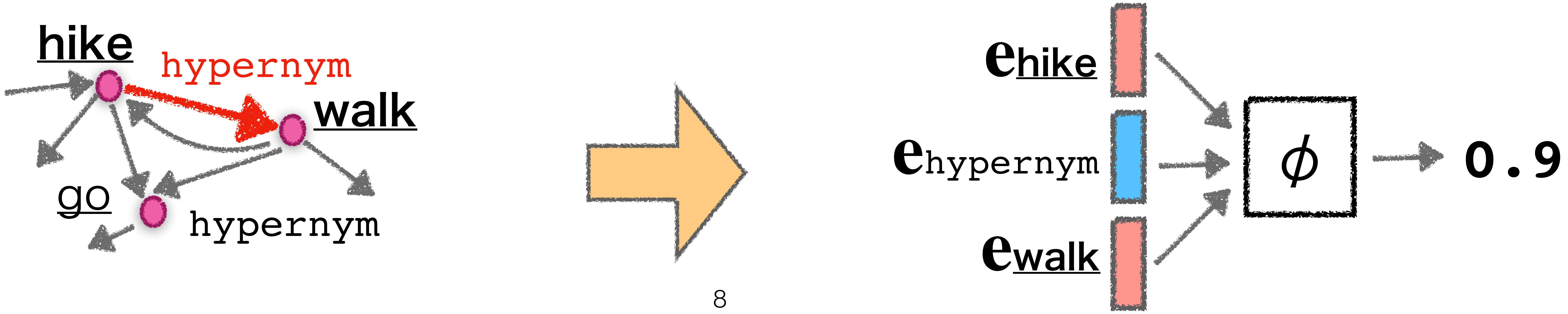


- We propose an **abduction mechanism based on KBC**:
  - If (s, r, o) is missing, use it as axiom if $\phi(s, r, o) \geq \delta$ (threshold)
  - ComplEx (Trouillon et al., 2016): $\phi(s, r, o) = \sigma(Re(\langle \mathbf{e}_s, \mathbf{e}_r, \mathbf{e}_o \rangle)), \forall \mathbf{e}_v \in \mathbb{C}^n$



1. Extending Abduction Mechanism with KBC

	Search on KB	KBC
Latent Knowledge	Hand-crafted rules (e.g. transitive closure of `hypernym`)	KBC models learn accurately
Efficiency	Multi-hop reasoning takes time	One dot product (ComplEx)
Scalability	Adding more knowledge harms the search time	Knowledge from VerbOcean (Chklovski et al., 2004) are added for free



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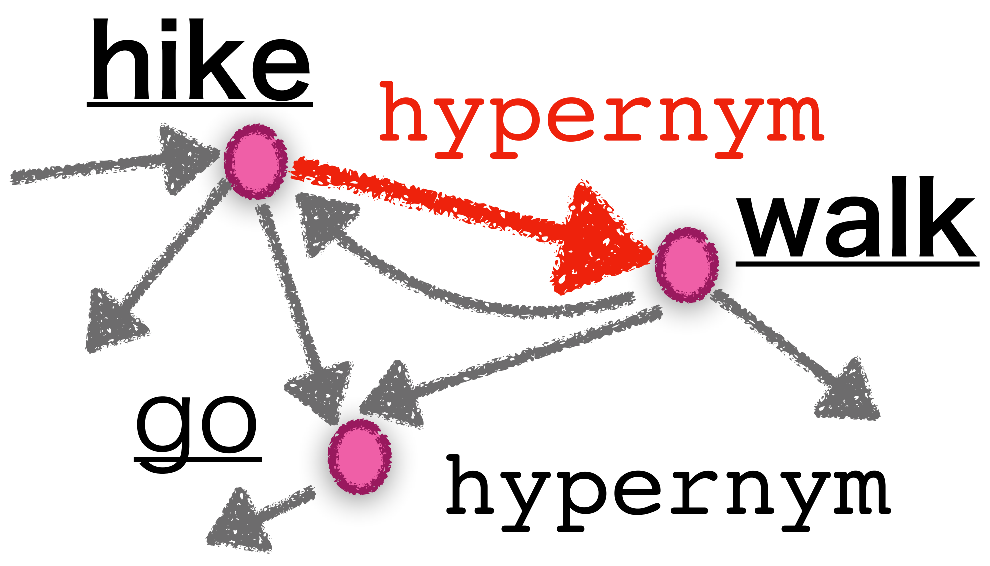

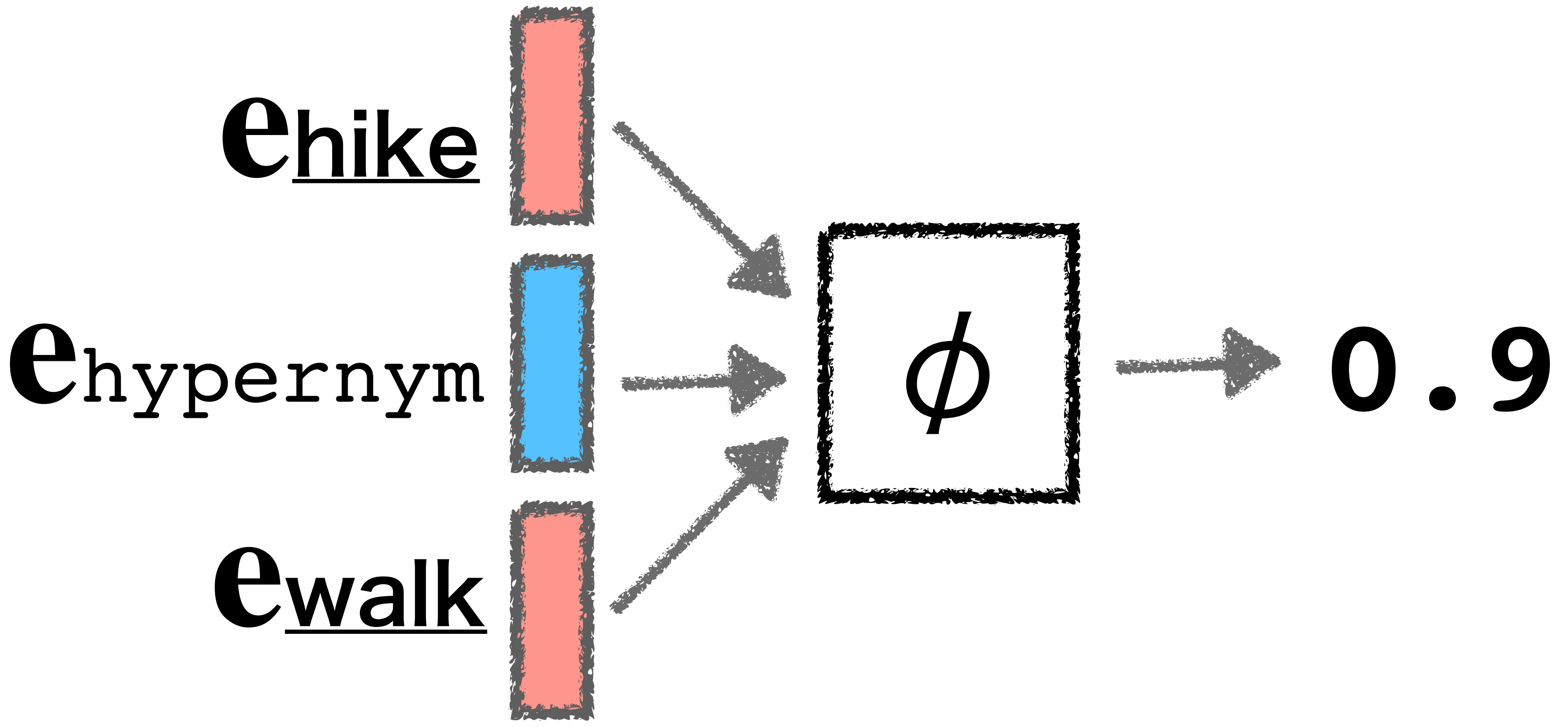

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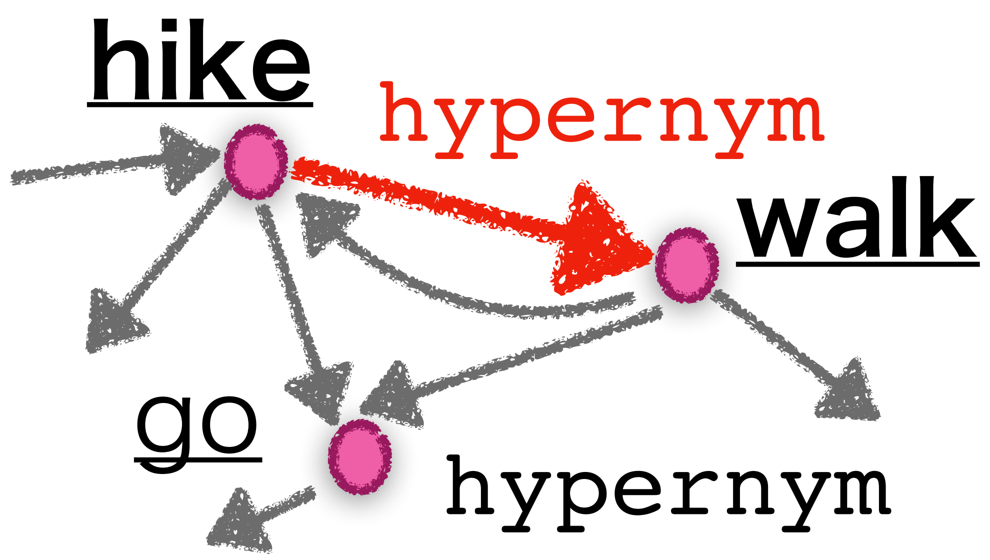

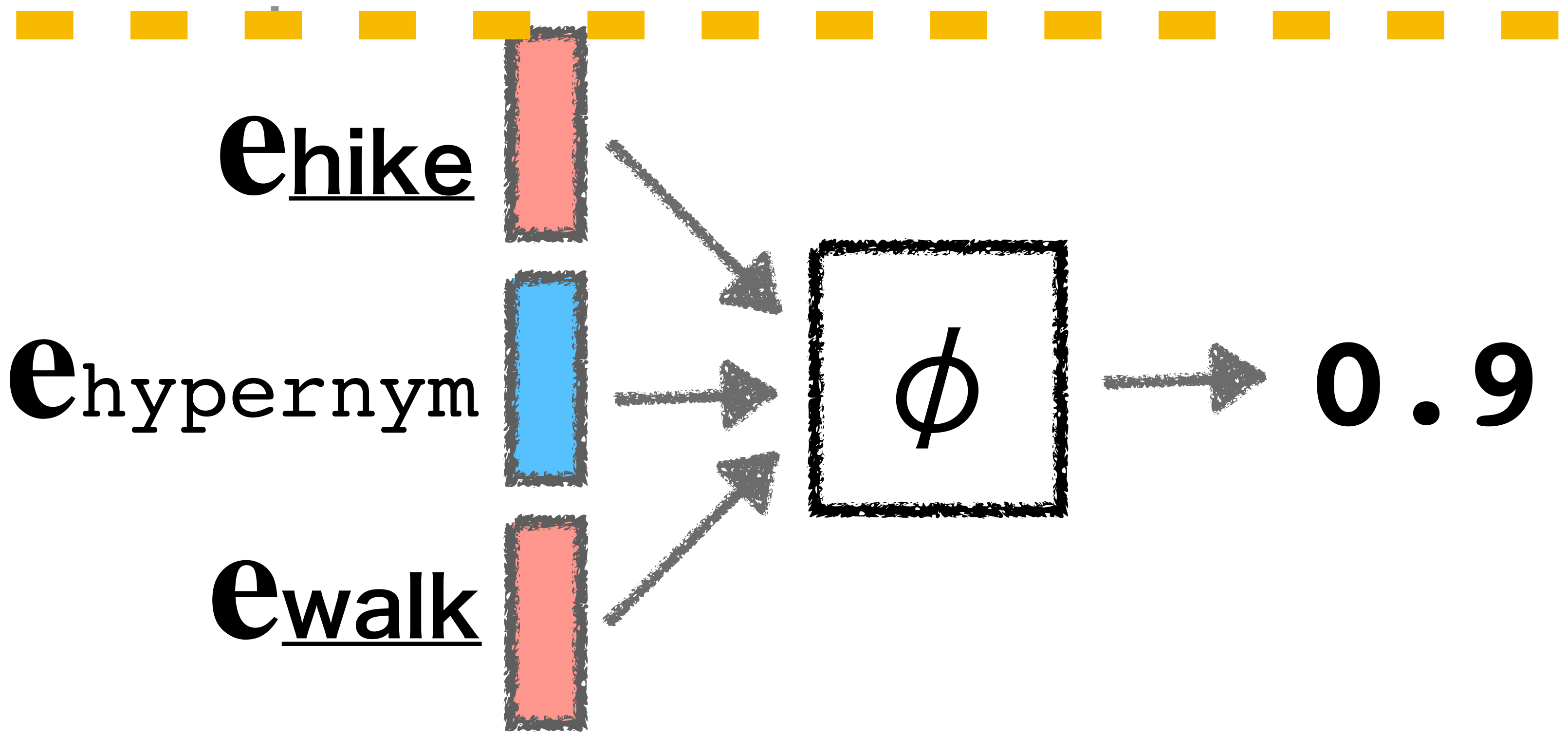

2. Faster Reasoning with "**abduction**" Coq plugin

Coq Interactive Session

```
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)
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Coq Interactive Session

Lexical gap!

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t < abduction.
```

2. Faster Reasoning with "abduction" Coq plugin

Coq Interactive Sessio

Lexical gap!

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

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2. Faster Reasoning with "abduction" Coq plugin

Construct a list of predicate pairs from context and goal

Coq Interactive Sessio

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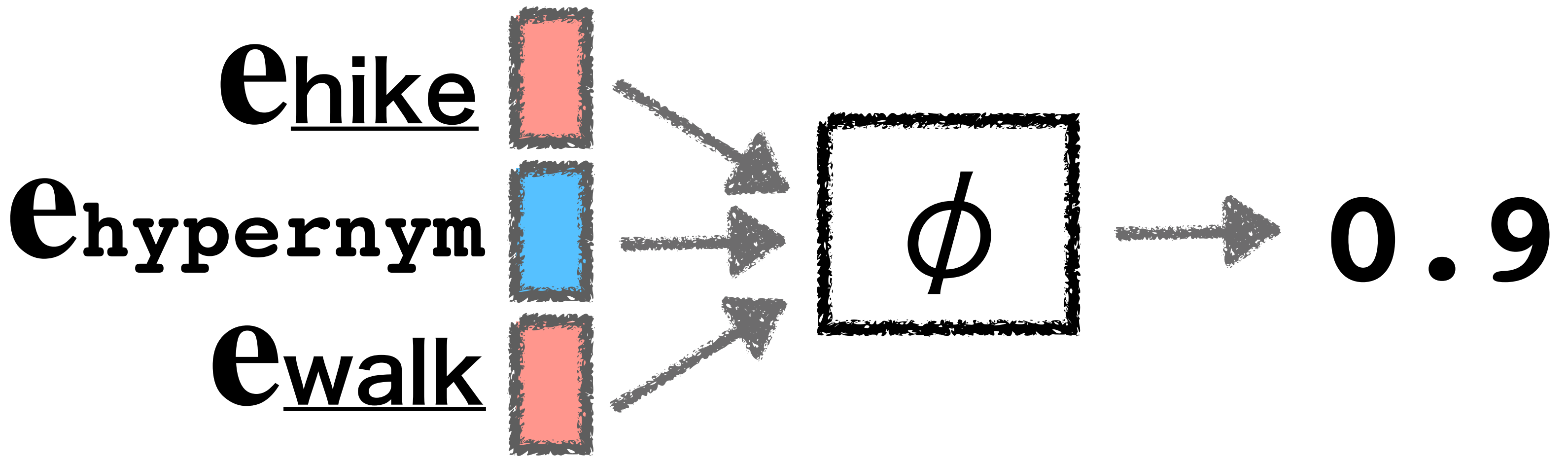
Construct a list of predicate pairs from context and goal

Evaluate all the predicate pairs using ComplEx



Filter them by score

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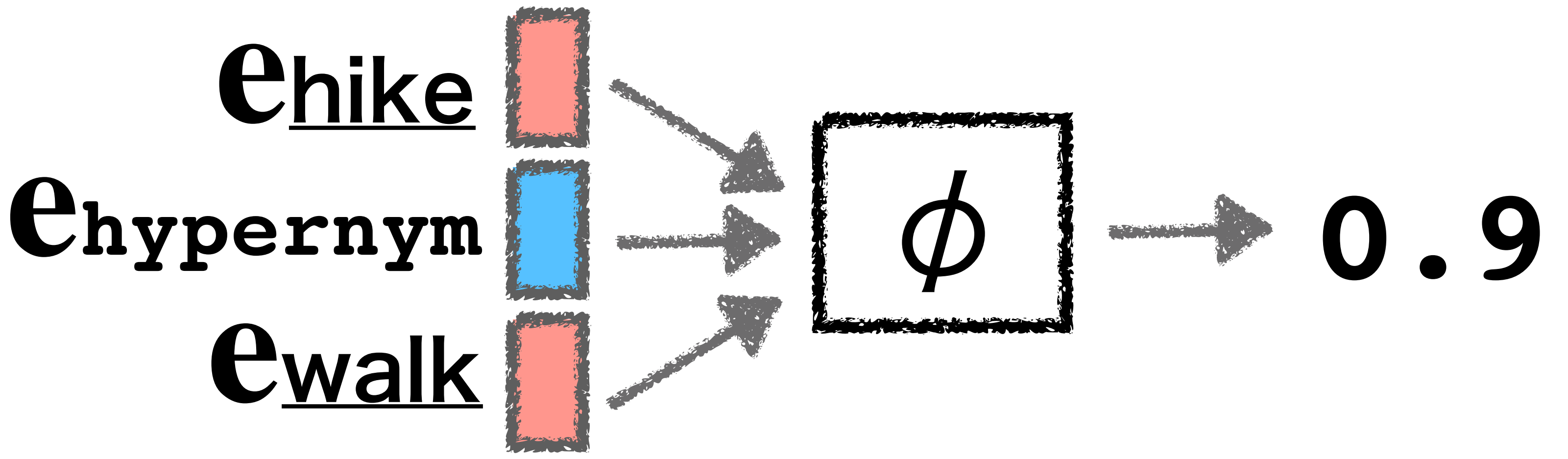

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Add them as axioms

(hike, hypernym, walk)

$$\forall x\,.\,\mathbf{hike}(x) \rightarrow \mathbf{walk}(x)$$

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Lexical gap!

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Construct a list of predicate pairs from context and goal

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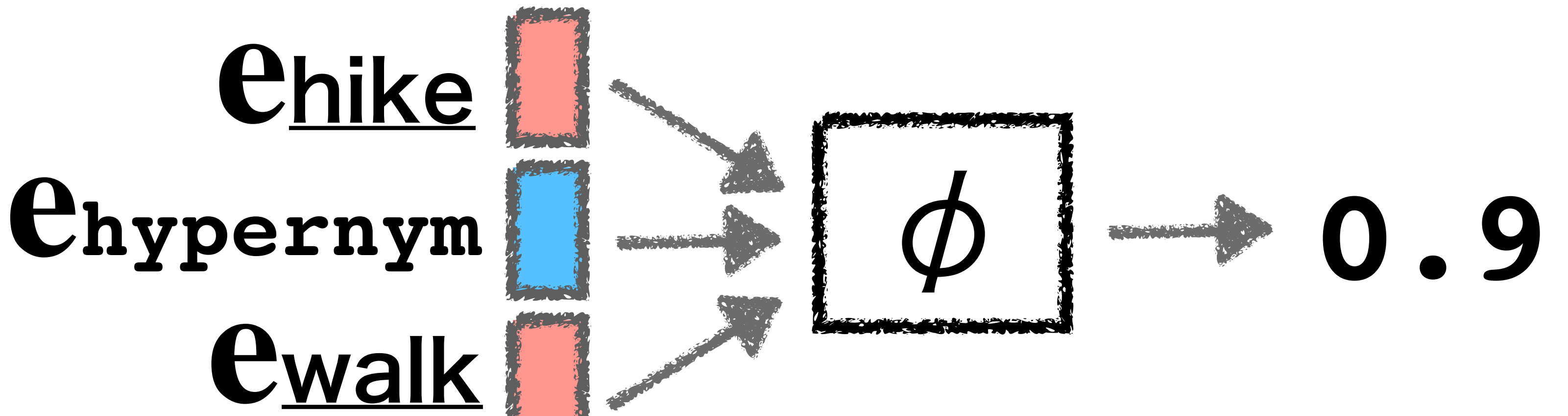

↓

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Summary so far…

Syntactic Parsing

CCG Derivations

Semantic Parsing

Logical Formulas

Theorem Proving

{ yes, no, unknown }

NP NP/N N S\NP A man hikes

NP NP/N N S\NP A man walks

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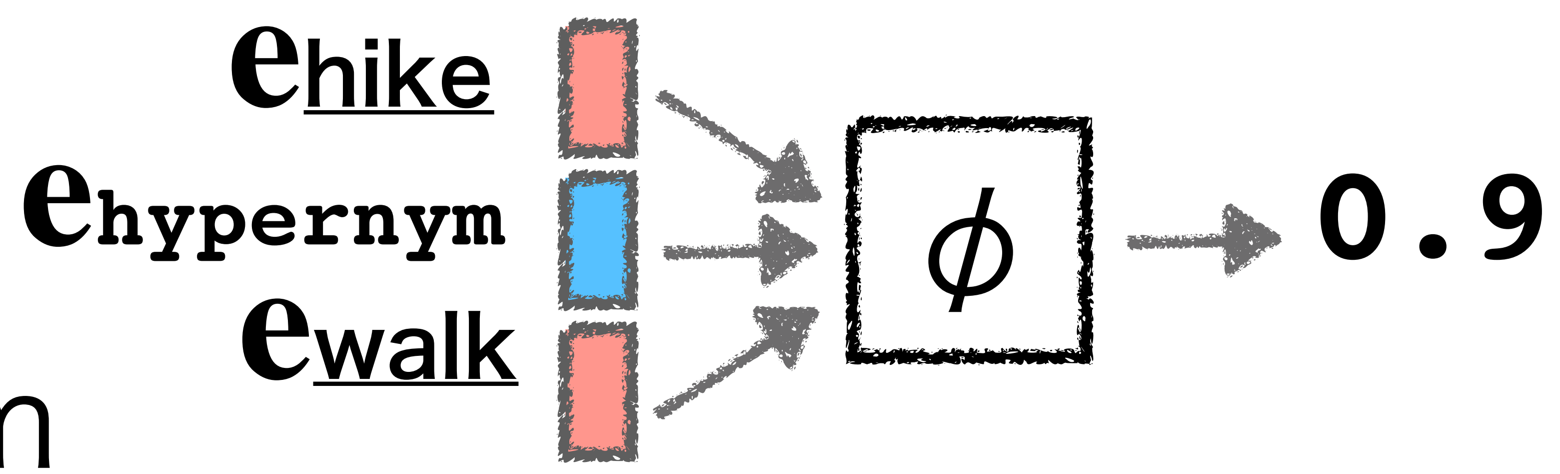
Coq

+abduction

result: yes



👍 Efficient and scalable abduction mechanism

👍 No need to rerun Coq in abduction

- Our method is applicable to other logic-based systems
  - e.g. Modern Type Theory (Bernandy and Chatzikyriakidis, 2017)

Experiments

- SICK RTE dataset (Marelli et al., 2014)
- Metrices: accuracy and processing time
- ComplEx is trained on logistic loss: $\sum_{((s,r,o),t)\in\mathcal{D}} t \log f(s,r,o) + (1-t)\log(1-f(s,r,o))$
- The training data is constructed using WordNet
  - synonym, antonym, hyponym, hypernyms, etc.
  - The trained ComplEx model achieves MRR of 77.68%

P: A flute is being played in a lovely way by a girl.

H: One woman is playing a flute.

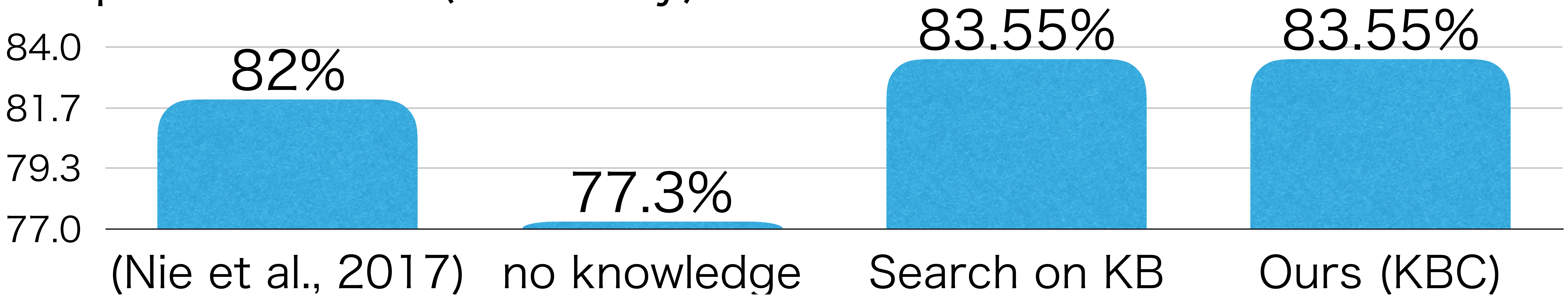
logical

lexical phenomena

syntactic

Experimental Results on SICK

- RTE performance (accuracy)



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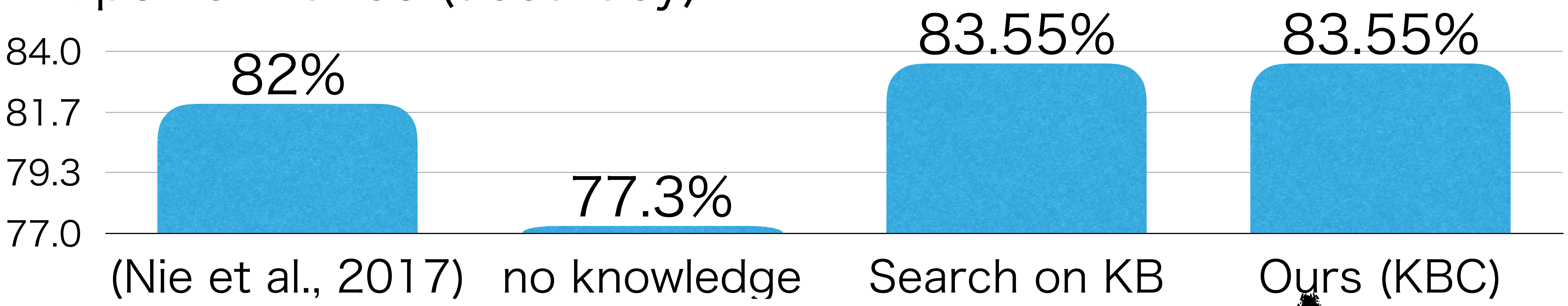

Achieves the same accuracy, improving significantly from "no knowledge" case

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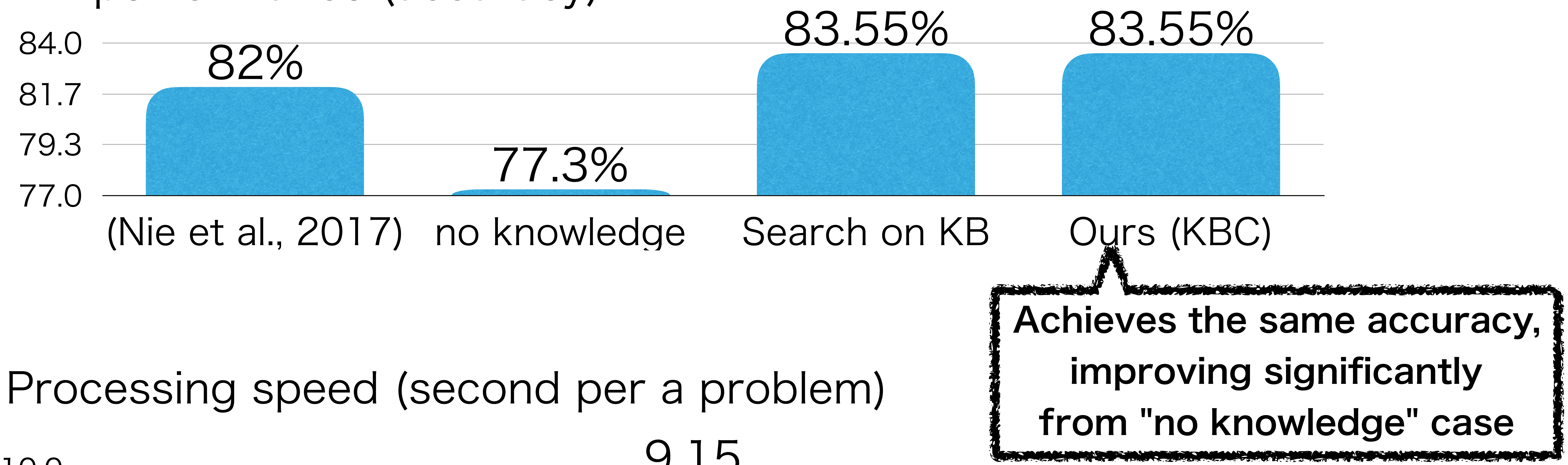
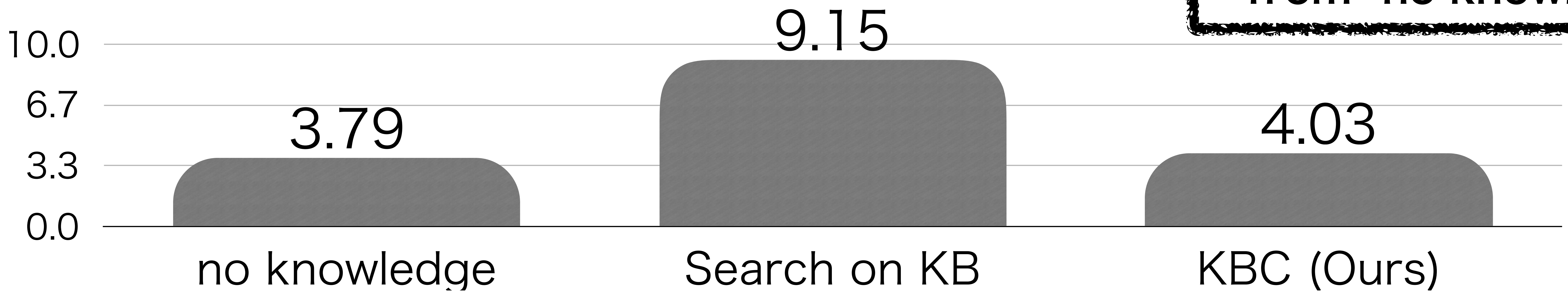


- Processing speed (second per a problem)



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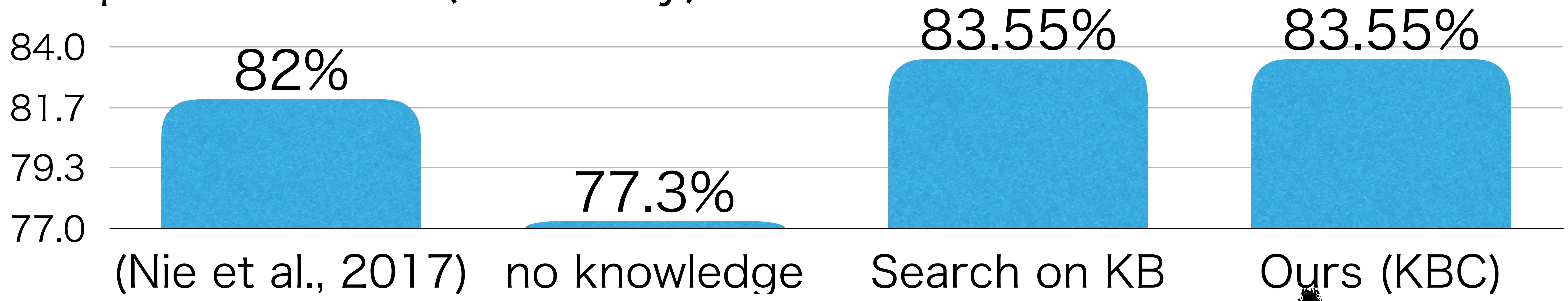
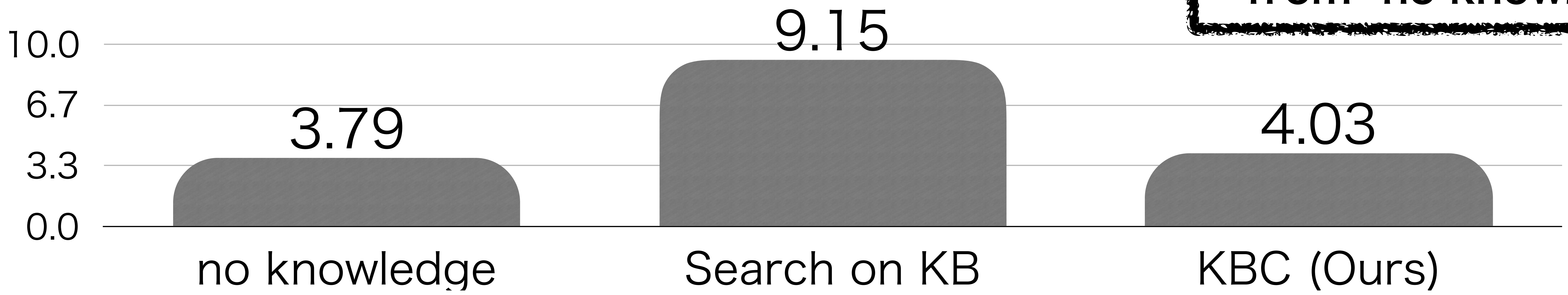
Experimental Results on SICK

- RTE performance (accuracy)



Achieves the same accuracy, improving significantly from "no knowledge" case

- Processing speed (second per a problem)



- Baselines: Search on KB (Martínez-Gómez et al., 2017), NN

Our method halves the time to process an RTE problem!

Thank you!

- A KBC-based axiom injection for logic-based RTE systems
  - Efficient, scalable, and it provides latent knowledge
- `abduction` tactic for further faster reasoning
- **Come to my poster (#1319) for other topics**:
  - Adding other KB (VerbOcean) without losing efficiency
  - Evaluating learned latent knowledge in terms of RTE (LexSICK dataset)
- **All the codes, dataset and slides are available**:
  - https://masashi-y.github.io