Learning to Make Inferences in a Semantic Parsing Task

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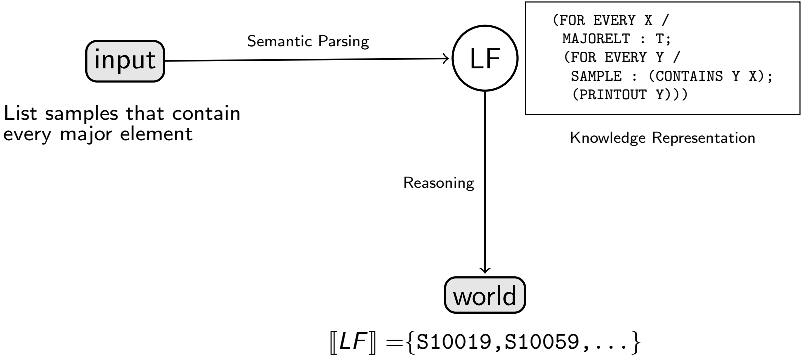
Natural Language Understanding and Semantic Parsing

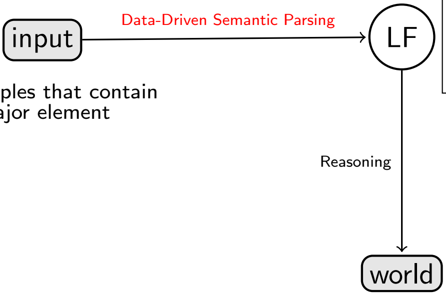
- Conventional pipeline model



Lunar QA system (Woods (1973))

Natural Language Understanding and Semantic Parsing

- Semantic parsing: Learning representations from corpora and databases.



List samples that contain every major element

```
(FOR EVERY X /
 MAJORELT : T;
 (FOR EVERY Y /
  SAMPLE : (CONTAINS Y X);
  (PRINTOUT Y)))
```

Knowledge Representation

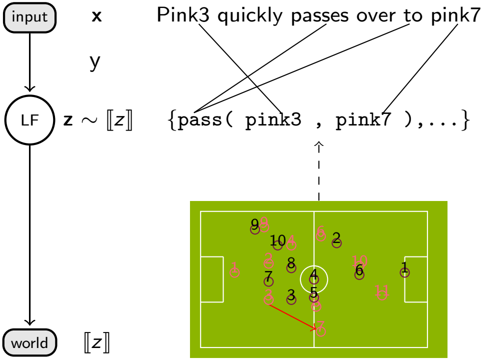
$$[\![LF]\!] = \{\texttt{S10019}, \texttt{S10059}, \ldots\}$$

Paradigm and Supervision	Dataset	Learning Goal
Learning from LFs [1]	$\{(input_i, LF_i)\}_i^N$	$input \xrightarrow{Trans.} LF$
Learning from Denotation[2]	$\{(input_i, [\![input_i]\!])\}_i^N$	$input \xrightarrow{LF+Trans.} [\![input]\!]$

[1] Zettlemoyer and Collins (2012); Wong and Mooney (2007) [2] Clarke et al. (2010); Liang et al. (2013)

Learning to Sportscast

- Learning from "grounded" and ambiguous supervision
- **Objective:** Generate correct representations for unseen commentary.



Game Simulator

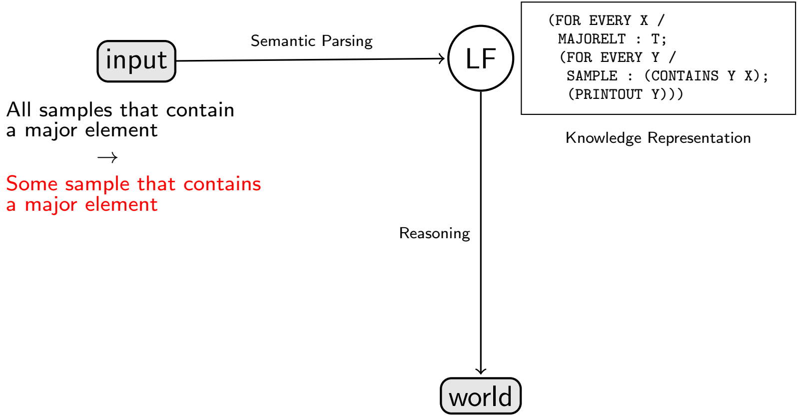
Supervision: Dataset D

Event Streams: $D = \{(x_i, \{z_1, \ldots z_k\})\}_{i=1}^{N}$
Task: learn (latent) y, **translation**

Sportscaster corpus (Chen and Mooney (2008))

Semantic Parsing and Entailment

- **Entailment:** One of the *basic aims* of semantics. (Montague (1970))
- Representations should be *grounded* in judgements about entailment.



$$[\![LF]\!] = \{\texttt{S10019}, \texttt{S10059}, \ldots\} \supseteq \{S10019\}$$

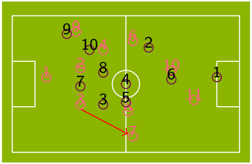
Requirements for Semantic Representations

- **Minimal requirement**: Semantic parser should be able to recognize certain types of entailments.
- **RTE:** Would a human reading t infer h? Dagan et al. (2005)

Text Input		Hypotheses	Entailments
input	**t:** Pink3 quickly kicks to Pink7 $\xrightarrow{?}$	**h$_1$:** pink3 kicks the ball	`Entail`
		h$_2$: pink3 blocks ball	`Contradict`
		h$_3$: pink3 passes near midfield	`Unknown`

LF **z:** `pass(pink3,pink7)`

world $[\![z]\!]$



$\longrightarrow$ $\mathbf{h}_1$, $\neg\mathbf{h}_2$, $?\mathbf{h}_3$

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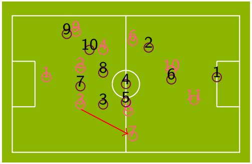

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Problem 1: Crude Representations

- Target representations are not expressive, underspecified
- Not based on background logical theory (no knowledge)

	Text t	Hypothesis h	Entailment $t \rightarrow h$ $h \rightarrow t$	Naive (do reps match?)
1.	Pink 3 quickly kicks to pink 1 `pass(pink3,pink1)`	Pink 3 kicks over to pink 1 near midfield `pass(pink3,pink1)`	`Unknown` `Unknown`	`Entail`
2.	Purple player 10 kicks the ball `kick(purple10)`	Purple 10 again shoots for the goal `kick(purple10)`	`Unknown` `Entail`	`Entail`

- **Desiderata:** explicit treatment of modifiers, sense distinctions

Problem 2: Missing Knowledge

- Target representations are not expressive, underspecified
- Not based on background logical theory (no knowledge)

	Text t	Hypothesis h	$t \rightarrow h$ $h \rightarrow t$	**Entailment** **Naive** (do reps match?)
1.	Pink 3 quickly kicks to pink 1 `pass(pink3,pink1)`	Pink 3 kicks over to pink 1 near midfield `pass(pink3,pink1)`	`Unknown` `Unknown`	`Entail`
2.	Purple player 10 kicks the ball `kick(purple10)`	Purple team scores another goal `playmode(goal_l)`	`Unknown` `Unknown`	`Contradict`

- **Desiderata:** explicit treatment of modifiers, sense distinctions abstract relations between symbols

How to improve this?

- **General Problem:** Semantic representations are underspecified, fail to capture entailments, background knowledge missing.
- **Goal:** Capture the missing knowledge and inferential properties of text.

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- **General Problem:** Semantic representations are underspecified, fail to capture entailments, background knowledge missing.
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- **Solution:** Use entailment information ($\texttt{EI}$) as weak signal to train parser and logical reasoning (an alternative to annotating representations).

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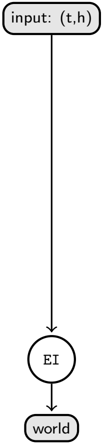
Learning from Entailment	$\{(input_t, input'_h)_i, \texttt{EI}_i)\}_i^N$	$(input_t, input'_h) \xrightarrow{Proof} \texttt{EI}$

Learning from Entailment: Illustration

- Entailments are used to reason about target symbols and find holes in the analyses.



t	pink3	λ	passes to	pink1
a	`pink3/pink3`	$\lambda/\sqsupseteq_c$	`pass/kick`	`pink1/`λ
h	pink3	quickly	kicks	λ

y

$$\dfrac{\dfrac{\texttt{pink3} \equiv \texttt{pink3}}{\text{pink3} \equiv \text{pink3}} \quad \Big| \quad \dfrac{\dfrac{\lambda \sqsupseteq \sqsubseteq_c}{\lambda \sqsupseteq \text{quickly}} \quad \Big| \quad \dfrac{\texttt{pass} \sqsubseteq \texttt{kick}, \quad \texttt{pink1} \sqsubseteq \lambda}{\text{passes to pink1} \sqsubseteq \text{kicks}} \bowtie}{\text{passes to pink 1} \# \text{quickly kicks}} \bowtie}{\text{pink3 passes to pink1} \# \text{pink3 quickly kicks}} \bowtie$$

z `Uncertain`

Data: $D = \{((t,h)_i, z_i)\}_{i=1}^{N}$, **Task:** learn (latent) proof y

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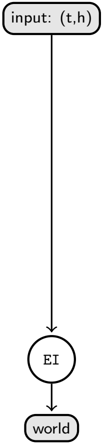

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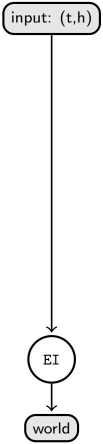

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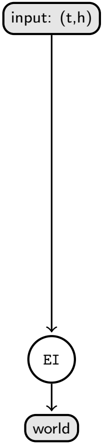

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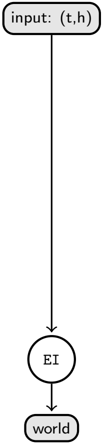

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- **Logic:** Natural logic calculus (MacCartney and Manning (2009)).

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  - I: axioms, set-theoretic relations between symbols.

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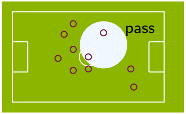
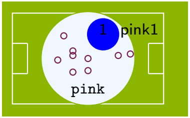
$\texttt{pink1} \sqsubseteq \texttt{pink team}$

$\forall x.\texttt{pink1}(x) \rightarrow \texttt{pink-team}(x)$ (**FOL**)





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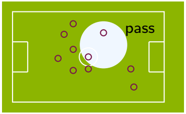

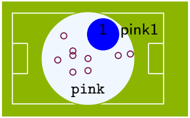

  - $\bowtie$: natural logic inference rule: $\equiv \bowtie \sqsubseteq = \sqsubseteq$

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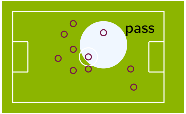

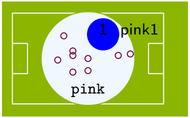

  - $\bowtie$: natural logic inference rule: $\equiv \bowtie \sqsubseteq = \sqsubseteq$
- **Latent variable:** axioms or relations in proofs.

Experiments with Sportscaster

- **Step 1:** Train a normal semantic parser, sentences $\rightarrow$ logical forms.
- **Step 2:** Jointly retrain on original data and inference pairs, sentences $\rightarrow$ logical forms, pairs $\rightarrow$ proofs.

- **Evaluation:** generating logical representations (**standard**), recognizing textual entailment (**novel**)

Semantic Parsing: Sentences to Logical Form

- Use a semantic CFG, rules constructed from target representations using small set of templates (Börschinger et al. (2011))

$(x$: purple 10 quickly kicks, z : $\{\texttt{kick(purple10)}$, block(purple7),...$\})$

$\downarrow$ (rule extraction)

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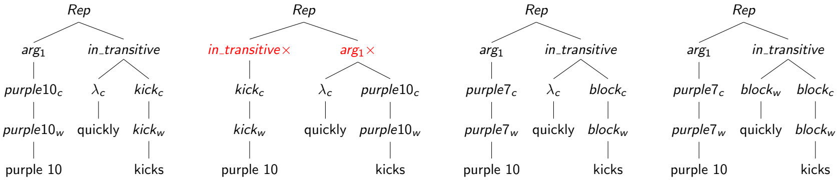

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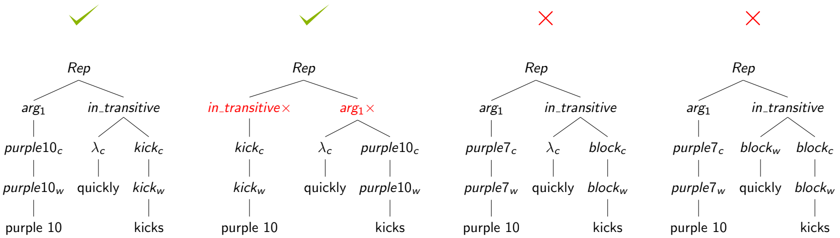
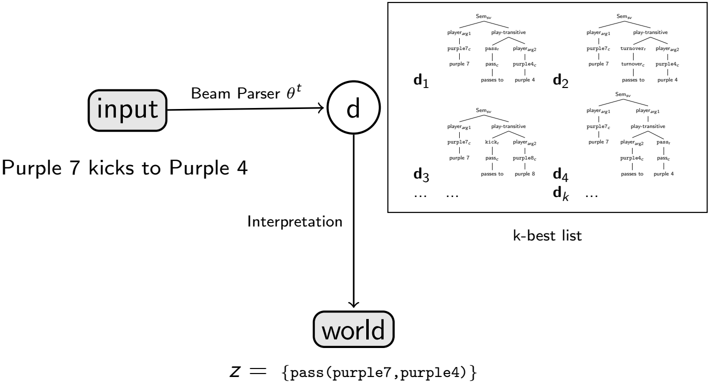


Learning for Semantic Parsing

- Rules used to define a PCFG $\mathcal{G}_\theta$, learn correct derivations.
- **Learning:** EM bootstrapping approach (Angeli et al. (2012)), **objective**:

$$\max_{\theta} \sum_{i=1}^{N} log\ p_\theta(z_i|x_i)$$



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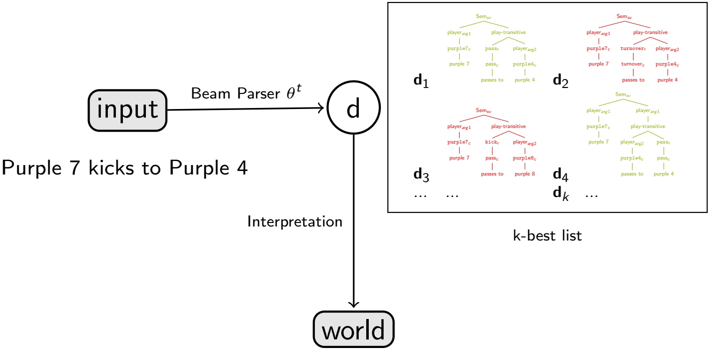

$z = \{\texttt{pass(purple7,purple4)}\}$

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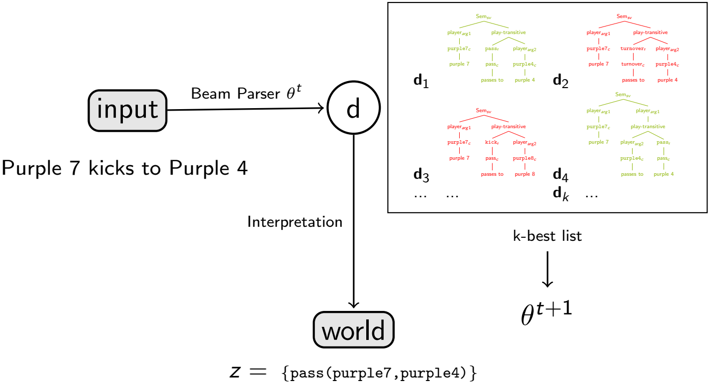
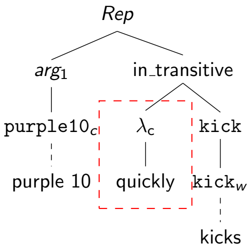


Semantic Parsing: Sentences to Logical Form

- Representations are a rough approximation, unknown items are ignored

$$(x : \text{purple 10 quickly kicks}, z : \{\texttt{kick(purple10)}, \text{block(purple7)},\ldots\})$$

$$\Big\downarrow \text{(parsing)}$$



Entailment Modeling: Sentence Pairs to Proofs

- **Alignment:** heuristic alignment between target/hypothesis parse trees.

$\big(\big($**t:** purple7 kicks the ball, **h:** purple team scores a goal$\big)$, `Uncertain`$\big)$

transform. relation. $\texttt{kick} \xrightarrow{\textit{sub.}} \texttt{score}$ $\texttt{purple7} \xrightarrow{\textit{sub.}} \texttt{purple team}$

inference

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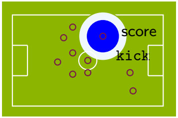
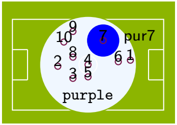
relation. $\sqsupseteq$ $\sqsubseteq$

symbol	definition
$\sqsubseteq$	$x \subset y$
$\sqsupseteq$	$x \supset y$
$\equiv$	$x = y$
$\mid$	neg.
$\#$	other





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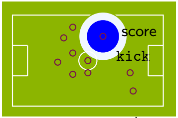
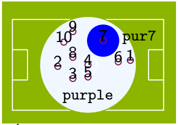
$\#$	`other`





inference $(\sqsupseteq \bowtie \sqsubseteq) = \#(\texttt{Uncertain})$

$\bowtie$	$\equiv$	$\sqsubseteq$	$\sqsupseteq$	$\mid$	$\#$
$\equiv$	$\equiv$	$\sqsubseteq$	$\sqsupseteq$	$\mid$	$\#$
$\sqsubseteq$	$\sqsubseteq$	$\sqsubseteq$	$\#$	$\mid$	$\#$
$\sqsupseteq$	$\sqsupseteq$	$\#$	$\sqsupseteq$	$\#$	$\#$
$\mid$	$\mid$	$\#$	$\mid$	$\#$	$\#$
$\#$	$\#$	$\#$	$\#$	$\#$	$\#$

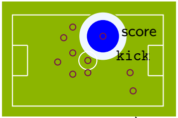
Entailment Modeling: Sentence Pairs to Proofs

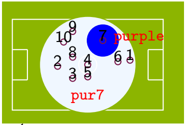
- **Alignment:** heuristic alignment between target/hypothesis parse trees.

$\big(\big($**t:** purple7 kicks the ball, **h:** purple team scores a goal$\big)$, `Uncertain`$\big)$

transform. $\texttt{kick} \xrightarrow{sub.} \texttt{score}$ $\qquad$ $\texttt{purple7} \xrightarrow{sub.} \texttt{purple team}$

relation. $\sqsupseteq$ $\qquad$ $\sqsupseteq$





inference $(\sqsupseteq \bowtie \sqsupseteq) = \sqsupseteq$ (`Uncertain`)

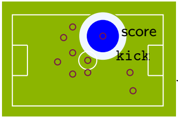
Entailment Modeling: Sentence Pairs to Proofs

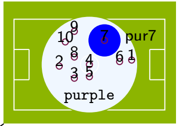
- **Alignment:** heuristic alignment between target/hypothesis parse trees.

((**t:** purple7 kicks the ball, **h:** purple team scores a goal again), $\texttt{Uncertain}$)

transform. $\texttt{kick} \xrightarrow{sub.} \texttt{score}$ $\lambda \xrightarrow{ins.} \sqsubseteq_c$ $\texttt{purple7} \xrightarrow{sub.} \texttt{purple team}$

relation. $\sqsupseteq$ $\sqsupseteq_{\texttt{modifier}}$ $\sqsubseteq$





$\sqsupseteq \bowtie \sqsupseteq = \sqsupseteq$

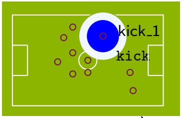
inference $(\sqsupseteq \bowtie \sqsubseteq) = \#(\texttt{Uncertain})$

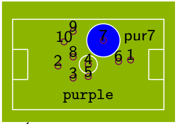
Entailment Modeling: Sentence Pairs to Proofs

- **Alignment:** heuristic alignment between target/hypothesis parse trees.

((**t:** purple7 kicks the ball, **h:** purple7 shoots for the goal), `Uncertain`)

transform.	`kick` $\xrightarrow{\textit{sub.}}$ `kick_1`	`purple7` $\xrightarrow{\textit{sub.}}$ `purple7`
relation.	$\sqsupseteq$	$\equiv$





inference $(\sqsupseteq \bowtie \equiv) = \sqsupseteq$ (`Uncertain`)

Natural Logic Rules as a PCFG

- Rules of the logic are encoded as probabilistic rewrite rules.
- **Proof example**

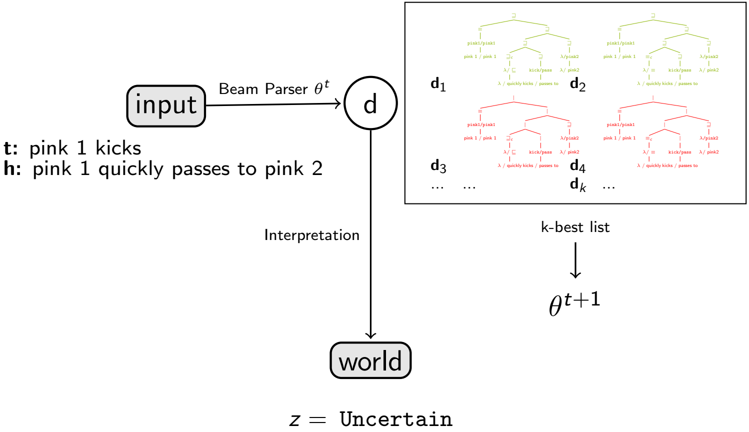
$$
\dfrac{\dfrac{\texttt{pink3} \equiv \texttt{pink3}}{\text{pink3} \equiv \text{pink3}} \mid \dfrac{\dfrac{\lambda \sqsupseteq \sqsubseteq_c}{\lambda \sqsupseteq \text{quickly}} \mid \dfrac{\texttt{pass} \equiv \texttt{pass}, \quad \texttt{pink1} \sqsubseteq \texttt{pink team}}{\text{passes to pink1} \sqsubseteq \text{kicks to the pink team}} \bowtie}{\text{passes to pink 1} \ \# \ \text{quickly kicks to the pink team}} \bowtie}{\text{pink3 passes to pink1} \ \# \ \text{pink3 quickly kicks to the pink team}} \bowtie
$$

- **PCFG rules**

	$(X \bowtie Y)$	$\longrightarrow_{\bowtie}$	X / Y
0.5	$\equiv_{\text{arg1}}$	$\longrightarrow_{I}$	pink3 / pink3
0.5	$\equiv_{\text{arg1}}$	$\longrightarrow_{I}$	pink1 / pink1
0.9	$\sqsubseteq_{\text{arg1}}$	$\longrightarrow_{I}$	pink1 / pink team
0.1	$\sqsubseteq_{\text{arg1}}$	$\longrightarrow_{I}$	pink team / pink1
1.0	$\sqsupseteq$	$\longrightarrow_{I}$	λ / $\sqsubseteq_c$
1.0	$\sqsubseteq$	$\longrightarrow_{I}$	$\sqsubseteq_c$ / λ
0.8	$\sqsubseteq_{\text{rel}}$	$\longrightarrow_{I}$	pass / kick
0.2	$\sqsubseteq_{\text{rel}}$	$\longrightarrow_{I}$	kick / pass
0.7	$\sqsupseteq_{\text{rel}}$	$\longrightarrow_{I}$	kick / pass
0.3	$\sqsupseteq_{\text{rel}}$	$\longrightarrow_{I}$	pass / kick

Learning Entailment Rules

- Rules define an inference PCFG $\mathcal{G}'_{\theta}$, learn correct proofs.
- **Learning:** Grammatical inference problem as before, EM boostrapping.



Experiment: Datasets

- **Sportscaster:** 4 games, 1872 sentences, 46 concept types.
- **Inference Dataset:** 461 pairs from training annotated (155 using AMT, 306 using local annotators).

- **Elicitation:** Directions from Snow et al. (2008). Those without agreement discarded (standard).

Text t	**Hypothesis h**	Entail?
purple 7 kicks the ball	purple 7 makes a bad pass	{`Entail`,`Contradict`,`Uncertain`}

Experiment: Evaluation and Results

- **Old Evaluation:** Can we generate the correct target representations for held-out examples? *(state-of-the-art results reported)*
- **New Evaluation:** Can we generate correct entailments given held-out pairs? *(positive results using our method)*

Experiment: Evaluation and Results

- **Old Evaluation:** Can we generate the correct target representations for held-out examples? *(state-of-the-art results reported)*
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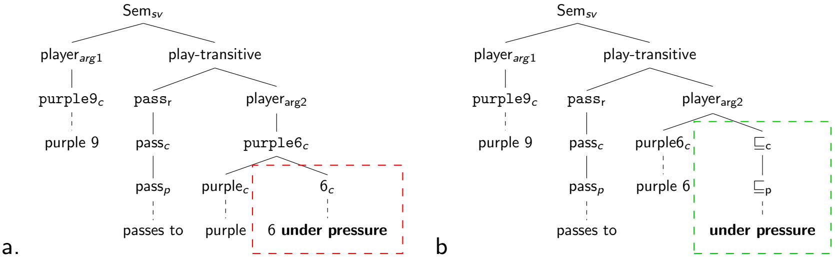
Inference Task	Accuracy
Majority Baseline	0.33
RTE classifier	0.52
Naive Inference	0.60
SVM Flat Classifier	0.64
Inference Grammar	**0.73**

Qualitative Analysis

- Improving the internal representations (before, a, after, b).



Qualitative Analysis

- Learned modifiers from example proofs trees.

(t, h): (a **beautiful** pass to,passes to)

$\sqsubseteq_c \bowtie \equiv_{\text{play-tran}} = \sqsubseteq_{\text{play-tran}}$

modifier

$\sqsubseteq_c$ $\equiv$play-tran.

$\sqsubseteq_c$ $/\lambda$ `pass/pass`

"**a beautiful**"$/\lambda$ "pass to'/"passes to"

analysis:
generalization: $\texttt{beautiful}(X) \sqsubseteq X$

(**gets a** free kick,freekick from the)

$\equiv_c \bowtie \equiv_{\text{game-play}} = \equiv_{\text{game-play}}$

modifier

$\equiv_c$ $\equiv$game-play

$\equiv_c$ $/\lambda$ `freekick/freekick`

"**gets a**"$/\lambda$ "free kick" / "freekick from the"

analysis:
generalization: $\texttt{get}(X) \equiv X$

(t, h): (**yet again** passes to,kicks to)

$\sqsubseteq_c \bowtie \equiv_{\text{play-tran.}} = \sqsubseteq_{\text{play-tran}}$

modifier

$\sqsubseteq_c$ $\equiv$play-tran.

$\sqsubseteq_c$ $/\lambda$ `pass/pass`

"**yet again**"$/\lambda$ "passes to"/"kicks to"

analysis:
generalization: $\texttt{yet-again}(X) \sqsubseteq X$

(purple 10,purple 10 **who is out front**)

$\equiv_{player_{arg2}} \bowtie \sqsupseteq_c = \sqsupseteq_{player_{arg2}}$

modifier

$\equiv_{player_{arg2}}$ $\sqsupseteq_c$

`purple10/purple10` $\lambda/\sqsubseteq_c$

"purple 10"/"purple 10" λ/"**who is out front**"

analysis:
generalization: $X \sqsupseteq \texttt{out\_front}(X)$

Qualitative Analysis

- Learned lexical relations from example proof trees

(t, h): (**pink team** is offsides,**purple 9** passes)

$|$ $team_{arg1}$

substitute

`pink team/purple9`

analysis: "pink team"/"purple 9"

relation: `pink team | purple9`

(t, h): (**bad pass..**, **loses the ball to**)

$\sqsubseteq$play-tran

substitute

`bad pass/turnover`

analysis: "bad pass .. picked off by"/"loses the ball to"

relation: `bad pass` $\sqsubseteq$ `turnover`

(t, h): (**free kick for**, **steals the ball from**)

$|$game-play

substitute

`free kick/steal`

analysis: "free kick for"/"steals the ball from"

relation: `free kick| steal`

(t, h): (purple 6 **kicks to**,purple 6 **kicks**)

$\sqsubseteq$play-tran.

substitute

`pass/kick`

analysis: "kicks to"/"kicks'

relation: `pass` $\sqsubseteq$ `kick`

Conclusion

- **Learning from Entailment:** Use entailment information and reasoning to help train semantic parsers.
  - *Improve learning:* learn background knowledge, find gaps.
  - *Evaluation:* provides a new way to evaluate semantic parsers.

Conclusion

- **Learning from Entailment:** Use entailment information and reasoning to help train semantic parsers.
  - *Improve learning:* learn background knowledge, find gaps.
  - *Evaluation:* provides a new way to evaluate semantic parsers.
- **Conceptually:** Make our semantic learner behave more like a semanticist, ground representation decisions in entailments.

Thank You

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