

Bootstrapping Semantic Parsers from Conversations

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Task Oriented Dialog

SYSTEM how can i help you ?

USER i ' d like to go from richmond to atlantic city on june seventh

SYSTEM leaving richmond on thursday, june seventh arriving in atlantic city leaving at what time ?

USER eight a. m.

SYSTEM leaving in the morning what airline would you prefer ?

USER u. s. air

SYSTEM i currently have you leaving richmond on thursday, june seventh in the morning arriving in atlantic city flying on u. s. air . is this correct ?

USER yes

SYSTEM o . k . then . where would you like to go next ?


USER richmond

[conversation continues]

Task Oriented Dialog

SYSTEM: how can i help you?

USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city?  *System fails*

USER: atlanta georgia

SYSTEM: leaving atlanta. going to which city?

USER: london

SYSTEM: arriving in london england. what date would you like to depart atlanta?

USER: september twenty fourth in the early evening

[conversation continues]

Dialog and Semantics

- Many dialog systems use semantic parsers.

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- Supervised learning of such parsers is expensive.

Dialog and Semantics

- Many dialog systems use semantic parsers.
- Supervised learning of such parsers is expensive.
- Can computers learn through raw conversations?

Learning from Conversations

- Human-machine dialogs aim to achieve a **goal**.

Learning from Conversations

- Human-machine dialogs aim to achieve a **goal**.
- A well-defined goal allows the system to **recover** from failures.

System Recovery

SYSTEM:

how can i help you?

USER:

i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

System Recovery

SYSTEM:

how can i help you?

USER:

i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

 *System fails*

System Recovery

SYSTEM: how can i help you?

USER:

i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city?

 *System fails*

System Recovery

SYSTEM: how can i help you?

USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city?

USER: atlanta georgia

System Recovery

SYSTEM: how can i help you?

USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city?

USER: atlanta georgia 

SYSTEM: leaving atlanta. going to which city?

System Recovery

SYSTEM: how can i help you?

USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city?

USER: atlanta georgia 

SYSTEM: leaving atlanta. going to which city?

USER: london

System Recovery

SYSTEM:

how can i help you?

USER:

i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM:

leaving what city?

USER:

atlanta georgia 

SYSTEM:

leaving atlanta. going to which city?

USER:

london 

SYSTEM:

arriving in london england. what date would you like to depart atlanta?

System Recovery

SYSTEM: how can i help you?

USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city?

USER: atlanta georgia ✓

SYSTEM: leaving atlanta. going to which city?

USER: london ✓

SYSTEM: arriving in london england. what date would you like to depart atlanta?

USER: september twenty fourth in the early evening

[conversation continues]

Complex request

Complex request



System fails

Complex request



System fails



Goal

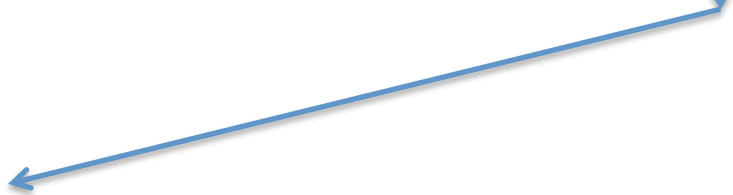
Complex request



System fails



Goal



Specific
information

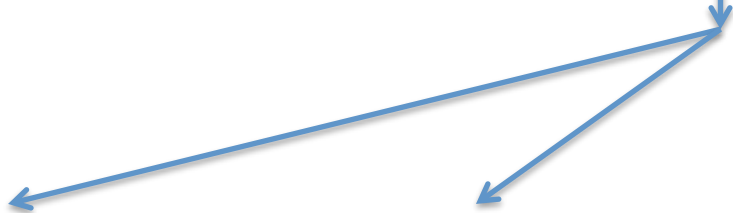
Complex request



System fails



Goal



Specific
information

Clarification

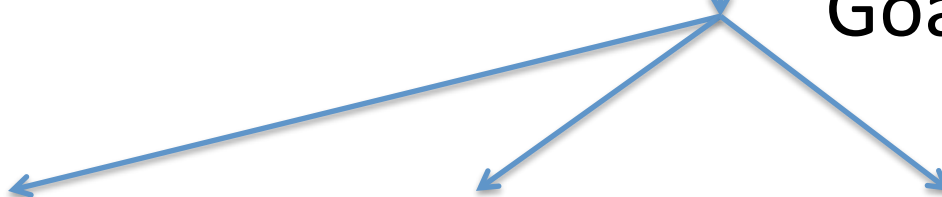
Complex request



System fails



Goal



Specific
information

Clarification

Rewording

Complex request



System fails



Goal



Specific
information



Clarification



Rewording



Additional
explanation

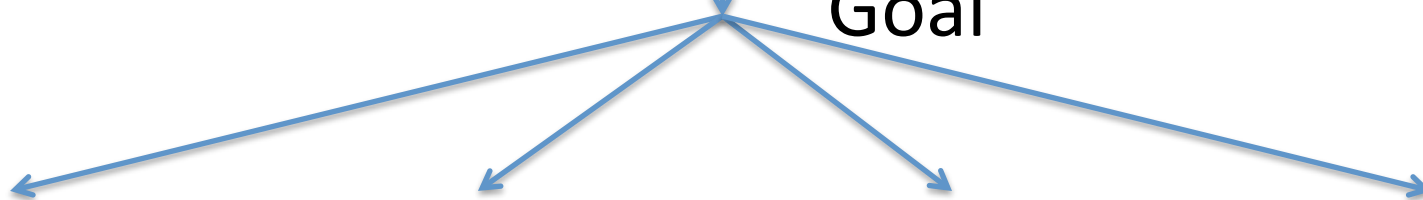
Complex request



System fails



Goal



Specific information

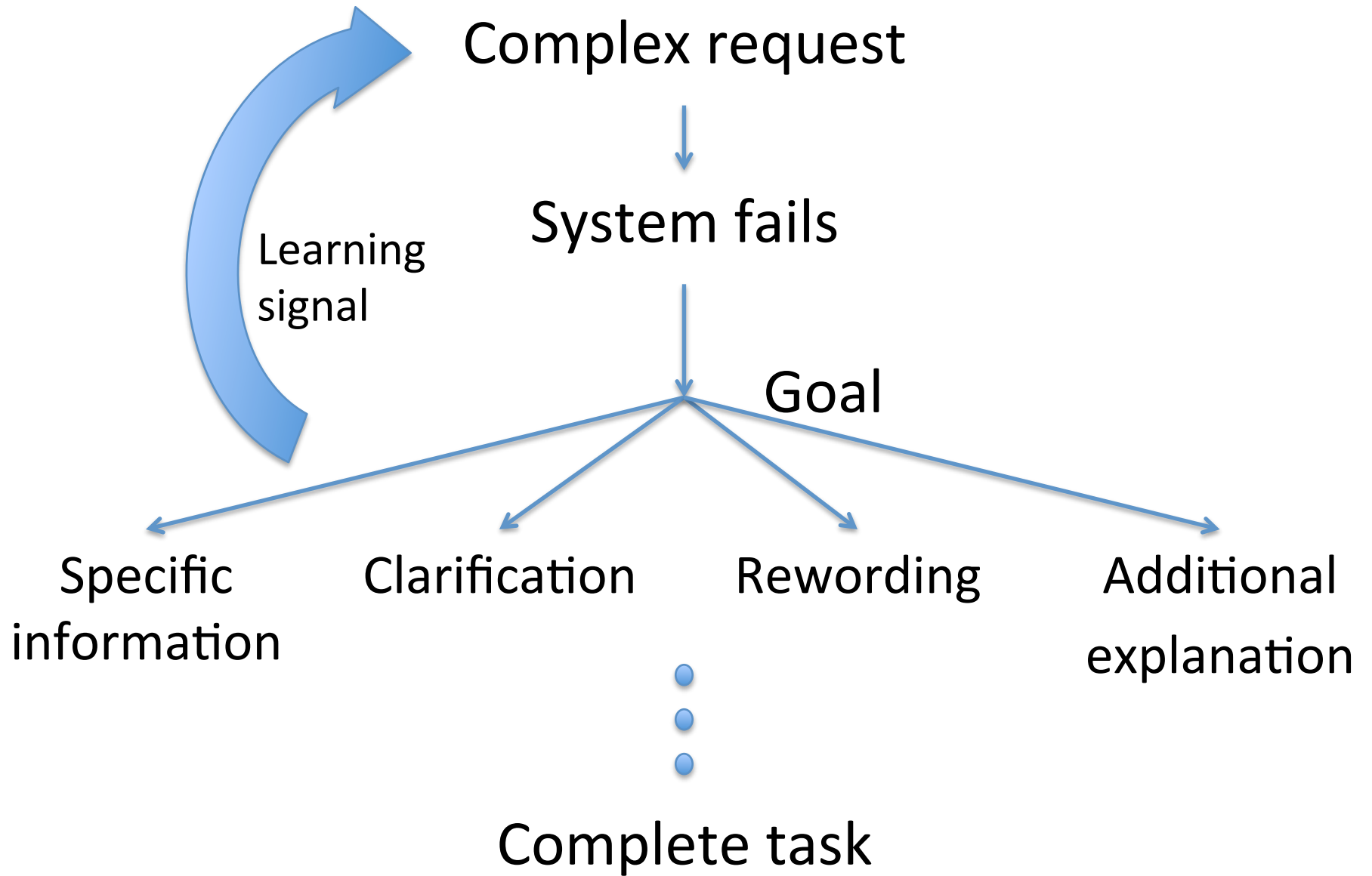
Clarification

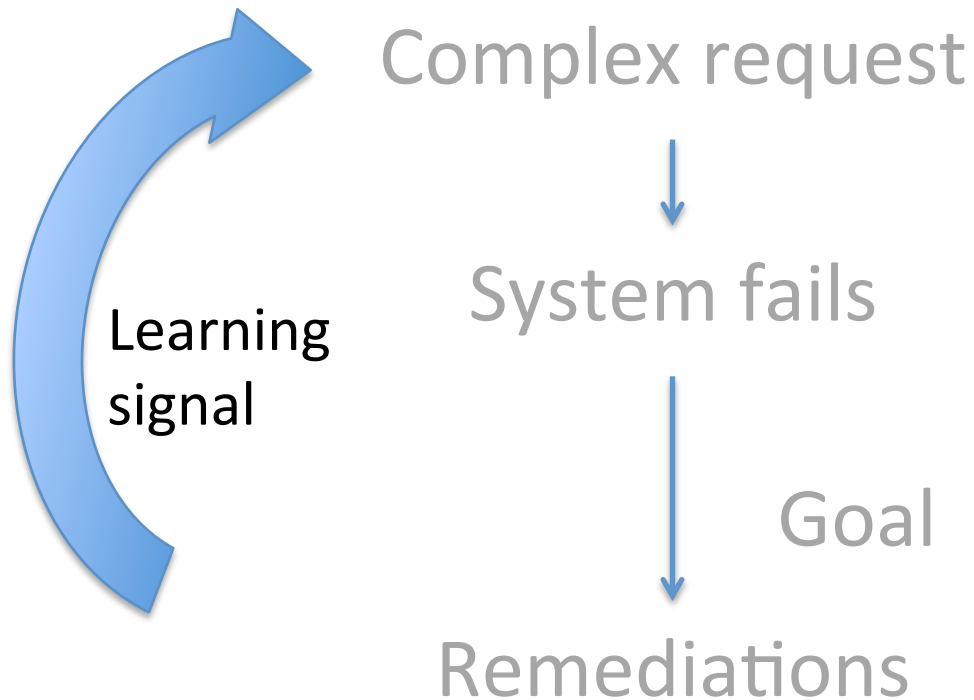
Rewording

Additional explanation



Complete task





Noisy signal:
premature end, goals change, incomplete
recovery etc.

The Problem

- Learn:

$f : \textit{sentence} \rightarrow \lambda\textit{-calculus expression}$

The Problem

- Learn:

$f : \textit{sentence} \rightarrow \lambda\text{-calculus expression}$

I want to go to Seattle on Friday



$\lambda x.to(x, SEA) \wedge date(x, FRI)$

Automatically Annotated Logs

SYSTEM: how can i help you? (**OPEN_TASK**)

USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city? (**ASK: $\lambda x.from(fl, x)$**)

USER: atlanta georgia

SYSTEM: leaving atlanta. (**CONFIRM: $from(fl, ATL)$**) going to which city? (**ASK: $\lambda x.to(fl, x)$**)

USER: london

[conversation continues]

Automatically Annotated Logs

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USER: atlanta georgia

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USER: london

[conversation continues]

System utterance



Automatically Annotated Logs

SYSTEM: how can i help you? (OPEN_TASK)

USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city? (ASK: $\lambda x. from(fl, x)$)

USER: atlanta georgia

SYSTEM: leaving atlanta. (CONFIRM: $from(fl, ATL)$) going to which city? (ASK: $\lambda x. to(fl, x)$)

USER: london

[conversation continues]

System utterance

Natural Language

Automatically Annotated Logs

SYSTEM: how can i help you? (OPEN_TASK)

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SYSTEM: leaving what city? (ASK: $\lambda x. \text{from}(fl, x)$)

USER: atlanta georgia

SYSTEM: leaving atlanta. (CONFIRM: $\text{from}(fl, ATL)$) going to which city? (ASK $\lambda x. \text{to}(fl, x)$)

USER: london

[conversation continues]

System utterance

Natural Language

Speech Act

Automatically Annotated Logs

SYSTEM: how can i help you? (OPEN_TASK)

USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city? (ASK: $\lambda x.from(fl, x)$)

USER: atlanta georgia

SYSTEM: leaving atlanta. (CONFIRM: $from(fl, ATL)$) going to which city? (ASK: $\lambda x.to(fl, x)$)

USER: london

[conversation continues]

System utterance

Natural Language

Speech Act

Logical
Meaning

Automatically Annotated Logs

SYSTEM: how can i help you? (**OPEN_TASK**)

USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

SYSTEM: leaving what city? (**ASK: $\lambda x. from(fl, x)$**)

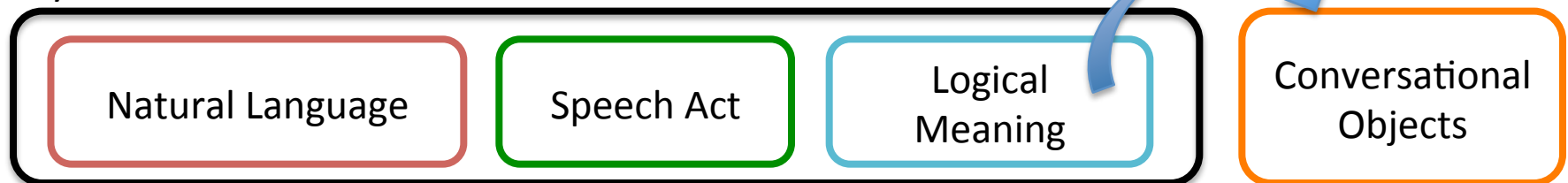
USER: atlanta georgia

SYSTEM: leaving atlanta. (**CONFIRM: $from(fl, ATL)$**) going to which city? (**ASK: $\lambda x. to(fl, x)$**)

USER: london

[conversation continues]

System utterance



Automatically Annotated Logs

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USER: i would like to fly from atlanta georgia to london england on september twenty fourth in the early evening i would like to return on october first departing from london in the late morning

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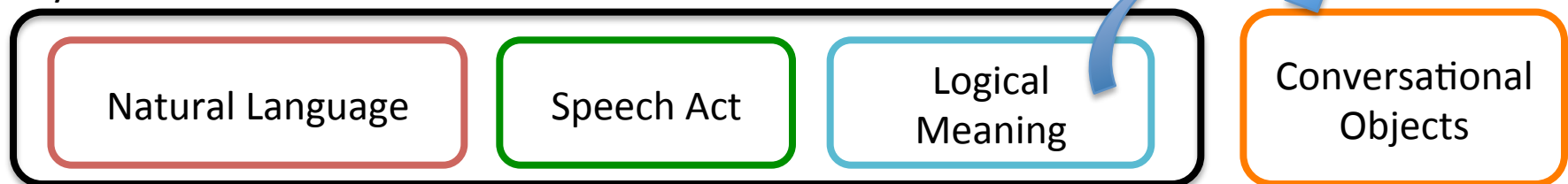
USER: atlanta georgia

SYSTEM: leaving atlanta. (**CONFIRM: $from(fl, ATL)$**) going to which city? (**ASK: $\lambda x. to(fl, x)$**)

USER: london

[conversation continues]

System utterance



Training Set

SYSTEM: how can i help you? (**OPEN_TASK**)

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SYSTEM: leaving atlanta. (**CONFIRM: $from(fl, ATL)$**) going to which city? (**ASK: $\lambda x.to(fl, x)$**)

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[conversation continues]

Training Set

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USER: london

[conversation continues]

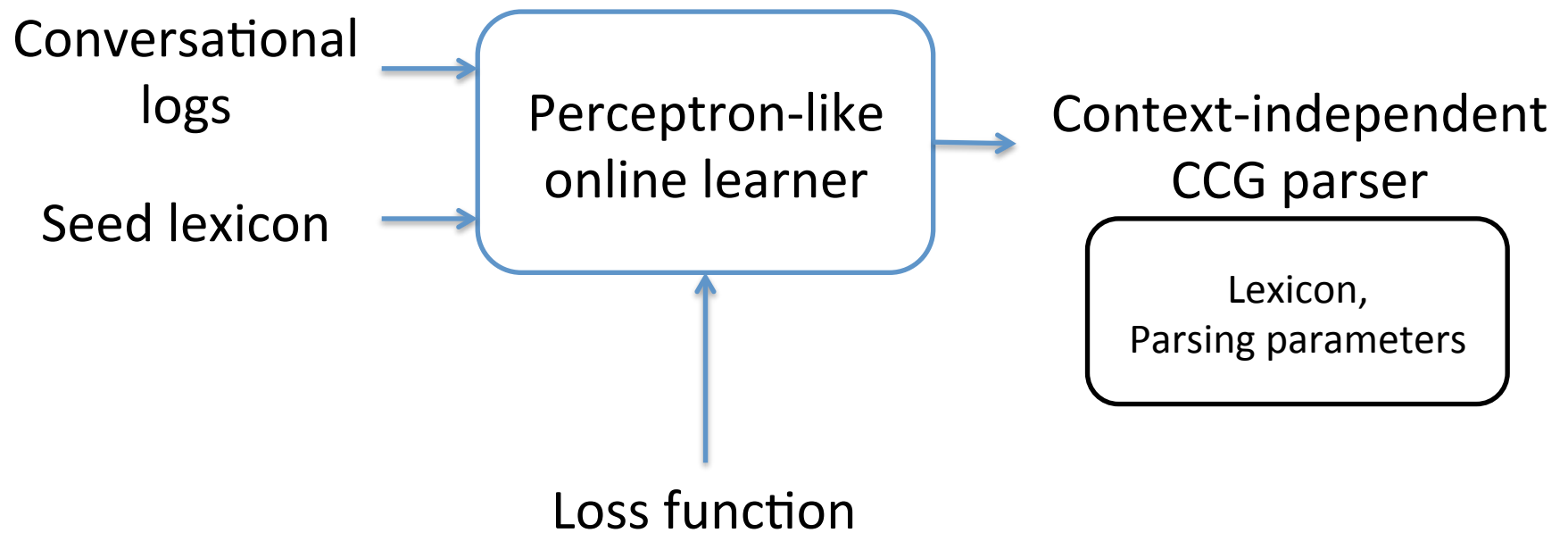
The Problem

- Learn:

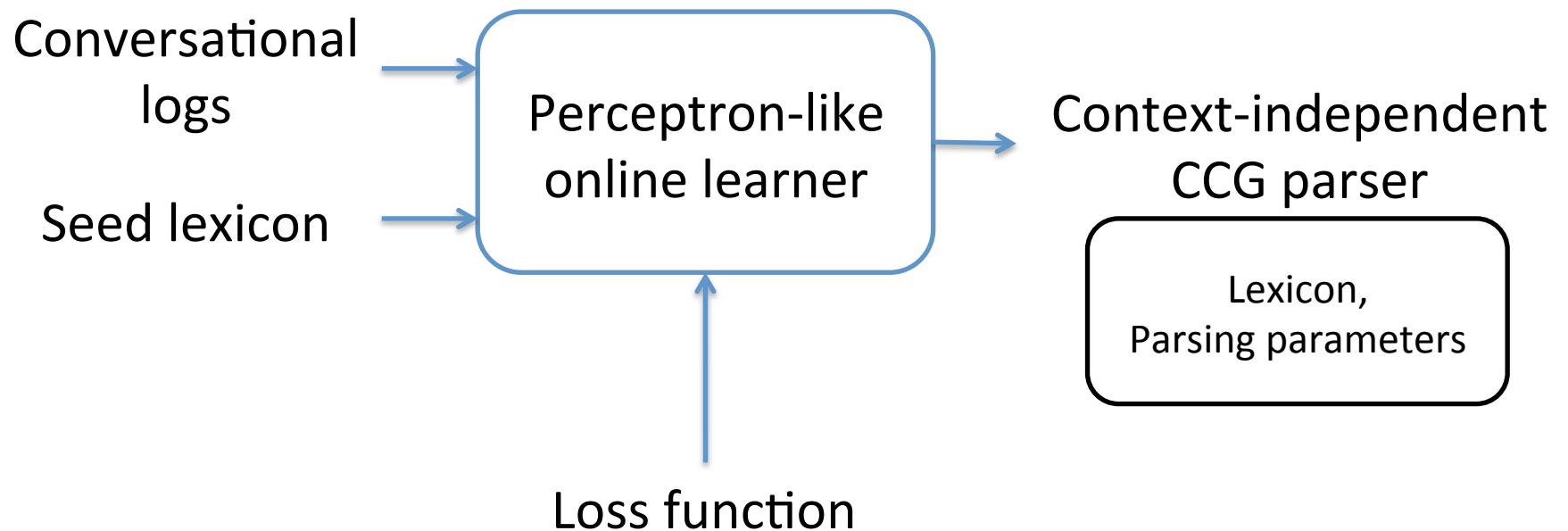
$f : \textit{sentence} \rightarrow \lambda\textit{-calculus expression}$

- Given logs of conversations
 - Automatically annotated system utterances

Our Approach



Our Approach



No direct evidence about the logical forms paired with user utterances

Related Work

Supervised semantic parsing with:

Machine Translation

[Papineni et al. 2007; Ramaswamy, Kleindienst
2000; Wong, Mooney 2006, 2007; Matuszek et al.
2010]

Inducting Logic Programming

[Zelle, Money 1996; Tang, Mooney 2000;
Thompson, Mooney 2002]

Prob. CFG Parsing

[Miller et al. 2006; Ge, Mooney 2006]

Prob. PDA

[He, Young 2005, 2006]

Support Vector Machines

[Kate, Mooney 2006; Nguyen et al. 2006]

Perceptron-style Learning

[Zettlemoyer, Collins 2005, 2007]

Less supervision for database query:

Question-Answers Semi-
supervision

[Clarke et al. 2010, Liang et al. 2011]

Confidence-driven

[Goldwasser et al. 2011]

Unsupervised

In This Work

- Develop an algorithm for bootstrapping semantic parsers from conversations
 - Loss-driven
 - Requires no labeling effort
- Demonstrate effective learning from conversations
- First step towards a long-term goal of autonomous self-learning dialog systems

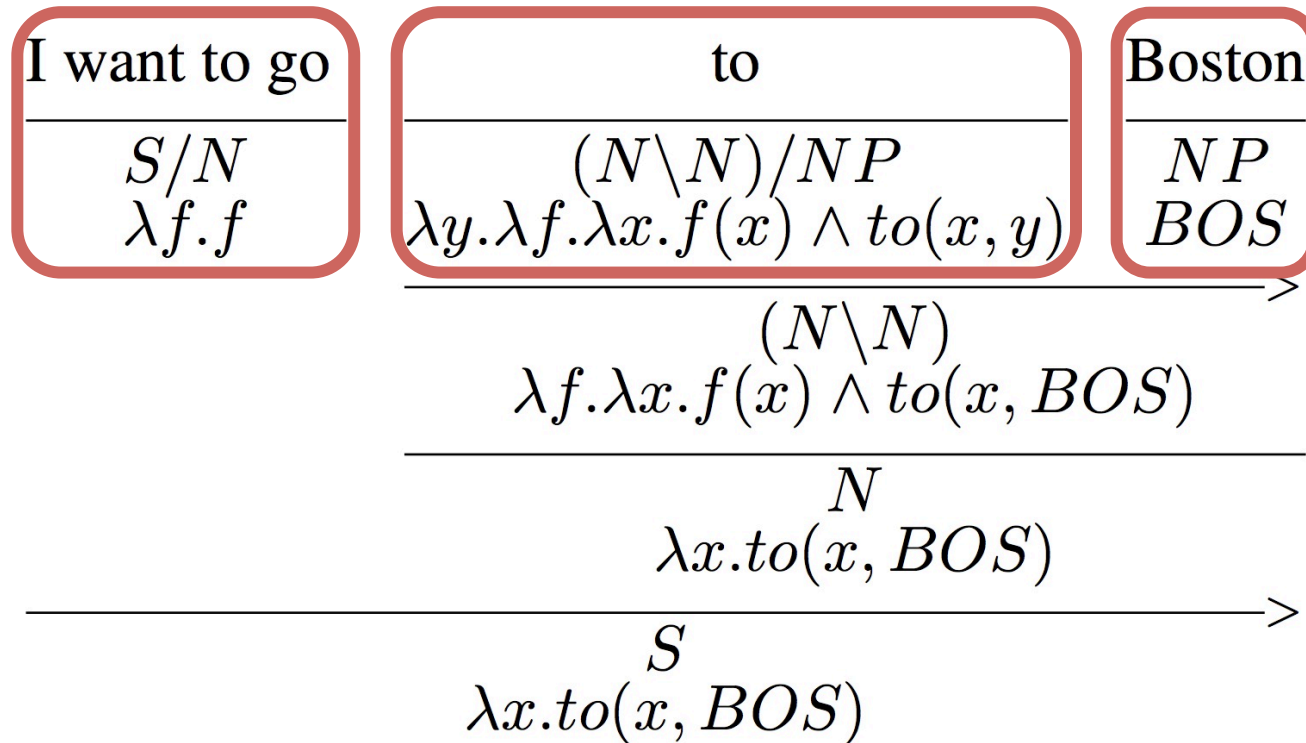
Mapping Sentences to λ -Calculus

- Combinatory Categorical Grammar (CCG)
- Weighted Linear CCGs

Combinatory Categorical Grammar (CCG)

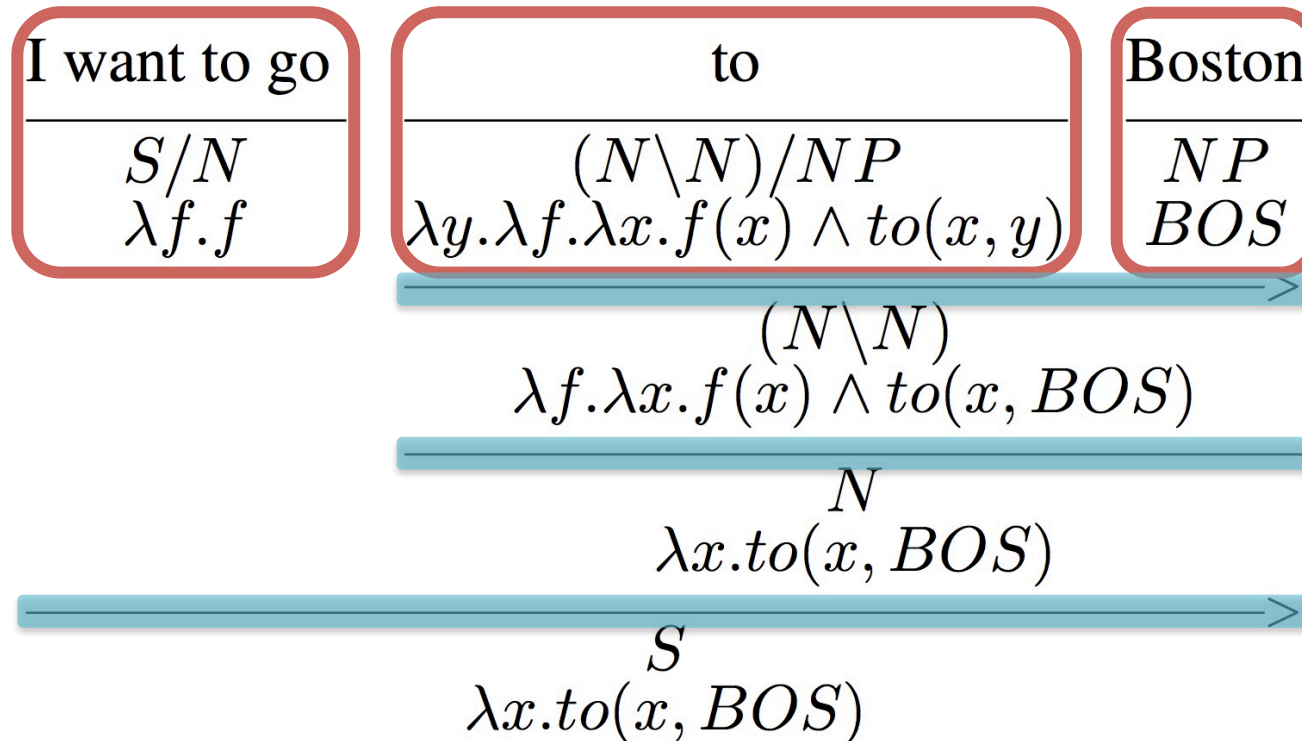
I want to go	to	Boston
S/N	$(N \setminus N)/NP$	NP
$\lambda f.f$	$\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)$	BOS
	\rightarrow	
	$(N \setminus N)$	
	$\lambda f.\lambda x.f(x) \wedge to(x, BOS)$	
	N	
	$\lambda x.to(x, BOS)$	
	\rightarrow	
	S	
	$\lambda x.to(x, BOS)$	

Combinatory Categorical Grammar (CCG)



Lexicon

Combinatory Categorical Grammar (CCG)



Lexicon

Combinators
Application, composition ...

Weighted Linear CCGs

- Given a log-linear model:
 - CCG lexicon Λ
 - Feature vector f
 - Weights w

- The best parse is:

$$y^* = \arg \max_y w \cdot f(x, y)$$

- We consider all possible parses y for sentence x given the lexicon Λ

So Far ...

- General overview of the problem and approach

Next ...

- Indirectly-supervised lexical generation
- Computing loss
- Our learning algorithm
- Evaluation on the DARPA Communicator corpus

Supervised Lexical Induction

Input
Training
Example

Sentence: i'd like to go to los angeles
Logical form: $\lambda x.to(x, LA)$

Output
Lexicon

i'd := $S/N : \lambda x.x$

i'd := $(N \setminus N)/NP : \lambda f.\lambda x.\lambda y.f(x) \wedge to(x, y)$

go to := $(N \setminus N)/NP : \lambda f.\lambda x.\lambda y.f(x) \wedge to(x, y)$

to go to := $(N \setminus N)/NP : \lambda f.\lambda x.\lambda y.f(x) \wedge to(x, y)$

to los := $S/N : \lambda x.x$

...

Supervised Lexical Induction

Input
Training
Example

Sentence: i'd like to go to los angeles

~~Logical form: $\lambda x.to(x, LA)$~~



Output
Lexicon

i'd := $S/N : \lambda x.x$

i'd := $(N \setminus N)/NP : \lambda f.\lambda x.\lambda y.f(x) \wedge to(x, y)$

go to := $(N \setminus N)/NP : \lambda f.\lambda x.\lambda y.f(x) \wedge to(x, y)$

to go to := $(N \setminus N)/NP : \lambda f.\lambda x.\lambda y.f(x) \wedge to(x, y)$

to los := $S/N : \lambda x.x$

...

Indirectly-supervised Lexical Induction

Input
Training
Example

Sentence: i'd like to go to los angeles

Conversation: **SYSTEM:** how can i help you? (**OPEN_TASK**)

USER: i'd like to go to los angeles

SYSTEM: leaving what city? (**ASK:** $\lambda x. \text{from}(fl, x)$)

USER: new york

SYSTEM: leaving new york. (**CONFIRM:** $\text{from}(fl, NYC)$) going to which city?
(**ASK:** $\lambda x. \text{to}(fl, x)$)

USER: los angeles

SYSTEM: flying to los angeles. (**CONFIRM:** $\text{to}(fl, LA)$)

[conversation continues]

Indirectly-supervised Lexical Induction

Input
Training
Example

Sentence: i'd like to go to los angeles

Conversation: **SYSTEM:** how can i help you? (**OPEN_TASK**)

USER: i'd like to go to los angeles

SYSTEM: leaving what city? (**ASK: $\lambda x.from(f, x)$**)

[conversation continues]



Output
Lexicon

$i'd := S/N : \lambda x.x$

$i'd := (N \setminus N)/NP : \lambda f.\lambda x.\lambda y.f(x) \wedge to(x, y)$

$i'd := (N \setminus N)/NP : \lambda f.\lambda x.\lambda y.f(x) \wedge from(x, y)$

...

Indirectly-supervised Lexical Induction

Input
Training
Example

Sentence: i'd like to go to los angeles

Conversation: **SYSTEM:** how can i help you? (**OPEN_TASK**)

USER: i'd like to go to los angeles

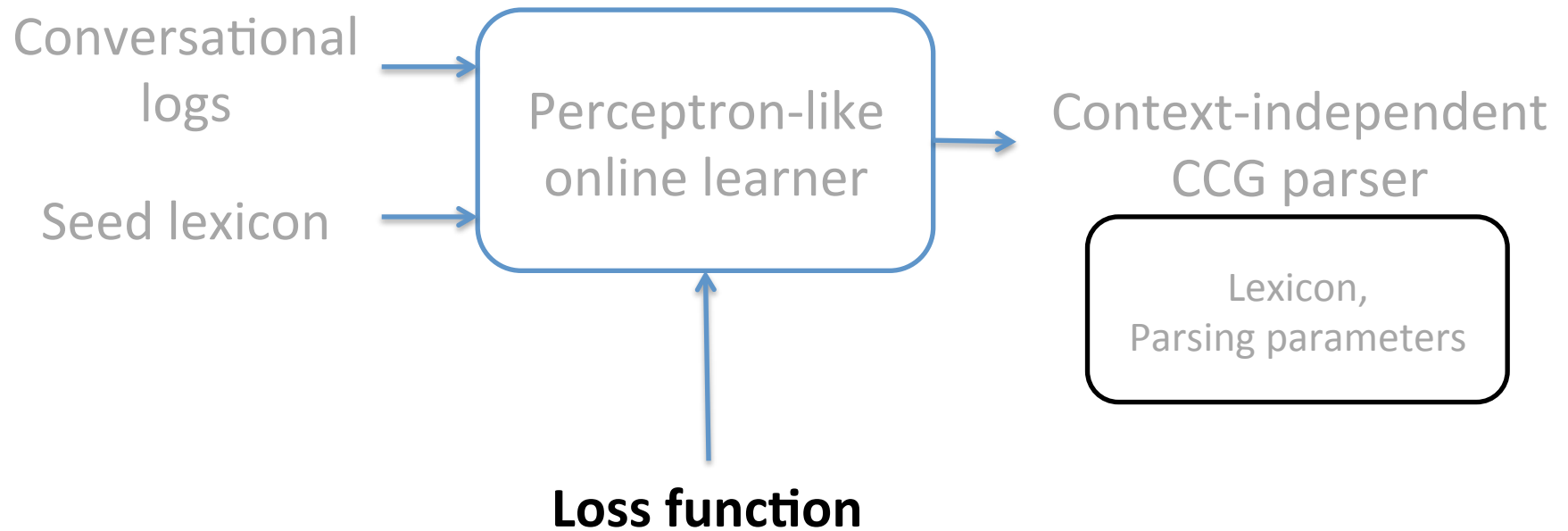
SYSTEM: leaving what city? (**ASK:** $\lambda x. from$
 $(f!, x)$)

[conversation continues]

Output
Lexicon

- Overgeneralized
- **Incomplete**

Loss-guided Learning



Supervised Case

i want to fly from new york to los angeles

$$\lambda x. \textit{from}(x, NYC) \wedge \textit{to}(x, LA)$$

Loss Signal Instead of Labels

$$\mathcal{L} : \langle z, \mathcal{C} \rangle \rightarrow \mathbb{R}$$

i want to fly from new york to los angeles

Loss Signal Instead of Labels

$$\mathcal{L} : \langle z, \mathcal{C} \rangle \rightarrow \mathbb{R}$$

i want to fly from new york to los angeles

$$\lambda x. \text{from}(x, NYC) \wedge \text{to}(x, LA)$$

$$\lambda x. \text{from}(x, NYC) \wedge \text{from}(x, LA)$$

$$\lambda x. \text{from}(x, LA)$$

$$\lambda x []. \text{to}(x[0], NYC) \wedge \text{from}(x[1], LA)$$

...

Loss Signal Instead of Labels

$$\mathcal{L} : \langle z, \mathcal{C} \rangle \rightarrow \mathbb{R}$$

i want to fly from new york to los angeles

-1.8 $\lambda x. \text{from}(x, NYC) \wedge \text{to}(x, LA)$

2.0 $\lambda x. \text{from}(x, NYC) \wedge \text{from}(x, LA)$

-0.9 $\lambda x. \text{from}(x, LA)$

1.5 $\lambda x []. \text{to}(x[0], NYC) \wedge \text{from}(x[1], LA)$

...

Loss Signal Instead of Labels

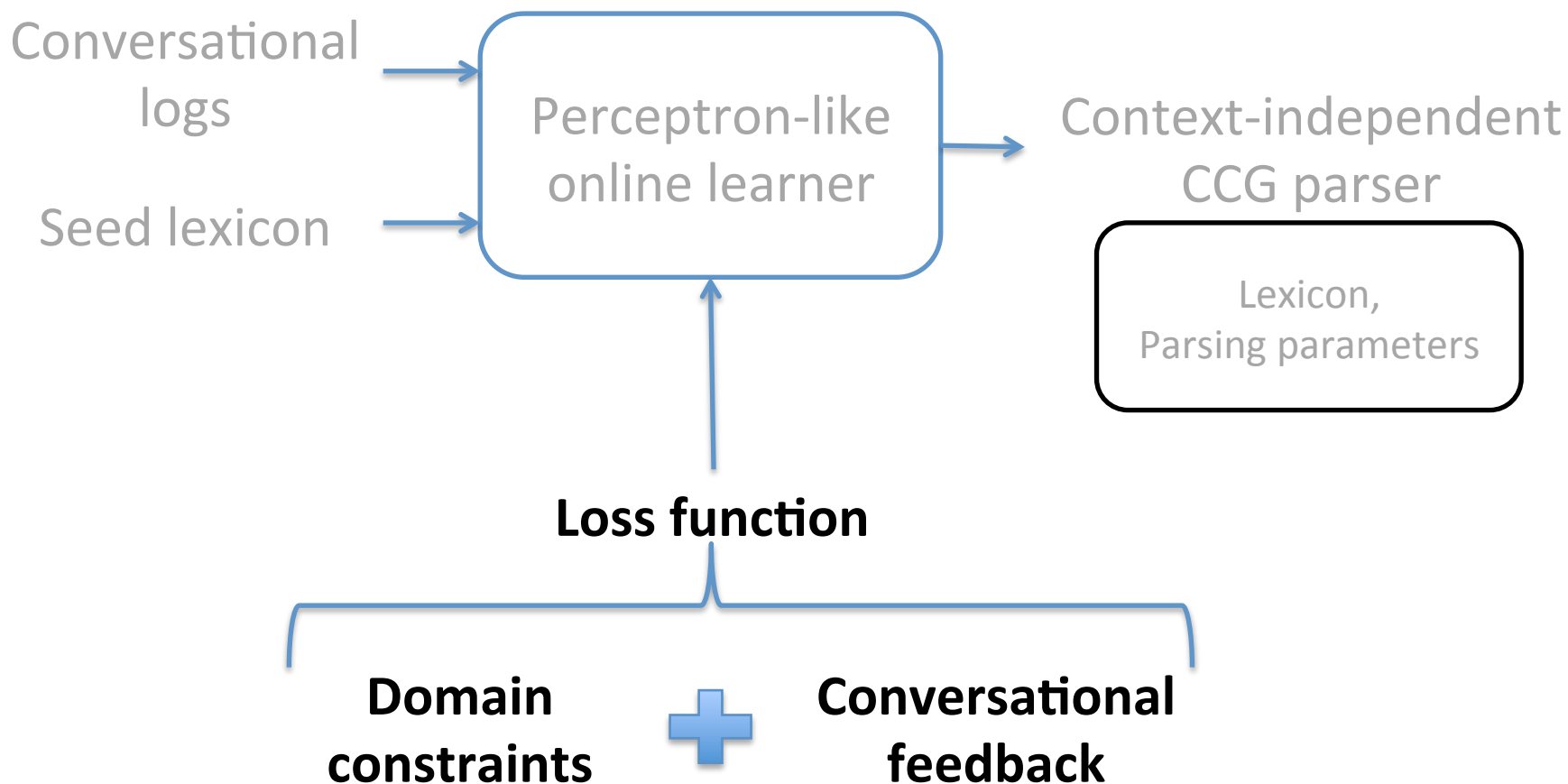
$$\mathcal{L} : \langle z, \mathcal{C} \rangle \rightarrow \mathbb{R}$$

i want to fly from new york to los angeles

- 1 -1.8 $\lambda x. \text{from}(x, NYC) \wedge \text{to}(x, LA)$
- 4 2.0 $\lambda x. \text{from}(x, NYC) \wedge \text{from}(x, LA)$
- 2 -0.9 $\lambda x. \text{from}(x, LA)$
- 3 1.5 $\lambda x []. \text{to}(x[0], NYC) \wedge \text{from}(x[1], LA)$

...

Loss Decomposition



Conversation Loss

- Provides rough indication of how well a logical expression represents a user utterance
- Based on system understanding

Computing Conversation Loss

1. Select the relevant subset of system utterances
2. Align the logical expression to content from selected system utterances
3. Score the alignment

Conversation Loss

SYSTEM: how can i help you (OPEN_TASK)

USER: i want to fly from new york to los angeles

SYSTEM: from new york. (CONFIRM: $from(fl, NYC)$) to where? (ASK: $\lambda x.to(fl, x)$)

USER: los angeles

SYSTEM: flying to los angeles. (CONFIRM: $to(fl, LA)$) where do you want to go from los angeles? ? (ASK: $\lambda x.to(fl2, x) \wedge from(fl2, LA)$)

USER: back to new york

SYSTEM: from los angeles to new york
(CONFIRM: $from(fl2, LA) \wedge to(fl2, NYC)$)

SYSTEM: i have a direct flight from new york to los angeles for \$480. ok? (OFFER: $direct(fl) \wedge from(fl, NYC) \wedge to(fl, LA) \wedge cost(fl, 480)$)

[conversation continues]

Segmenting

SYSTEM: how can i help you (OPEN_TASK)

USER: i want to fly from new york to los angeles

SYSTEM: from new york. (CONFIRM: *from(fl, NYC)*) to where? (ASK: $\lambda x.to(fl, x)$)

USER: los angeles

SYSTEM: flying to los angeles. (CONFIRM: *to(fl, LA)*) where do you want to go from los angeles? ? (ASK: $\lambda x.to(fl2, x) \wedge from(fl2, LA)$)

USER: back to new york

SYSTEM: from los angeles to new york
(CONFIRM: *from(fl2, LA) \wedge to(fl2, NYC)*)

SYSTEM: i have a direct flight from new york to los angeles for \$480. ok? (OFFER: *direct(fl) \wedge from(fl, NYC) \wedge to(fl, LA) \wedge cost(fl, 480)*)

[conversation continues]

Extract Properties

SYSTEM: how can i help you (OPEN_TASK)

USER: i want to fly from new york to los angeles

SYSTEM: from new york. (CONFIRM: *from(f1, NYC)*) to where? (ASK: $\lambda x.to(f1, x)$)

USER: los angeles

SYSTEM: flying to los angeles. (CONFIRM: *to(f1, LA)*) where do you want to go from los angeles? ? (ASK: $\lambda x.to(f12, x) \wedge from(f12, LA)$)

USER: back to new york

SYSTEM: from los angeles to new york (CONFIRM: *from(f12, LA) \wedge to(f12, NYC)*)

SYSTEM: i have a direct flight from new york to los angeles for \$480. ok? (OFFER: $direct(f1) \wedge from(f1, NYC) \wedge to(f1, LA) \wedge cost(f1, 480)$)

[conversation continues]



Property

(from, f1, NYC)

Extract Properties

SYSTEM: how can i help you (OPEN_TASK)

USER: i want to fly from new york to los angeles

SYSTEM: from new york. (CONFIRM: *from(f1, NYC)*) to where? (ASK: $\lambda x.to(f1, x)$)

USER: los angeles

SYSTEM: flying to los angeles. (CONFIRM: *to(f1, LA)*) where do you want to go from los angeles? ? (ASK: $\lambda x.to(f12, x) \wedge from(f12, LA)$)

USER: back to new york

SYSTEM: from los angeles to new york (CONFIRM: *from(f12, LA)* / *to(f12, NYC)*)

SYSTEM: i have a direct flight from new york to los angeles for \$480. ok? (OFFER: $direct(f1) \wedge from(f1, NYC) \wedge to(f1, LA) \wedge cost(f1, 480)$)

[conversation continues]



Property

(*from, f1, NYC*)

(*to, f1, LA*)

(*from, f12, LA*)

(*to, f12, NYC*)

Extract Properties

SYSTEM: how can i help you (OPEN_TASK)

USER: i want to fly from new york to los angeles

SYSTEM: from new york. (CONFIRM: $from(f1, NYC)$) to where? (ASK: $\lambda x.to(f1, x)$)

USER: los angeles

SYSTEM: flying to los angeles. (CONFIRM: $to(f1, LA)$) where do you want to go from los angeles? ? (ASK: $\lambda x.to(f12, x) \wedge from(f12, LA)$)

USER: back to new york

SYSTEM: from los angeles to new york (CONFIRM: $from(f12, LA) \wedge to(f12, NYC)$)

SYSTEM: i have a direct flight from new york to los angeles for \$480. ok? (OFFER: $direct(f1) \wedge from(f1, NYC) \wedge to(f1, LA) \wedge cost(f1, 480)$)

[conversation continues]



<u>Property</u>	<u>Loss</u>
$(from, f1, NYC)$	-0.5
$(to, f1, LA)$	-0.83
$(from, f12, LA)$	-0.16
$(to, f12, NYC)$	-0.16

Given a Candidate Logical Expression

USER: i want to fly from new york to los angeles

$\lambda x. from(x, NYC) \wedge to(x, LA)$

<u>Property</u>	<u>Loss</u>
$(from, fl, NYC)$	-0.5
(to, fl, LA)	-0.83
$(from, fl2, LA)$	-0.16
$(to, fl2, NYC)$	-0.16

Align

USER: i want to fly from new york to los angeles

$\lambda x. \text{from}(x, \text{NYC}) \wedge \text{to}(x, \text{LA})$

Alignment: $x \rightarrow fl$

<u>Property</u>	<u>Loss</u>
$(\text{from}, fl, \text{NYC})$	-0.5
$(\text{to}, fl, \text{LA})$	-0.83
$(\text{from}, fl2, \text{LA})$	-0.16
$(\text{to}, fl2, \text{NYC})$	-0.16

Match

USER: i want to fly from new york to los angeles

$\lambda x. \text{from}(x, \text{NYC}) \wedge \text{to}(x, \text{LA})$

Alignment: $x \rightarrow fl$

<u>Property</u>	<u>Loss</u>
$(\text{from}, fl, \text{NYC})$	-0.5
$(\text{to}, fl, \text{LA})$	-0.83
$(\text{from}, fl2, \text{LA})$	-0.16
$(\text{to}, fl2, \text{NYC})$	-0.16

Score

USER: i want to fly from new york to los angeles

$\lambda x. \text{from}(x, \text{NYC}) \wedge \text{to}(x, \text{LA})$

Alignment: $x \rightarrow fl$

$Loss = -0.5 - 0.83 = -1.33$

Property	Loss
$(\text{from}, fl, \text{NYC})$	-0.5
$(\text{to}, fl, \text{LA})$	-0.83
$(\text{from}, fl2, \text{LA})$	-0.16
$(\text{to}, fl2, \text{NYC})$	-0.16

Align and Score

USER: i want to fly from new york to los angeles

$\lambda x. \text{from}(x, NYC) \wedge \text{to}(x, LA)$

Alignment: $x \rightarrow fl$

$$\text{Loss} = -0.5 - 0.83 = -1.33$$

<u>Property</u>	<u>Loss</u>
(from, fl, NYC)	-0.5
(to, fl, LA)	-0.83
$(\text{from}, fl2, LA)$	-0.16
$(\text{to}, fl2, NYC)$	-0.16

$\lambda x []. \text{from}(x[0], NYC) \wedge \text{from}(x[1], LA)$

Alignment: $x[0] \rightarrow fl, x[1] \rightarrow fl2$

$$\text{Loss} = -0.5 - 0.16 = -0.66$$

Comparing Two Candidates

USER: i want to fly from new york to los angeles

$\lambda x. \text{from}(x, NYC) \wedge \text{to}(x, LA)$ ✓

Alignment: $x \rightarrow fl$

$$Loss = -0.5 - 0.83 = -1.33$$

<u>Property</u>	<u>Loss</u>
(from, fl, NYC)	-0.5
(to, fl, LA)	-0.83
$(\text{from}, fl2, LA)$	-0.16
$(\text{to}, fl2, NYC)$	-0.16

$\lambda x []. \text{from}(x[0], NYC) \wedge \text{from}(x[1], LA)$ ✗

Alignment: $x[0] \rightarrow fl, x[1] \rightarrow fl2$

$$Loss = -0.5 - 0.16 = -0.66$$

- So far:
 - Showed how to generate lexicon using the conversation
 - Introduced our sources of loss
- Next:
 - Combine everything into a Perceptron-like learning algorithm

Learning Algorithm

- Online
- Loss-driven
- 2 steps:
 - Lexical generation
 - Parameter update [Singh-Miller and Collins 2007]

Learning Algorithm

For T iterations, for each training sample:

- Step 1: Lexical generation
 - Generate a large lexicon from system utterances
 - Parse with the generated lexicon using the model
 - Get the minimal loss parses from the k-best parses
 - Add their lexical items to the lexicon
- Step 2: Update parameters

Learning Algorithm

For T iterations, for each training sample:

- Step 1: Lexical generation
- Step 2: Update parameters
 - Parse using the model
 - Split all parses into two sets using the loss function: optimal and non-optimal
 - Find model score violations between the sets
 - Do a perceptron update using these violations

Evaluation

- Dataset
- Experimental setup
- Evaluation metrics
- Systems and results

DARPA Communicator

- Raw conversational logs [Walker et al. 2002]
- Annotated system utterances

	Lucent		BBN	
	Train	Test	Train	Test
Conversations	144	70	71	91
Context Independent Utterances	208	96	67	67

Experimental Setup

- Features similar to Zettlemoyer and Collins 2007:
 - Indicators for lexical item use
 - Indicators for parsing operators use
 - Properties of the logical form
- Seed lexicon:
 - Domain independent
 - “and”, “the” ...
 - List of domain-specific noun phrases
 - “new york”, “jfk”, “delta” ...
- Learning parameters optimized on training data

Evaluation Metrics

- Performance against gold standard:
 - Exact match
 - Partial credit

Sentence: i want to return from seattle to boston

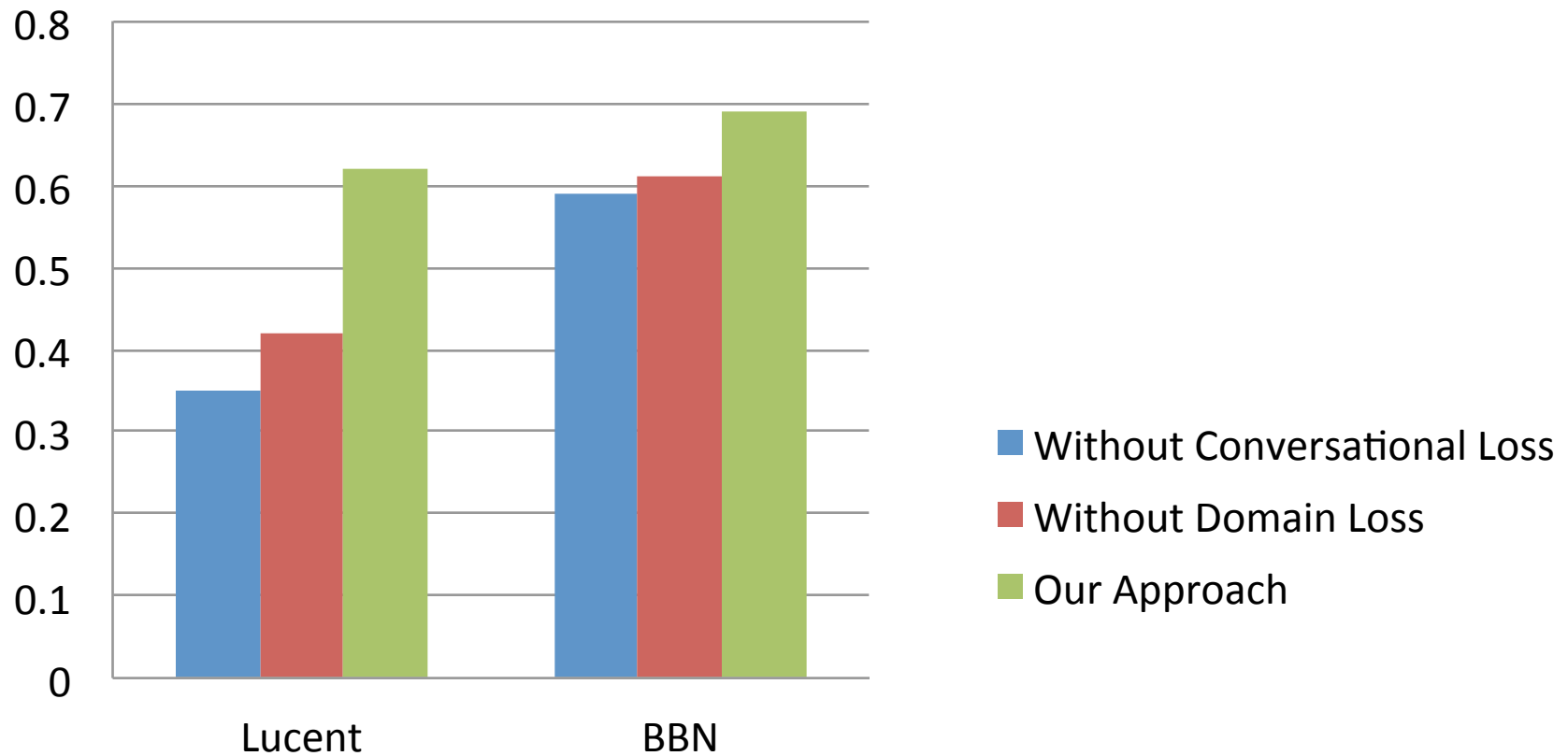
Label: $\lambda x.to(x, BOS) \wedge from(x, SEA) \wedge return(x)$

Guess: $\lambda x.to(x, BOS) \wedge from(x, SEA)$ **X**

Partial Credit	Recall	Precision
	2/3	2/2

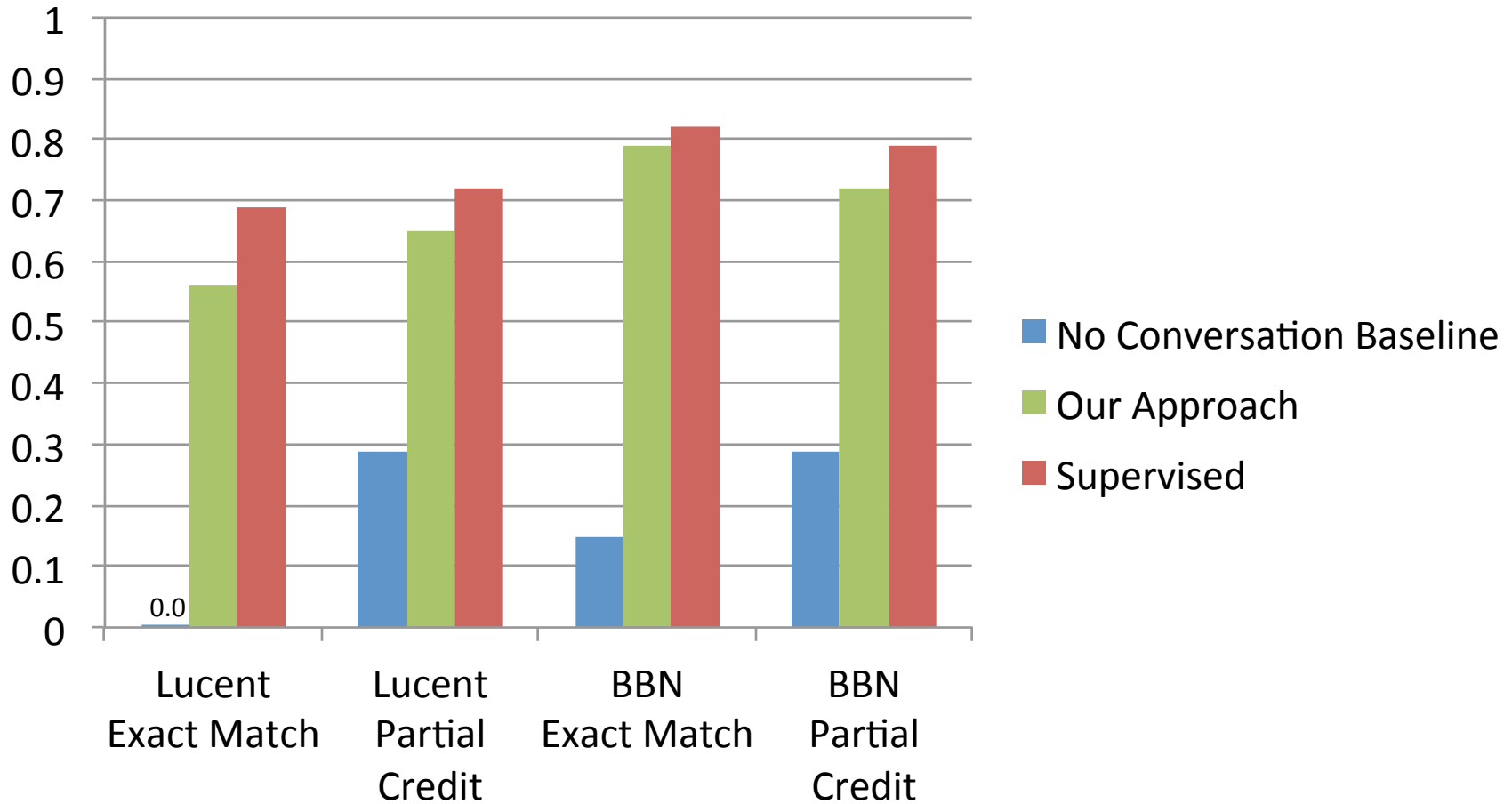
Results: Ablation Tests

Development Set Results
Exact Match, F1 Measure



Results: Evaluation Data

F1 Measure



Future Work

- Reason about context-dependent meaning
- Model and recover speech acts
- Combine in a complete self-improving dialog system

Contributions

- Developed a loss-driven learning approach for semantic parsers
- Demonstrated learning of semantic parsers from conversational logs
- Described a learning approach that will allow dialog systems to learn from failures

Contributions

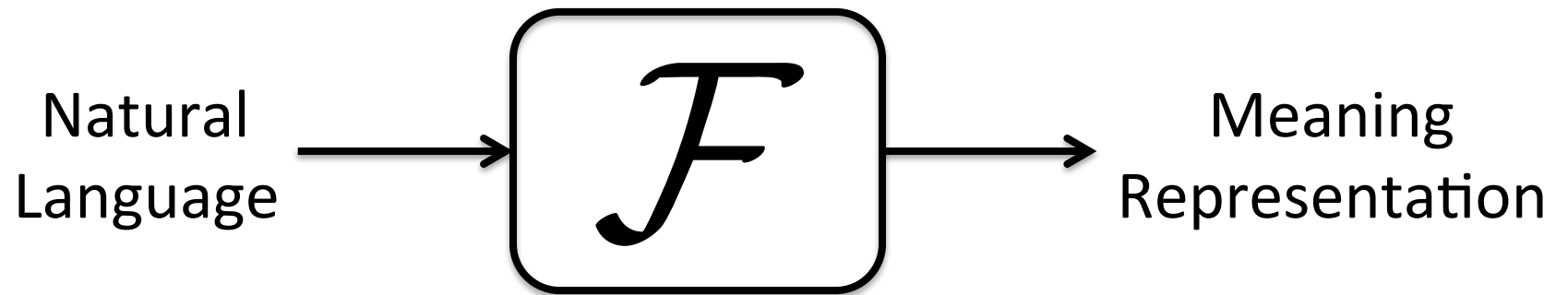
- Developed a loss-driven learning approach for semantic parsers
- Demonstrated learning of semantic parsers from conversational logs
- Described a learning approach that will allow dialog systems to learn from failures

Thanks for listening

[Empty slide]

Supplementary Slides

Semantic Parsing



Context-Dependent vs. Context-Independent

SYSTEM hello , evaluation user . welcome to the bell labs travel reservation system . i have a tutorial explaining my new features . if you ' d like to hear it , just ask me for the tutorial . how can i help you ?

USER i ' d like to go from richmond to atlantic city on june seventh

SYSTEM leaving richmond on thursday, june seventh arriving in kansas city leaving at what time ?

USER eight a. m.

SYSTEM leaving in the morning what airline would you prefer ?

USER u. s. air

SYSTEM i currently have you leaving richmond on thursday, june seventh in the morning arriving in kansas city flying on u. s. air . is this correct ?

USER yes

SYSTEM o . k . then . where would you like to go next ?

USER richmond

[conversation continues]

Parsing with CCGs

i'd like to go

from

seattle

to

denver

Parsing with CCGs

i'd like to go	from	seattle	to	denver
$\frac{S/N}{\lambda f.f}$	$\frac{(N \setminus N)/NP}{\lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y)}$	$\frac{NP}{SEA}$	$\frac{(N \setminus N)/NP}{\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)}$	$\frac{NP}{DEN}$

Lexicon



Parsing with CCGs

$\frac{\text{i'd like to go}}{S/N}$	$\frac{\text{from}}{(N \setminus N) / NP}$	$\frac{\text{seattle}}{NP}$	$\frac{\text{to}}{(N \setminus N) / NP}$	$\frac{\text{denver}}{NP}$
$\lambda f.f$	$\lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y)$	SEA	$\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)$	DEN

Lexicon

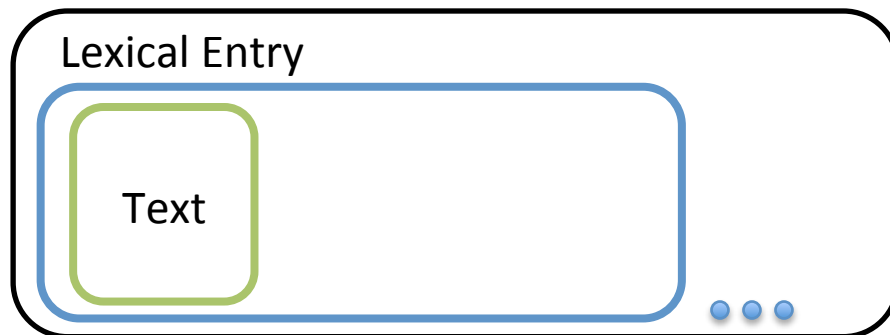
Lexical Entry

...

Parsing with CCGs

i'd like to go	from	seattle	to	denver
S/N	$(N \setminus N)/NP$	NP	$(N \setminus N)/NP$	NP
$\lambda f.f$	$\lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y)$	SEA	$\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)$	DEN

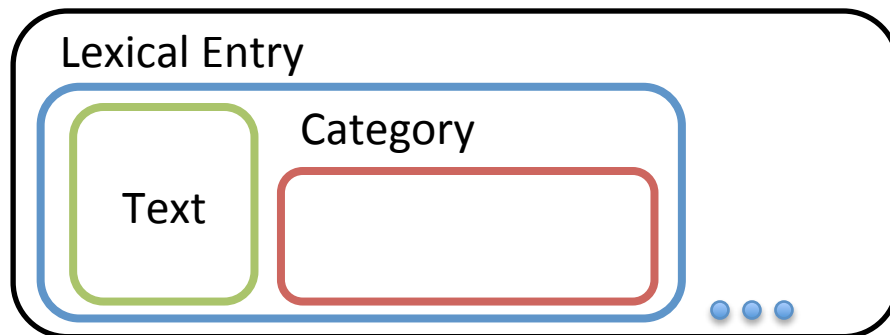
Lexicon



Parsing with CCGs

i'd like to go	from	seattle	to	denver
S/N	$(N \setminus N)/NP$	NP	$(N \setminus N)/NP$	NP
$\lambda f.f$	$\lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y)$	SEA	$\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)$	DEN

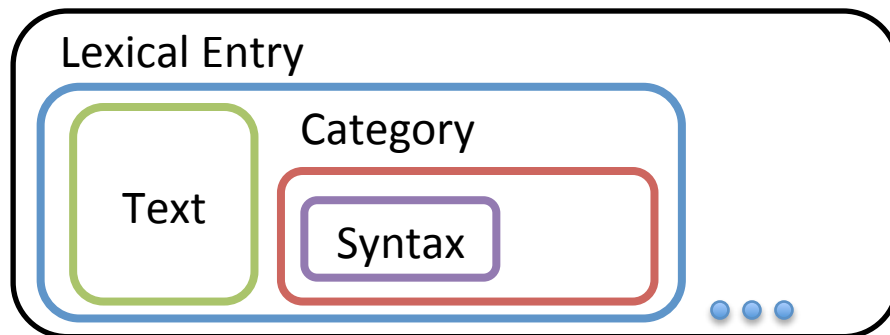
Lexicon



Parsing with CCGs

i'd like to go	from	seattle	to	denver
S/N	$(N \setminus N)/NP$	NP	$(N \setminus N)/NP$	NP
$\lambda f.f$	$\lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y)$	SEA	$\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)$	DEN

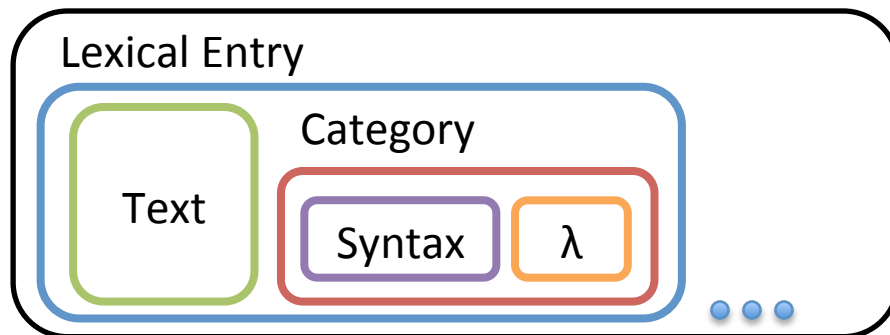
Lexicon



Parsing with CCGs

i'd like to go	from	seattle	to	denver
S/N	$(N \setminus N)/NP$	NP	$(N \setminus N)/NP$	NP
$\lambda f.f$	$\lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y)$	SEA	$\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)$	DEN

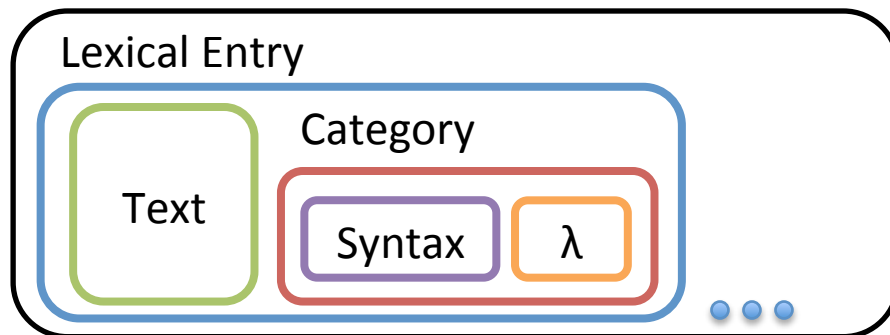
Lexicon



Parsing with CCGs

i'd like to go	from	seattle	to	denver
S/N	$(N \setminus N)/NP$	NP	$(N \setminus N)/NP$	NP
$\lambda f.f$	$\lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y)$	SEA	$\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)$	DEN

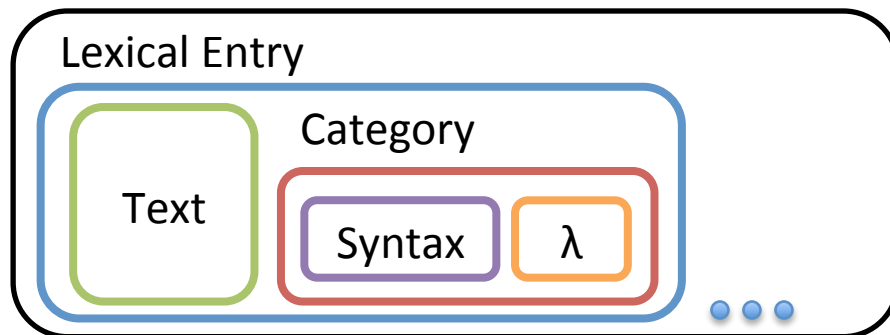
Lexicon



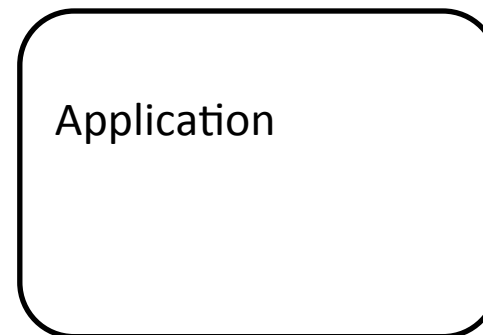
Parsing with CCGs

i'd like to go	from	seattle	to	denver
S/N	$(N \setminus N)/NP$	NP	$(N \setminus N)/NP$	NP
$\lambda f.f$	$\lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y)$	SEA	$\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)$	DEN
			$(N \setminus N)$	$\lambda f.\lambda x.f(x) \wedge to(x, DEN)$

Lexicon



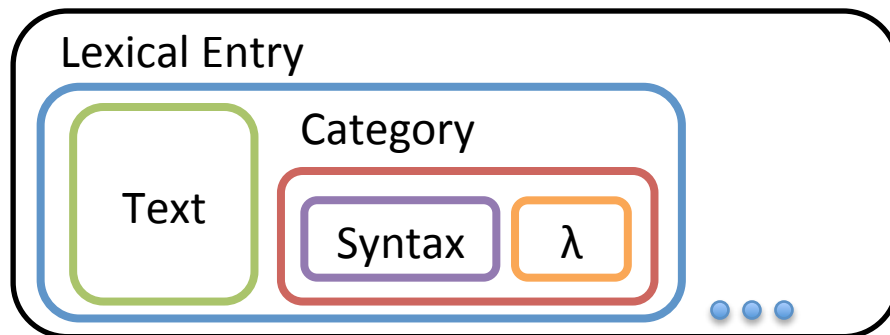
Combinators



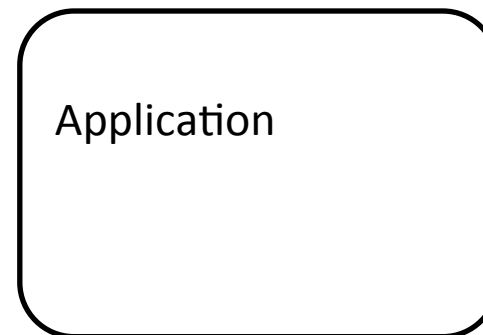
Parsing with CCGs

i'd like to go	from	seattle	to	denver
S/N	$(N \setminus N)/NP$	NP	$(N \setminus N)/NP$	NP
$\lambda f.f$	$\lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y)$	SEA	$\lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y)$	DEN
	$(N \setminus N)$ $\lambda f.\lambda x.f(x) \wedge from(x, SEA)$	>	$(N \setminus N)$ $\lambda f.\lambda x.f(x) \wedge to(x, DEN)$	>

Lexicon



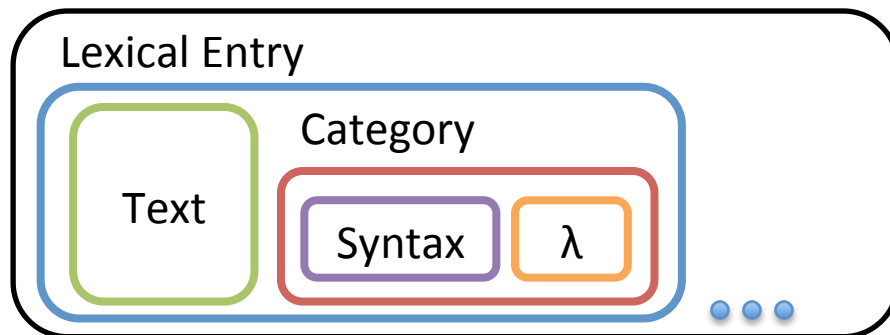
Combinators



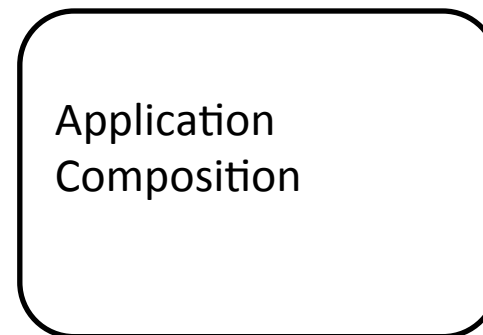
Parsing with CCGs

$$\begin{array}{c}
 \frac{\text{i'd like to go}}{S/N} \quad \frac{\text{from}}{(N \setminus N)/NP} \quad \frac{\text{seattle}}{NP} \quad \frac{\text{to}}{(N \setminus N)/NP} \quad \frac{\text{denver}}{NP} \\
 \lambda f.f \quad \lambda y.\lambda f.\lambda x.f(x) \wedge \text{from}(x, y) \quad SEA \quad \lambda y.\lambda f.\lambda x.f(x) \wedge \text{to}(x, y) \quad DEN \\
 \hline
 \frac{\lambda f.\lambda x.f(x) \wedge \text{from}(x, SEA)}{(N \setminus N)} \quad \frac{\lambda f.\lambda x.f(x) \wedge \text{to}(x, DEN)}{(N \setminus N)} \\
 \hline
 \lambda f.\lambda x.f(x) \wedge \text{from}(x, SEA) \wedge \text{to}(x, DEN) \quad \leftarrow B
 \end{array}$$

Lexicon



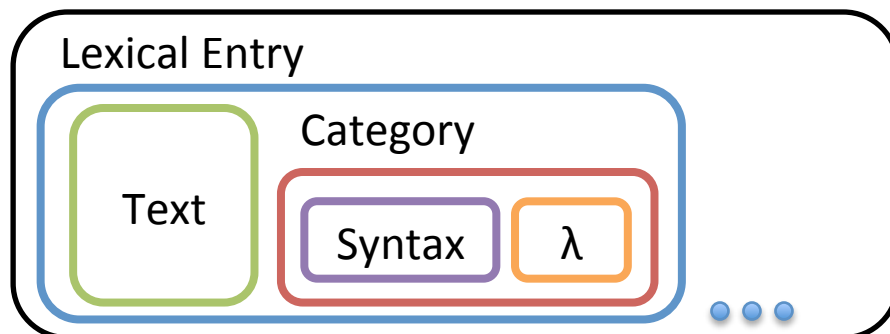
Combinators



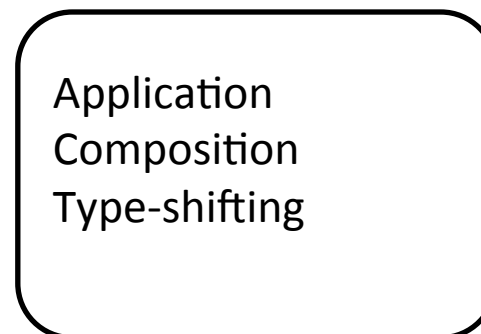
Parsing with CCGs

$$\begin{array}{c}
 \frac{\text{i'd like to go}}{S/N} \quad \frac{\text{from}}{(N \setminus N)/NP} \quad \frac{\text{seattle}}{NP} \quad \frac{\text{to}}{(N \setminus N)/NP} \quad \frac{\text{denver}}{NP} \\
 \lambda f.f \quad \lambda y.\lambda f.\lambda x.f(x) \wedge \text{from}(x, y) \quad SEA \quad \lambda y.\lambda f.\lambda x.f(x) \wedge \text{to}(x, y) \quad DEN \\
 \hline
 \frac{\lambda f.\lambda x.f(x) \wedge \text{from}(x, SEA)}{(N \setminus N)} \quad \frac{\lambda f.\lambda x.f(x) \wedge \text{to}(x, DEN)}{(N \setminus N)} \\
 \hline
 \frac{\lambda f.\lambda x.f(x) \wedge \text{from}(x, SEA) \wedge \text{to}(x, DEN)}{N \setminus N} \\
 \hline
 \frac{\lambda x.\text{from}(x, SEA) \wedge \text{to}(x, DEN)}{N}
 \end{array}$$

Lexicon



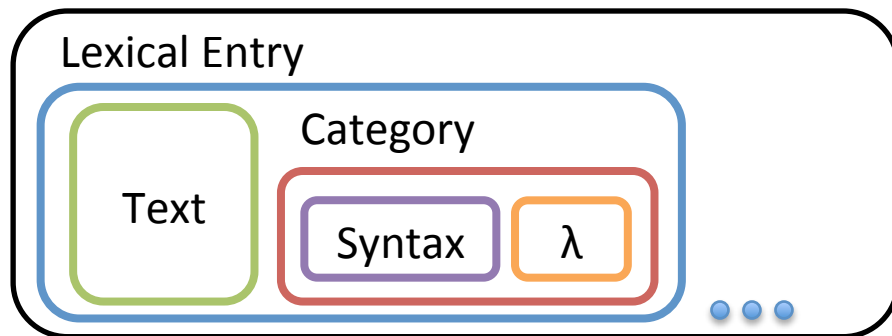
Combinators



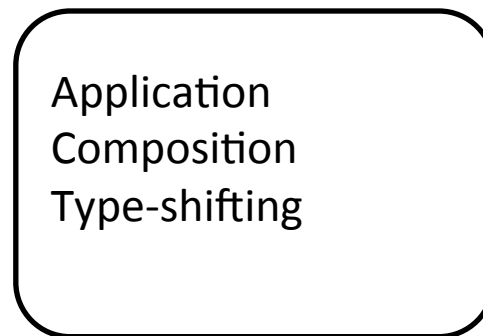
Parsing with CCGs

$$\begin{array}{c}
 \frac{\text{i'd like to go}}{S/N} \quad \frac{\text{from}}{(N \setminus N)/NP} \quad \frac{\text{seattle}}{NP} \quad \frac{\text{to}}{(N \setminus N)/NP} \quad \frac{\text{denver}}{NP}}{\lambda f.f \quad \lambda y.\lambda f.\lambda x.f(x) \wedge from(x, y) \quad SEA \quad \lambda y.\lambda f.\lambda x.f(x) \wedge to(x, y) \quad DEN}}{\lambda f.\lambda x.f(x) \wedge from(x, SEA) \quad \lambda f.\lambda x.f(x) \wedge to(x, DEN)} \begin{array}{l} > \\ > \\ <B \end{array} \\
 \frac{\lambda f.\lambda x.f(x) \wedge from(x, SEA) \wedge to(x, DEN)}{N \setminus N} \\
 \frac{\lambda x.from(x, SEA) \wedge to(x, DEN)}{N} \\
 \frac{\lambda x.from(x, SEA) \wedge to(x, DEN)}{S}
 \end{array}$$

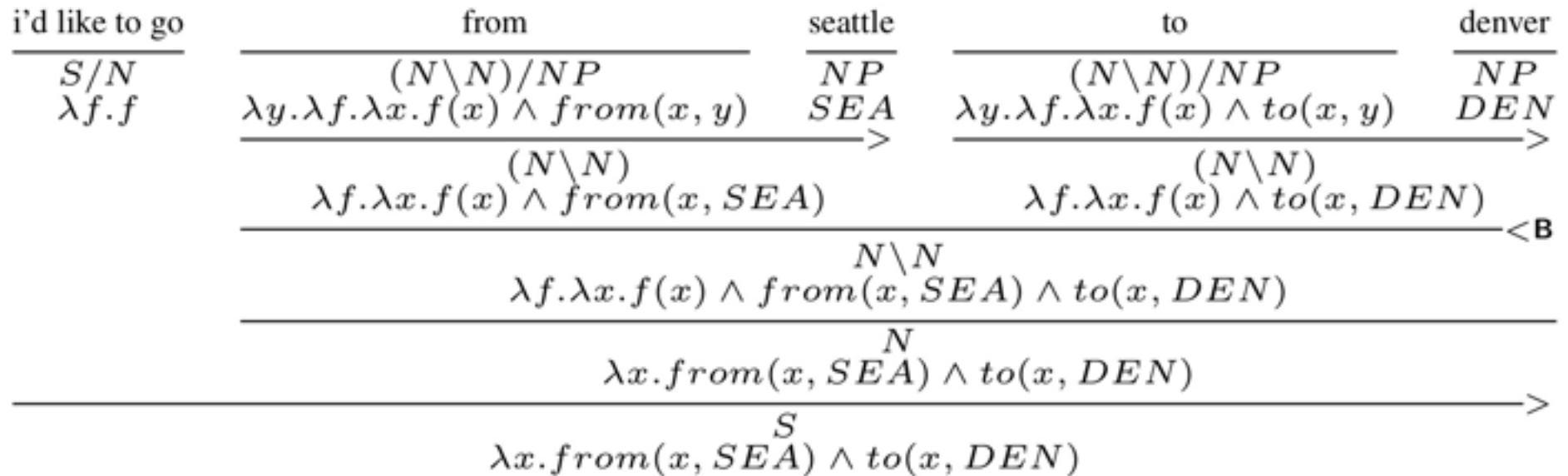
Lexicon



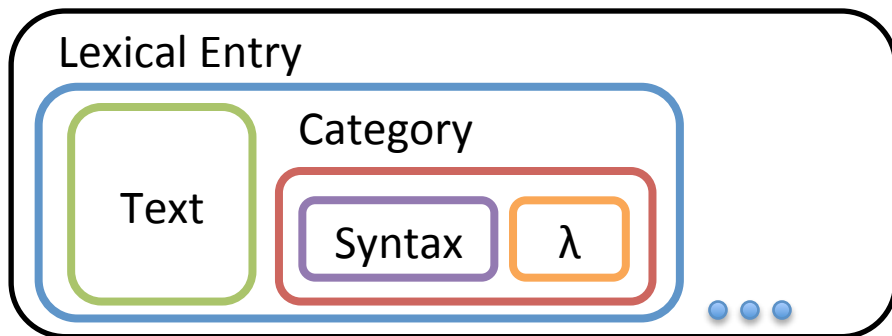
Combinators



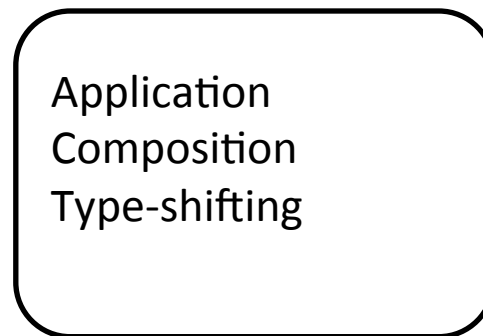
Parsing with CCGs



Lexicon



Combinators



Supervised Lexical Learning with GENLEX

Input
Training
Example

Sentence: i'd like to go to los angeles

Logical form: $\lambda x.to(x,LA)$

Supervised Lexical Learning with GENLEX

Input
Training
Example

Sentence: i'd like to go to los angeles
Logical form: $\lambda x.to(x,LA)$



Output
Lexicon

Supervised Lexical Learning with GENLEX

Input
Training
Example

Sentence: i'd like to go to los angeles
Logical form: $\lambda x.to(x,LA)$



Output
Lexicon

All possible sub-strings:

i'd
like
i'd like
to go to
to los
...

X

Categories created by rules
triggered from the logical form:

S/N : $\lambda x.x$
N\N/NP : $\lambda x. \lambda y. \lambda z.y(z) \wedge to(z,x)$
...

Supervised Lexical Learning with GENLEX

Input
Training
Example

Sentence: i'd like to go to los angeles

~~Logical form: $\lambda x.to(x,LA)$~~



Output
Lexicon

All possible sub-strings:

i'd
like
i'd like
to go to
to los
...

X

Categories created by rules
triggered from the logical form:

S/N : $\lambda x.x$
N\N/NP : $\lambda x. \lambda y. \lambda z.y(z) \wedge to(z,x)$
...

Indirectly-supervised Lexical Learning with GENLEX

Input
Training
Example

Sentence: i'd like to go to los angeles

Conversation: **SYSTEM:** how can i help you? (**OPEN_TASK**)

USER: i'd like to go to los angeles

SYSTEM: leaving what city? (**ASK:** $\lambda x. \text{from}(fl, x)$)

USER: new york

SYSTEM: leaving new york. (**CONFIRM:** $\text{from}(fl, NYC)$) going to which city? (**ASK:** $\lambda x. \text{to}(fl, x)$)

USER: los angeles

SYSTEM: flying to los angeles. (**CONFIRM:** $\text{to}(fl, LA)$)

[conversation continues]

Indirectly-supervised Lexical Learning with GENLEX

Input
Training
Example

Sentence: i'd like to go to los angeles

Conversation: **SYSTEM:** how can i help you? (**OPEN_TASK**)

USER: i'd like to go to los angeles

SYSTEM: leaving what city? (**ASK:** λx **from**
 (fl, x))

USER: new york

SYSTEM: leaving new york. (**CONFIRM:**
from (fl, NYC)) going to which city?
(**ASK:** λx **to** fl, x)

USER: los angeles

SYSTEM: flying to los angeles. (**CONFIRM:**
to fl, LA)

[conversation continues]

Use logical
constants from
system utterances
as triggers

Indirectly-supervised Lexical Learning with GENLEX

Input
Training
Example

Sentence: i'd like to go to los angeles

Conversation: **SYSTEM:** how can i help you? (OPEN_TASK)

USER: i'd like to go to los angeles

SYSTEM: leaving what city? (ASK: λx from (f, x))

[conversation continues]

Output
Lexicon



All possible sub-strings:

i'd
like
i'd like
to go to
to los
...

Categories created by rules
triggered from the logical form:

S/N : $\lambda x.x$
N\N/NP : $\lambda x. \lambda y. \lambda z.y(z) \wedge to(z,x)$
N\N/NP : $\lambda x. \lambda y. \lambda z.y(z) \wedge from(z,x)$
...

X

Indirectly-supervised Lexical Learning with GENLEX

Generated Lexicon is:

- Overgeneralized
- **Incomplete**

Output
Lexicon

All possible sub-strings:

i'd
like
i'd like
to go to
to los
...

X

Categories created by rules
triggered from the logical form:

S/N : $\lambda x.x$
N\N/NP : $\lambda x. \lambda y. \lambda z.y(z) \wedge to(z,x)$
N\N/NP : $\lambda x. \lambda y. \lambda z.y(z) \wedge from(z,x)$
...

Results: Ablation Tests

Development Set Results

Exact Match Metric	Lucent			BBN		
	Prec.	Recall	F1	Prec.	Recall	F1
Without conversational loss	0.35	0.34	0.35	0.66	0.54	0.59
Without domain loss	0.42	0.42	0.42	0.69	0.56	0.61
Our approach	0.63	0.61	0.62	0.77	0.64	0.69

Results: Evaluation Data

Exact Match Metric	Lucent			BBN		
	Prec.	Recall	F1	Prec.	Recall	F1
No conversations baseline	0	0	0	0.16	0.15	0.15
Our approach	0.58	0.55	0.56	0.85	0.75	0.79
Supervised method	0.7	0.68	0.69	0.87	0.78	0.82

Partial Credit Metric	Lucent			BBN		
	Prec.	Recall	F1	Prec.	Recall	F1
No conversations baseline	0.26	0.35	0.29	0.26	0.33	0.29
Our approach	0.68	0.63	0.65	0.97	0.57	0.72
Supervised method	0.75	0.68	0.72	0.96	0.68	0.79