Learning to Map Context-Dependent Sentences to Executable Formal Queries

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Context-Dependent Language Understanding

• **Our goal:** language understanding in long interactions

• Prior work in semantic parsing, language to code focuses on sentences in isolation

• How can we make use of interaction history when interpreting later utterances?
Context-Dependent Language Understanding

User  Show me flights from Seattle to Boston next Monday
Context-Dependent Language Understanding

User: Show me flights from Seattle to Boston next Monday
Context-Dependent Language Understanding

**User**

Show me flights from Seattle to Boston next Monday

**SQL Query**

```
(SELECT DISTINCT flight.flight_id FROM flight WHERE
  (flight.from_airport IN (SELECT airport_service.airport_code
   FROM airport_service WHERE airport_service.city_code IN
   (SELECT city.city_code FROM city WHERE city.city_name = 'SEATTLE')))
  AND (flight.to_airport IN (SELECT airport_service.airport_code
   FROM airport_service WHERE airport_service.city_code IN
   (SELECT city.city_code FROM city WHERE city.city_name = 'BOSTON')))
  AND (flight.flight_days IN (SELECT days.days_code FROM days
   WHERE days.day_name IN (SELECT date_day.day_name FROM
   date_day WHERE date_day.year = 1993 AND
   date_day.month_number = 2 AND date_day.day_number = 8))));
```
Context-Dependent Language Understanding

**User** Show me flights from Seattle to Boston next Monday

**Result**
Found 31 Flights:
Context-Dependent Language Understanding

User  On American Airlines

Result  Found 2764 Flights:
Context-Dependent Language Understanding

User: Show me flights from Seattle to Boston next Monday

Result: Found 31 Flights:

User: On American Airlines

Result: Found 5 Flights:
Context-Dependent Language Understanding

User: Show me flights from Seattle to Boston next Monday

Result: Found 31 Flights:

User: On American Airlines

Result: Found 5 Flights:

User: Which ones arrive after 7pm?

Result: No flights found.
Context-Dependent Language Understanding

User: Show me flights from Seattle to Boston next Monday

Result: Found 31 Flights:

User: On American Airlines

Result: Found 5 Flights:

User: Which ones arrive after 7pm?

Result: No flights found.

User: Show me Delta flights

Result: Found 5 Flights:
Context-Independent Prior Work

- **Semantic parsing**
  

- **Language to code**


- **Our approach: language understanding in interaction context**
## Context-Dependent Prior Work

<table>
<thead>
<tr>
<th><strong>SCONE</strong> (Long et al. 2016): micro domains focused on specific interaction phenomena</th>
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<tbody>
<tr>
<td>Guu et al. 2017, Fried et al. 2018, Suhr et al. 2018</td>
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<tr>
<th><strong>ATIS</strong> (Hemphill et al. 1990, Dahl et al. 1994):</th>
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<tr>
<td>Miller et al. 1996, Zettlemoyer and Collins 2009</td>
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Use different representations; extra training & annotation.

- Our approach: single end-to-end model using only interaction data
Interaction History

• As an interaction progresses, the meaning of an utterance becomes highly dependent on the history of the interaction

• History includes both previous requests and generated SQL queries

• Two mechanisms
Incorporating Previous Requests

User: Show me all flights from Boston to Pittsburgh on Wednesday of next week which depart from Boston after 5pm

User: Please describe the class of service Y

User: Show the cost of tickets on flight US 345
Incorporating Previous Requests

• Relevant but elided information was mentioned many turns before

• User may change focus during interaction

• **Solution:** implicit mechanism for carrying information from beginning to end of interaction
Incorporating Previous Queries

User

Show me flights from Seattle to Boston next Monday

SQL Query

(SELECT DISTINCT flight.flight_id FROM flight WHERE
(flight.from_airport IN (SELECT airport_service.airport_code
FROM airport_service WHERE airport_service.city_code IN
(SELECT city.city_code FROM city WHERE city.city_name =
'SEATTLE'))) AND (flight.to_airport IN (SELECT
airport_service.airport_code FROM airport_service WHERE
airport_service.city_code IN (SELECT city.city_code FROM
city WHERE city.city_name = 'BOSTON'))) AND
(flight.flight_days IN (SELECT days.days_code FROM days
WHERE days.day_name IN (SELECT date_day.day_name FROM
date_day WHERE date_day.year = 1993 AND
date_day.month_number = 2 AND date_day.day_number = 8))));
Incorporating Previous Queries

User

On American Airlines

SQL Query

(SELECT DISTINCT flight.flight_id FROM flight WHERE
(flight.airline_code = 'AA') AND (flight.from_airport IN
(SELECT airport_service.airport_code FROM airport_service
WHERE airport_service.city_code IN (SELECT city.city_code
FROM city WHERE city.city_name = 'SEATTLE'))) AND
(flight.to_airport IN (SELECT airport_service.airport_code
FROM airport_service WHERE airport_service.city_code IN
(SELECT city.city_code FROM city WHERE city.city_name =
'BOSTON'))) AND (flight.flight_days IN (SELECT days.days_code
FROM days WHERE days.day_name IN (SELECT date_day.day_name
FROM date_day WHERE date_day.year = 1993 AND
date_day.month_number = 2 AND date_day.day_number = 8)))));
Incorporating Previous Queries

- Segments corresponding to earlier constraints appear in later queries

- **Solution:** explicit mechanism for composing later SQL queries from segments of previous ones
Model Overview

Show me flights from Seattle to Boston next Monday
Model Overview

Show me flights from Seattle to Boston next Monday

On American Airlines
Model Overview

Show me flights from Seattle to Boston next Monday

On American Airlines

Mechanism 1 Previous Requests: Turn-level Encoder
Show me flights from Seattle to Boston next Monday

On American Airlines

Mechanism 1
Mechanism 2

Previous Requests: Turn-level Encoder
Previous Queries: Query Segment Copying
Turn-level Encoder

Show me flights from Seattle to Boston next Monday

On American Airlines

Mechanism 1 Previous Requests: Turn-level Encoder
Turn-level Encoder

1. State Update

Encoded request → RNN Update → Discourse-level vector state

Show me flights from Seattle to Boston next Monday
2. Using State

On American Airlines
Turn-level Encoder

- Persistent vector state, updated throughout interaction
- Encode information from beginning to end of interaction
- Completely learned

Show me flights from Seattle to Boston next Monday

On American Airlines
Show me flights from Seattle to Boston next Monday

On American Airlines

Query Segment Copying

Previous Queries: Query Segment Copying

Mechanism 2
Query Segment Copying

Previous Query:
(SELECT DISTINCT flight.flight_id FROM flight
WHERE (flight.from_airport IN (SELECT
airport_service.airport_code FROM airport_service
WHERE airport_service.city_code IN (SELECT
city.city_code FROM city WHERE city.city_name =
...)

1. Segment Extraction

city.city_name = 'SEATTLE'
city.city_name = 'BOSTON'
date_day.year = 1993
date_day.month_number = 2
date_day.day_number = 8

Deterministic, operates on the SQL tree
Previous Query:
(SELECT DISTINCT flight.flight_id FROM flight
WHERE (flight.from_airport IN (SELECT airport_service.airport_code FROM airport_service
WHERE airport_service.city_code IN (SELECT city.city_code FROM city WHERE city.city_name = 'SEATTLE'))

2. Segment Encoding

... WHERE city.city_name = 'SEATTLE' ...
3. Generating Query Segments

Probability of query segment computed using its vector state
Query Segment Copying

- Explicit mechanism for copying previous constraints
- Encoding and generating segments learned with the rest of the model
Inference

Show me flights from Seattle to Boston next Monday
Inference

Show me flights from Seattle to Boston next Monday
Inference

Show me flights from Seattle to Boston next Monday

On American Airlines
Inference

Show me flights from Seattle to Boston next Monday

On American Airlines
Learning

• Training data: interactions with request-SQL pairs
• Objective: minimize token-level cross-entropy loss
• All learned components updated together
ATIS
(Hemphill et al. 1990, Dahl et al. 1994)

• Flight information, 27 tables, 162K entries
• Small corpus: <2000 interactions
• Long interactions: average 7 turns; maximum: 64
• Complex queries: average 102.9 tokens each; 93% reference >3 tables
Handling Entities

- Need to generalize to rare or unseen constraints
- Can take advantage of database context
- Apply entity identification, anonymization techniques
Handling Entities

User: Show me flights from Seattle to Boston next Monday

User: Show me flights from CITY1 to CITY2 YEAR MONTH DAY

SQL Query: ...
... city.city_name_name = CITY1 ...

SQL Query: ...
... city.city_name_name = 'SEATTLE' ...
Experiments

• **Seq2Seq w/o history**
  seq2seq on current utterance only

• **Seq2Seq + history**
  seq2seq by concatenating last four utterances

• **Full model**
  use turn-level encoder
  and query segment copying

Evaluation metric:
Denotation accuracy
(compare tables)

• Measure effect of error propagation:
  full model with access to gold previous query
Results

- Using interaction history is critical
- Error propagation contributes about 3% performance drop
Performance as Interactions Progress

- Without interaction history, performance drops immediately
- Our model: relatively stable

Denotation accuracy (dev)

Turn index in interaction

- Seq2Seq w/o history
- Seq2Seq + history
- Full model
- Full model (with gold previous query)
Ablation Results

Denotation accuracy (dev)

- Full model: 62.5
- w/o turn-level encoder: 61.4
- w/o query segment copying: 58.3

Legend:
- Full model
- w/o turn-level encoder
- w/o query segment copying
Which ones arrive around 7pm?

```
(SELECT DISTINCT flight.flight_id FROM flight WHERE
 flight.from_airport IN ( SELECT airport_service.airport_code FROM airport_service WHERE
 airport_service.city_code IN ( SELECT city.city_code FROM city WHERE city.city_name = 'ATLANTA' ) ) AND
 flight.to_airport IN ( SELECT airport_service.airport_code FROM airport_service WHERE airport_service.city_code IN
 ( SELECT city.city_code FROM city WHERE city.city_name = 'BALTIMORE' ) ) AND
 flight.flight_days IN ( SELECT days.days_code FROM days WHERE days.day_name IN ( SELECT date_day.day_name FROM date_day WHERE date_day.year = 1991
 AND date_day.month_number = 9 AND date_day.day_number = 6 ) ) AND
 flight.arrival_time >= 1630 AND
 flight.arrival_time <= 1730 ) ) ) )
```
Error Propagation

User

Which ones arrive around 7pm?

SQL Query

```
flight.arrival_time >= 1630 AND flight.arrival_time <= 1730
```

Error: looking for flights around 5pm
Error Propagation

- Selecting an incorrect segment
- Previous generated query didn’t contain a necessary segment

**Future work:** how to mitigate error propagation? New training procedures?
• Language understanding in long, complex interactions

• **Turn-level encoder**: implicit mechanism for reasoning about previous requests

• **Query segment copying**: explicitly derive meaning of request (SQL query) from interaction history

**Thank you!**

https://github.com/clic-lab/atis