Executable Semantic Parsing

ESSLLI
Aug 22, 2016

Instructor: Jonathan Berant
1B dollars please
Why is this an important language problem?

what is the second biggest city in california that is not near a river?
Why is this an important language problem?

*What is the second biggest city in California that is not near a river?*

- You can not memorize this
Why is this an important language problem?

what is the second biggest city in California that is not near a river?

- You can not memorize this
- Understand language atoms
- Understand how to compose them
- Generalize to any utterance
- Collect evidence from multiple sources
Executable semantic parsing

*Which states’ capitals are also their largest cities by area?*
Executable semantic parsing

Which states’ capitals are also their largest cities by area?

\[ \mu x. \text{Type.USState} \sqcap \text{Capital}.\text{argmax}(\text{Type.City} \sqcap \text{ContainedBy}.x, \text{Area}) \]
Executable semantic parsing

Which states’ capitals are also their largest cities by area?

semantic parsing

\[ \mu x. \text{Type.USState} \sqcap \text{Capital.} \arg \max (\text{Type.City} \sqcap \text{ContainedBy}.x, \text{Area}) \]

execute logical form

Arizona, Hawaii, Idaho, Indiana, Iowa, Oklahoma, Utah
Executable semantic parsing

Which states’ capitals are also their largest cities by area?

\[ \mu x. \text{Type.USState} \sqcap \text{Capital}.\text{argmax}(\text{Type.City} \sqcap \text{ContainedBy}.x, \text{Area}) \]

execute logical form

Arizona, Hawaii, Idaho, Indiana, Iowa, Oklahoma, Utah

Execute query against knowledge-base
Send a reminder to all students who haven’t turned in their homework.
Executable semantic parsing

Send a reminder to all students who haven’t turned in their homework.

∀x ∈ (Student ⊓ ¬Submit.Homework) : Remind(x)
Send a reminder to all students who haven’t turned in their homework.

∀x ∈ (Student ⊓ ¬Submit.Homework) : Remind(x)

execute logical form

[50 emails sent]
Send a reminder to all students who haven’t turned in their homework.

∀x ∈ (Student ⊓ ¬Submit.Homework) : Remind(x)

[50 emails sent]

Execute command against personal assistant
Executable semantic parsing

[utterance: user input]

semantic parsing

[program]

execute logical form

[behavior: user output]
Executable semantic parsing

[utterance: user input]

semantic parsing

[program]

execute logical form

[behavior: user output]

Execution connects language with the world
Outline

• Introduction (30 min.)
  – Applications
  – Background
  – Short history
  – Goals and plan

• Representation (30 min.)
  – Worlds
    – Simply-typed lambda calculus
    – Lambda-DCS

• Exercise (30 min.)
Outline

• Introduction (30 min.)
  – Applications
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• Exercise (30 min.)
Personal assistants everywhere!

Show me photos from Utah last august
Find videos I took at Ive’s birthday party
What movies are playing today?

...
Personal assistants everywhere!

Alexa, Play some Christmas music
Alexa, turn the bedroom lights on
Alexa, what’s my commute?

...
Personal assistants everywhere!

Can you help me order flowers for my mom’s birthday
Where’s the best place to go hiking in the bay area
Is there a dog friendly beach nearby?
Remind me to congratulate Tanya the next time she calls

...
Personal assistant everywhere!
Question answering
Robot control
Which country has the highest CO2 emissions?

Which had the highest increase since last year?

What fraction is from the five countries with highest GDP?
Outline

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• Exercise (30 min.)
But executable!
Non-executable semantic parsing

The boy wants to go

[Banarescu et al., 2013]
Non-executable semantic parsing

The boy wants to go

No environment to execute semantic representation
Semantics

Sentiment analysis, Semantic Role Labeling, Named Entity Recognition, ...
Semantics

Sentiment analysis, Semantic Role Labeling, Named Entity Recognition, ...

**Semantic parsing:** Full meaning representation
Outline

• Introduction (30 min.)
  – Applications
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  – Goals and plan

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  – Worlds
  – Simply-typed lambda calculus
  – Lambda-DCS

• Exercise (30 min.)
Person: Pick up a big red block.
Computer: OK.
Person: Grasp the pyramid.
Computer: I don’t understand which pyramid you mean.
Person (changing their mind): Find a block which is taller than the one you are holding and put it into the box.
Computer: By ”it”, I assume you mean the block which is taller than the one I am holding.
Computer: OK.
Person: Pick up a big red block.
Computer: OK.
Person: Grasp the pyramid.
Computer: I don’t understand which pyramid you mean.
Person (changing their mind): Find a block which is taller than the one you are holding and put it into the box.
Computer: By ”it”, I assume you mean the block which is taller than the one I am holding.
Computer: OK.
Person: What does the box contain?
Computer: The blue pyramid and the blue block.
Person: What is the pyramid supported by?
Computer: The box.
Person: How many blocks are not in the box?
Computer: Four of them.
Person: Is at least one of them narrower than the one which I told you to pick up?
Computer: Yes, the red cube.
Other grammar-based approaches

Lunar (1972):

List the rocks that contain chromite and ulvospinel
What minerals have been identified in the lunar samples?
What is the average analysis of Ir in rock S10055?
Give me the K / Rb ratios for all lunar samples

Chat-80 (1982):

Does Afghanistan border China?
How many countries does the Danube flow through?
What is the capital of each country bordering the Baltic?
Which country is bordered by two seas?
Other grammar-based approaches

Lunar (1972):

- List the rocks that contain chromite and ulvospinel
- What minerals have been identified in the lunar samples?
- What is the average analysis of Ir in rock S10055?
- Give me the K / Rb ratios for all lunar samples

Chat-80 (1982):

- Does Afghanistan border China?
- How many countries does the Danube flow through?
- What is the capital of each country bordering the Baltic?
- Which country is bordered by two seas?

Problem: does not scale!
Statistical semantic parsing

Learn from data:

Input:

What’s California’s capital?

How long is the Mississippi river?

...
Statistical semantic parsing

Learn from data:

Input:

What’s California’s capital?  
How long is the Mississippi river?

Output:

countries in asia  ⇒  Type.Country ⊓ ContainedBy.Asia
Statistical semantic parsing

Learn from data:

Input:

- What’s California’s capital?  
  \text{Capital(California)}

- How long is the Mississippi river?  
  \text{RiverLength(Mississippi)}

- ...

Output:

- \text{countries in asia}  \Rightarrow  \text{Type.Country} \sqcap \text{ContainedBy.Asia}

What are the problems with this form of supervision?
information retrieval

semantic parsing

Breadth

Depth
Outline

• Introduction (30 min.)
  – Applications
  – Background
  – Short history
  – **Goals and plan**

• Representation (30 min.)
  – Worlds
  – Simply-typed lambda calculus
  – Lambda-DCS

• Exercise (30 min.)
Goals

Be able to go and build a semantic parser

Learn about modern techniques and challenges in semantic parsing
Plan

Class 1: Representation

- Lambda calculus
- Lambda DCS
Plan

Class 1: Representation

- Lambda calculus
- Lambda DCS

Class 2: Compositionality

- Grammars
- Lexicons
- Derivations
- Modelling
Plan

Class 3: Learning

- Training from logical forms
- Training from denotations
- Additional training signals
Plan

Class 3: Learning

- Training from logical forms
- Training from denotations
- Additional training signals

Class 4: Search

- CKY
- Beam-search
- Agenda-based parsing
Plan

Class 5: Advanced topics

• Intermediate representations

• Building semantic parsers overnight

• Deep learning
About me
Outline

• Introduction (30 min.)
  – Applications
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• Representation (30 min.)
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• Exercise (30 min.)
Expressing language with logical form

How to handle various linguistic phenomena

- entities, relations
- Multi-arg events
- Comparatives, superlatives
- Quantifiers, determiners

Goal: Intuition for how to write down logical forms
Outline

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• Exercise (30 min.)
Worlds
μx. Type.USState ⊓ Capital.argmax(Type.City ⊓ ContainedBy.x, Area)
∀x ∈ (Student ⊓ ¬Submit.Homework) : Remind(x)
Which states’ capitals are also their largest cities by area?
Send a reminder to students that did not submit homework
Worlds

\[ \mu x. \text{Type.USState} \sqcap \text{Capital.argmax}(\text{Type.City} \sqcap \text{ContainedBy}.x, \text{Area}) \]

\[ \forall x \in (\text{Student} \sqcap \neg \text{Submit.Homework}) : \text{Remind}(x) \]

Which states’ capitals are also their largest cities by area?

Send a reminder to students that did not submit homework

World determines relevant language
Worlds

• Query a DB

Mountains in Italy
Worlds

- Query a DB

Mountains in Italy

- Update a DB

Add a meeting from 8am-10am Monday to Friday
Worlds

- Query a DB

Mountains in Italy

- Update a DB

Add a meeting from 8am-10am Monday to Friday

- Execute in an environment

Bring me the cup on the table
## Querying a DB

<table>
<thead>
<tr>
<th>Type</th>
<th>ContainedBy</th>
</tr>
</thead>
<tbody>
<tr>
<td>BarackObama Person</td>
<td>Honolulu Hawaii</td>
</tr>
<tr>
<td>MichelleObama Person</td>
<td>Honolulu UnitedStates</td>
</tr>
<tr>
<td>Honolulu CityTown</td>
<td>Chicago Illinois</td>
</tr>
<tr>
<td>Hawaii USState</td>
<td>Chicago UnitedStates</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Profession</th>
<th>PlaceOfBirth</th>
<th>Marriage</th>
</tr>
</thead>
<tbody>
<tr>
<td>BarackObama Politician</td>
<td>BarackObama Honolulu</td>
<td>BarackObama Event8</td>
</tr>
<tr>
<td>BarackObama Author</td>
<td>MichelleObama Chicago</td>
<td>MichelleObama Event8</td>
</tr>
<tr>
<td>MichelleObama Lawyer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GreaterThan</th>
<th>startDate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 1</td>
<td>Event8 1992.10.03</td>
</tr>
<tr>
<td>8 3</td>
<td>Event13 2001.13.02</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Representations

Simply-typed lambda calculus (Carpenter, 1998)

- General formalism for natural language semantics

Lambda-DCS (Liang, 2013)

- Natural language interface for databases
Outline

- Introduction (30 min.)
  - Applications
  - Background
  - Short history
  - Goals and plan

- Representation (30 min.)
  - Worlds
  - Simply-typed lambda calculus
  - Lambda-DCS

- Exercise (30 min.)
Simply-typed lambda calculus

- Constants
- Variables
- Lambda terms
- Function application

adapted from Yoav Artzi
Simply-typed lambda calculus

Each type has a set of constants and variables

Constants

\textsc{Chicago}_e
\textsc{Event8}_{ev}
\textsc{City}_{⟨e,t⟩}
\textsc{PlaceOfBirthOf}_{⟨e⟨e,t⟩⟩}
Simply-typed lambda calculus

Each type has a set of constants and variables

Constants

\textsc{chicago}_e
\textsc{event8}_ev
\textsc{city}_{\langle e,t \rangle}
\textsc{placeofbirthof}_{\langle e_{\langle e,t \rangle} \rangle}

Variables

x_e, y_e
a_{ev}, b_{ev}
f_{\langle e_{\langle e,t \rangle} \rangle}, g_{\langle e_{\langle e,t \rangle} \rangle}
Simply-typed lambda calculus

Function application

\( t: (\text{PlaceOfBirthOf}(\text{BarackObama}))\text{Chicago}) \)

\( t: \text{City}(\text{Honolulu}) \)
Simply-typed lambda calculus

Function application

\[ t: \text{PlaceOfBirthOf(BarackObama)} \Rightarrow \text{Chicago} \]
\[ t: \text{City(Honolulu)} \]

Lambda terms

\[ \langle e, t \rangle: \lambda x.\text{President}_{\langle e, t \rangle}(x_e) \]
\[ \langle e, t \rangle: \lambda x.\text{President}(x) \land \text{Lawyer}(x) \]
\[ \langle e\langle e, t \rangle \rangle: \lambda x.\lambda y.\text{PlaceOfBirthOfBirthOf}(x, y) \]

Logical operators are defined as higher-order constants
Simply-typed lambda calculus

Function application and beta reduction

\[ t : \lambda x.\text{CITY}(x)(\text{HONOLULU}) \]

beta

\[ t : \text{CITY}(	ext{HONOLULU}) \]
Simply-typed lambda calculus

Function application and beta reduction

\[ t : \lambda x. \text{City}(x)(\text{Honolulu}) \]
\[ \text{beta} \]
\[ t : \text{City}(\text{Honolulu}) \]
\[ t : \lambda x. (\lambda y. \text{PlaceOfBirthOf}(x,y)(\text{BarackObama}))(\text{Chicago}) \]
\[ \text{beta} \]
\[ t : \text{PlaceOfBirthOf}(\text{BarackObama},\text{Chicago}) \]
Outline

• Introduction (30 min.)
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• Exercise (30 min.)
Lambda-DCS

- Can be viewed as syntactic sugar for lambda-calculus

- Concise logical forms that mirror natural language
## Logical forms: entity

### proper nouns

<table>
<thead>
<tr>
<th>lambda-dcs</th>
<th>Chicago</th>
</tr>
</thead>
<tbody>
<tr>
<td>lambda calculus</td>
<td>$\lambda x.x = \text{CHICAGO}$</td>
</tr>
<tr>
<td>denotation</td>
<td>${\text{CHICAGO}}$</td>
</tr>
<tr>
<td>graph template</td>
<td>Chicago</td>
</tr>
</tbody>
</table>
Logical forms: join

Verbs and prepositions

HasBirthplace.Chicago

$\lambda x.\text{HAS\_BIRTHPLACE}(x, \text{CHICAGO})$

\{MichelleObama\}

o  HasBirthplace  Chicago
Logical forms: join

Verbs and prepositions

HasBirthplace.Chicago

\( \lambda x.\text{HASBIRTHPLACE}(x, \text{CHICAGO}) \)

\{MichelleObama\}

\( o \) HasBirthplace \( \rightarrow \) Chicago

ChildOf.HasBirthplace.Chicago

\( \lambda x.\exists y\text{CHILDOF}(x, y) \land \text{HASBIRTHPLACE}(y, \text{CHICAGO}) \)

\{NatashaObama, MaliaObama\}

\( o \) ChildOf \( \rightarrow \) \( y \) HasBirthplace \( \rightarrow \) Chicago
Logical forms: join

Verbs and prepositions

HasBirthplace.Chicago
\( \lambda x. \text{HASBIRTHPLACE}(x, \text{CHICAGO}) \)
\{\text{MICHELLE OBAMA}\}

\( \text{CHICAGO} \)

ChildOf.HasBirthplace.Chicago
\( \lambda x. \exists y \text{CHILDOF}(x, y) \land \text{HASBIRTHPLACE}(y, \text{CHICAGO}) \)
\{\text{NATASHA OBAMA, MALIA OBAMA}\}

\( \text{CHICAGO} \)

BirthDateOf.ChildOf.HasBirthplace.Chicago
\( \lambda x. \exists y \exists z \text{BIRTHDATEOF}(x, y) \land \text{CHILDOF}(y, z) \land \text{HASBIRTHPLACE}(z, \text{CHICAGO}) \)
\{06.10.2001, 07.04.1998\}

\( \text{CHICAGO} \)
Logical forms: intersection, union, negation

\[ \text{PROFESSION}\text{.LAWYER} \cap \text{HasBirthplace}\text{.CHICAGO} \]

\[ \lambda x. \text{PROFESSION}(x, \text{LAWYER}) \land \text{HASBIRTHPLACE}(x, \text{CHICAGO}) \]

\{\text{MICHELLEOBAMA}\}

Diagram:

- Profession
  - HasBirthplace
    - Lawyer
    - Chicago
Logical forms: intersection, union, negation

\[
\text{Profession.Lawyer} \sqcap \text{HasBirthplace.Chicago} \\
\lambda x. \text{Profession}(x, \text{Lawyer}) \land \text{HasBirthplace}(x, \text{Chicago}) \\
\{\text{MichelleObama}\}
\]

\[
\text{Profession.Lawyer} \sqcup \text{HasBirthplace.Chicago} \\
\lambda x. \text{Profession}(x, \text{Lawyer}) \lor \text{HasBirthplace}(x, \text{Chicago}) \\
\{\text{MichelleObama, BarackObama}\}
\]
Logical forms: intersection, union, negation

**Profession.Lawyer \( \sqcap \) HasBirthplace.Chicago**

\( \lambda x.\text{Profession}(x, \text{Lawyer}) \land \text{HasBirthplace}(x, \text{Chicago}) \)

\{MichelleObama\}

\[ \text{Profession.Lawyer} \sqcap \text{HasBirthplace.Chicago} \]

**Profession.Lawyer \( \sqcup \) HasBirthplace.Chicago**

\( \lambda x.\text{Profession}(x, \text{Lawyer}) \lor \text{HasBirthplace}(x, \text{Chicago}) \)

\{MichelleObama, BarackObama\}

\[ \neg \text{Profession.Lawyer} \]

\( \lambda x.\neg \text{Profession}(x, \text{Lawyer}) \)

\{MaliaObama, NatashaObama\}
Logical forms: n-ary relations

*Where did Barack Obama live in 1985?*

*Where did Barack Obama live?*
Logical forms: n-ary relations

Where did Barack Obama live in 1985?
Where did Barack Obama live?
Do we need a ternary predicate?

\[ \lambda x. \text{PlaceLivedBy}(x, \text{BarackObama}) \]

\[ \lambda x. \text{PlaceLivedBy}(x, \text{BarackObama}, 1985) \]
Logical forms: n-ary relations

Where did Barack Obama live in 1985?
Where did Barack Obama live?
Do we need a ternary predicate?

\[ \lambda x. \text{PlaceLivedBy}(x, \text{BarackObama}) \]
\[ \lambda x. \text{PlaceLivedBy}(x, \text{BarackObama}, 1985) \]

Neo-Davidsonian semantics: Event node modified by several arguments

\[
\text{LivedLocation.}(\text{PersonLiving. BarackObama } \sqcap \text{StartLiving.1985})
\]
\[ \lambda x. \exists e. \text{LivedLocation}(x, e) \land \text{PersonLiving}(e, \text{BarackObama}) \land \text{StartLiving}(e, 1985) \]
\{Chicago\}
Logical forms: higher order functions

Operate on sets of entities (not entities)

\[
\text{count}(\text{Type.USState}) \\
\text{count}(\lambda x.\text{Type}(x, \text{USState})) \\
\{50\}
\]

Similar for MIN, MAX, SUM
Logical forms: higher order functions

Operate on **sets** of entities (not entities)

\[
\text{count}(	ext{Type.USState})
\]
\[
\text{count}(\lambda x.\text{Type}(x, \text{USState}))
\]
\[
\{50\}
\]

Similar for **MIN, MAX, SUM**

\[
\text{argmax}(\text{Type-USState, Area})
\]
\[
\text{argmax}(\lambda x.\text{Type}(x, \text{USState}), \lambda x.\lambda y.\text{Area}(x, y))
\]
\[
\{\text{Alaska}\}
\]

Similar for **ARGMIN**
Logical forms: anaphora

those whose children influenced Barack Obama

HasChild.HasInfluence.BarackObama

\( \lambda x. \exists y. \text{HasChild}(x, y) \land \text{HasInfluence}(y, \text{BarackObama}) \)
Logical forms: anaphora

*those whose children influenced Barack Obama*

\[ \text{HasChild}.\text{HasInfluence}.\text{BarackObama} \]

\[ \lambda x. \exists y. \text{HasChild}(x, y) \land \text{HasInfluence}(y, \text{BarackObama}) \]

*those whose child influenced them*

\[ \mu x. \text{HasChild}.\text{HasInfluence}.x \]

\[ \lambda x. \exists y. \text{HasChild}(x, y) \land \text{HasInfluence}(y, x) \]
Logical forms: lambda abstraction

How to construct compositional binary relations?
Logical forms: lambda abstraction

How to construct compositional binary relations?

*Person who has the most children*

\[
\text{argmax}(\text{Type.Person, Rev}[\lambda x.\text{count}(\text{Rev}[\text{HasChildren}].x)])
\]

\[
\text{argmax}(\lambda x.\text{Type}(x, \text{Person}), \lambda x.\text{count}(\lambda y.\text{HasChildren}(x, y)))
\]
Logical forms: lambda abstraction

How to construct compositional binary relations?

*Person who has the most children*

\[
\text{argmax} \left( \text{Type} . \text{Person}, \text{Rev} [ \lambda x . \text{count} (\text{Rev} [\text{HasChildren}] . x)] \right)
\]

\[
\text{argmax} (\lambda x . \text{Type}(x, \text{Person}), \lambda x . \text{count}(\lambda y . \text{HasChildren}(x, y)))
\]

In some cases lambda calculus is more transparent
Some things we skip

Determiners and quantification
Dynamic environments

Database updates

Add a meeting with Tom from 2 to 4pm
ADD(TYPE.Meeting \sqcap ATTENDEE.Tom \sqcap START_TIME.1400 \sqcap END_TIME.1600)
Dynamic environments

Database updates

*Add a meeting with Tom from 2 to 4pm*

\[ \text{Add} \left( \text{Type.Meeting} \sqcap \text{Attendee.Tom} \sqcap \text{StartTime.1400} \sqcap \text{EndTime.1600} \right) \]

Executing instruction
Outline

• Introduction (30 min.)
  – Applications
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  – Lambda-DCS

• Exercise (30 min.)
Exercise

http://esslli2016.unibz.it/?page_id=356

or

cd /usr/local/sempre
./run @mode=simple-lambdadcs
(loadgraph esslli 2016/geo880.kg)
Exercise

\[ a \cdot b \]
\[ a \sqcap b \]
\[
\text{rank-m top-n for unary and binary}
\]
\[ \text{count} \]
\[ \text{numbers} \]
\[ \mu x. u \]
\[ \text{Rev}(u) \]
\[ \text{Type} \]
\[ \text{USState} \]
\[ \text{City} \]
\[ \text{MajorCity} \]
\[ \text{Area} \]
\[ \text{Size} \]
\[ \text{Population} \]
\[ \text{Capital} \]
\[ \text{Border} \]
\[ \text{Traverse} \]
Exercise

Write logical forms for the following utterances:

state with the largest area
Top 5 cities by area
Major cities with at least 140,000 inhabitants
How many states have capitals with at least 200,000 inhabitants
State bordering Oregon and Washington
Second highest mountain in California
Which states’ capitals are also their largest cities by population
State that is traversed by the most rivers
Solution

(argmax 1 1 (type.object.type location.us_state) location.location.area)
(argmax 1 5 (type.object.type location.citytown) location.location.size)
(and (type.object.type location.major_citytown) (location.location.population (> (number 140000))))
(count (location.us_state.capital (and (type.object.type location.capital) (location.location.population (> (number 200000))))))
(and (type.object.type location.us_state) (and (location.us_state.border state.oregon) (location.us_state.border state.washington)))
(argmax 2 1 (and (type.object.type location.mountain) (location.location.containedby state.california)) location.location.elevation)
(and (type.object.type location.us_state) (mark x (location.us_state.capital (argmax 1 1 (location.location.containedby (var x)) location.location.population))))
(argmax 1 1 (type.object.type location.us_state) (reverse (lambda x (count (location.river.traverse (var x)))))
Summary

• Key technology for conversational interfaces
Summary

- Key technology for conversational interfaces
- Expressing language constructs with logical forms
Summary

- Key technology for conversational interfaces
- Expressing language constructs with logical forms
- But how do we construct logical forms automatically?