SEMANTIC PARSING: NATURAL LANGUAGE UNDERSTANDING IN PYTHON

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THINGS TO KEEP IN MIND

1. You'll get access to the information covered in this session after the conference.

2. Visit the Intel® AI Academy for additional resources, training materials and videos related to today's presentation.
   software.intel.com/AI


4. Check out more examples of Intel AI/Movidius NCS/Intel AI DevCloud in action on DevMesh – Intel’s Developer Network
   https://devmesh.intel.com/
REFERENCES

- Stanford CS 224U: Natural Language Understanding
- Original SippyCup Github Repository
- Fork for this class: https://github.com/mspandit/sippycup
A computation which takes a linguistic expression and returns as output a structured, machine-interpretable representation of its meaning, known as the **semantic representation**.
EXAMPLE: QUESTION ANSWERING APPLICATION

“How tall is Obama?”

(/person/height /m/02mjmr)
EXAMPLE: QUESTION ANSWERING APPLICATION

Linguistic Expression
“How tall is Obama?”

Semantic Parser

Semantic Representation
(/person/height /m/02mjmr)

Executor

Denotation
1.85 m

https://github.com/mspandit/sippycup
WHY SEMANTIC PARSING IS HARD

• Multiple linguistic expressions can have the same meaning
  • Example: “nyc population,” “How many people live in New York City?”
  • Canonicalization: Same meaning $\rightarrow$ Same semantic representation

• A single linguistic expression can have multiple meanings—depending on the context
  • Example: “How big is New York?” (area, population) $\times$ (city, state)
  • Ambiguity resolution: Different meanings $\rightarrow$ Different semantic representations
WHY SEMANTIC PARSING IS HARD

• Linguistic expressions can be messy with typos, misspellings, loose syntax: “where r u”
• Internationalization compounds the problem
• Scale of the problem demands machine learning
NATURAL LANGUAGE ARITHMETIC
THE PROBLEM

- Interpret natural language arithmetic expressions
  - "one plus one"
  - "minus three minus two" (lexical ambiguity)
  - "three plus three minus two"
  - "two times two plus three" (syntactic ambiguity)
- Small, closed vocabulary
- Limited variety of syntactic structures
## SEMANTIC REPRESENTATION: BINARY EXPRESSION TREES

<table>
<thead>
<tr>
<th>Expression</th>
<th>Tree Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>one plus one</td>
<td>('+', 1, 1)</td>
</tr>
<tr>
<td>minus three minus two</td>
<td>('-', ('~', 3), 2)</td>
</tr>
<tr>
<td>three plus three minus two</td>
<td>('-', ('+', 3, 3), 2)</td>
</tr>
<tr>
<td>two times two plus three</td>
<td>('+', ('*', 2, 2), 3)</td>
</tr>
</tbody>
</table>
executor.py
CONSTITUENCY STRUCTURE

How we group words into larger and larger phrases.
Syntactic Parsing

Build a tree structure (a parse) over the input which describes its constituency structure. Assign categories to each word and phrase.
### Example Input and Denotation

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>minus three</td>
<td>-5</td>
</tr>
<tr>
<td>minus two</td>
<td></td>
</tr>
<tr>
<td>minus three</td>
<td>-1</td>
</tr>
<tr>
<td>minus two</td>
<td></td>
</tr>
</tbody>
</table>
### Example with Words Grouped

<table>
<thead>
<tr>
<th></th>
<th>Expression</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>minus three</td>
<td>((minus three) minus two)</td>
<td>-5</td>
</tr>
<tr>
<td>minus two</td>
<td></td>
<td></td>
</tr>
<tr>
<td>minus three</td>
<td>(minus (three minus two))</td>
<td>-1</td>
</tr>
<tr>
<td>minus two</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EXAMPLE WITH CATEGORIES ASSIGNED

<table>
<thead>
<tr>
<th>minus three minus two</th>
<th>((minus three) minus two)</th>
<th>($E ($E ($UnOp minus) ($E three)) ($BinOp minus) ($E two))</th>
<th>-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>minus three minus two</td>
<td>(minus (three minus two))</td>
<td>($E ($UnOp minus) ($E ($E three) ($BinOp minus) ($E two)))</td>
<td>-1</td>
</tr>
</tbody>
</table>

$E$

<table>
<thead>
<tr>
<th>$E$</th>
<th>$UnOp$</th>
<th>$E$</th>
<th>$BinOp$</th>
<th>$E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>minus</td>
<td>three</td>
<td>minus</td>
<td>two</td>
<td></td>
</tr>
</tbody>
</table>

$E$

<table>
<thead>
<tr>
<th>$UnOp$</th>
<th>$E$</th>
<th>$BinOp$</th>
<th>$E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>minus</td>
<td>three</td>
<td>minus</td>
<td>two</td>
</tr>
</tbody>
</table>

**Category** | **Definition**
---|---
$E$ | Expression
$UnOp$ | Unary Operator
$BinOp$ | Binary Operator
## Example with Local Subtrees Highlighted

<table>
<thead>
<tr>
<th>Expression</th>
<th>Highlighted Subtrees</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(minus three) minus two</td>
<td>($E ($UnOp minus) ($E three)) ($BinOp minus) ($E two))</td>
<td>-5</td>
</tr>
<tr>
<td>(minus (three minus two))</td>
<td>($E ($UnOp minus) ($E ($E three) ($BinOp minus) ($E two)))</td>
<td>-1</td>
</tr>
</tbody>
</table>

### Category Definition

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E</td>
<td>Expression</td>
</tr>
<tr>
<td>$UnOp</td>
<td>Unary Operator</td>
</tr>
<tr>
<td>$BinOp</td>
<td>Binary Operator</td>
</tr>
</tbody>
</table>
## PARTIAL CONTEXT FREE GRAMMAR RULES

<table>
<thead>
<tr>
<th>Left Hand Side</th>
<th>Right Hand Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$</td>
<td>two</td>
</tr>
<tr>
<td>$E$</td>
<td>three</td>
</tr>
<tr>
<td>$\text{UnOp}$</td>
<td>minus</td>
</tr>
<tr>
<td>$\text{BinOp}$</td>
<td>minus</td>
</tr>
<tr>
<td>$E$</td>
<td>$\text{UnOp} \ E$</td>
</tr>
<tr>
<td>$E$</td>
<td>$E \ \text{BinOp} \ E$</td>
</tr>
</tbody>
</table>
## COMPLETE CONTEXT FREE GRAMMAR RULES

<table>
<thead>
<tr>
<th>Left Hand Side</th>
<th>Right Hand Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$</td>
<td>one</td>
</tr>
<tr>
<td>$E$</td>
<td>two</td>
</tr>
<tr>
<td>$E$</td>
<td>three</td>
</tr>
<tr>
<td>$E$</td>
<td>four</td>
</tr>
<tr>
<td>$\text{UnOp}$</td>
<td>minus</td>
</tr>
<tr>
<td>$\text{BinOp}$</td>
<td>minus</td>
</tr>
<tr>
<td>$\text{BinOp}$</td>
<td>plus</td>
</tr>
<tr>
<td>$\text{BinOp}$</td>
<td>times</td>
</tr>
<tr>
<td>$E$</td>
<td>$\text{UnOp} \ E$</td>
</tr>
<tr>
<td>$E$</td>
<td>$E \ \text{BinOp} \ E$</td>
</tr>
</tbody>
</table>
# Chomsky Normal Form (Binarized) CFG Rules

<table>
<thead>
<tr>
<th>Left Hand Side</th>
<th>Right Hand Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$</td>
<td>one</td>
</tr>
<tr>
<td>$E$</td>
<td>two</td>
</tr>
<tr>
<td>$E$</td>
<td>three</td>
</tr>
<tr>
<td>$E$</td>
<td>four</td>
</tr>
<tr>
<td>$UnOp$</td>
<td>minus</td>
</tr>
<tr>
<td>$BinOp$</td>
<td>minus</td>
</tr>
<tr>
<td>$BinOp$</td>
<td>plus</td>
</tr>
<tr>
<td>$BinOp$</td>
<td>times</td>
</tr>
<tr>
<td>$E$</td>
<td>$UnOp$ $E$</td>
</tr>
<tr>
<td>$EBO$</td>
<td>$E$ $BinOp$</td>
</tr>
<tr>
<td>$E$</td>
<td>$EBO$ $E$</td>
</tr>
</tbody>
</table>

[GitHub Repository](https://github.com/mspandit/sippycup)
**SEMANTICS**

\[
\begin{array}{c}
\text{$E$ [(- (~ 3) 2)]} \\
\hline
\text{$EBO$ [(- (~ 3))]}
\end{array}
\]

\[
\begin{array}{c}
\text{$E$ [(~ 3)]} \\
\hline
\text{$UnOp$ [~]} & \text{$E$ [3]} & \text{$BinOp$ [-]} & \text{$E$ [2]}
\end{array}
\]

<table>
<thead>
<tr>
<th>$UnOp$</th>
<th>$E$</th>
<th>$BinOp$</th>
<th>$E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>minus</td>
<td>three</td>
<td>minus</td>
<td>two</td>
</tr>
</tbody>
</table>

[https://github.com/mspandit/sippycup](https://github.com/mspandit/sippycup)
THE PRINCIPLE OF COMPOSITIONALITY

The meaning of a compound expression is a function of the meanings of its parts and the manner of their combination.

https://github.com/mspandit/sippycup
In every example, we produced some correct parse

In three examples, the parse at position 0 was incorrect

Conclusion: Rank candidate parses so that correct parses are likely to appear higher in the list.
LINEAR SCORING FUNCTION

• Define multiple feature functions \( \phi_i(p) \), each taking a parse \( p \) as input and returning a real number as output.
• Store a weight \( w_i \) for each feature function.
• For parse \( p \):
• \( \text{score}(p) = \sum_i w_i \cdot \phi_i(p) \)
LINEAR SCORING FUNCTION

• Define multiple feature functions $\phi_i(p)$, each taking a parse $p$ as input and returning a real number as output.
• Store a weight $w_i$ for each feature function.
• For parse $p$:
  • $score(p) = \sum_i w_i \cdot \phi_i(p)$
• What if there are many features? Learn weights from training data!
NATURAL LANGUAGE ARITHMETIC—SUMMARY

- Grammar with rules in Chomsky Normal (Binarized) Form
- Semantic representation derived from syntactic parses
- Feature functions for parses
- Machine learning of feature weights from semantics or denotation
- Performance improvement on ranking parses
THE PROBLEM

• Interpret natural language travel queries
  • “birmingham al distance from indianapolish in” (misspelling)
  • “directions from washington to canada” (ambiguity: which Washington?)
  • “discount travel flights to Austin texas”
• Much larger vocabulary, potentially unbounded
• Large variety of syntactic structures
• Accommodate misspellings, bad syntax
• Flat—not recursive nested—semantic structure: destination, origin, mode, etc.
DATASET

- **Pass, Greg; Chowdhury, Abdur; Torgeson, Cayley; A Picture of Search**
- Start: ~10 million unique search queries issued by ~650 thousand AOL users in 2006
- Selected queries containing one of the 600 locations named in Geobase (1M queries).
- Selected queries containing "from" or "to" (23K queries).
- Selected queries containing one of about 60 travel terms, or containing both "from" and "to" (6,588 queries).
- Many misspellings.

https://github.com/mspandit/sippycup
### Semantic Representation: Nested Key-Value Pairs

<table>
<thead>
<tr>
<th>Query</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>driving directions to Williamsburg, VA</td>
<td>{'domain': 'travel', 'type': 'directions', 'mode': 'car', 'destination': {'id': 4793846, 'name': 'Williamsburg, VA, US'}}</td>
</tr>
<tr>
<td>travel time by bus from Atlantic City to NYC</td>
<td>{'domain': 'travel', 'type': 'duration', 'mode': 'bus', 'origin': {'id': 4500546, 'name': 'Atlantic City, NJ, US'}, 'destination': {'id': 5128581, 'name': 'New York City, NY, US'}}</td>
</tr>
<tr>
<td>airfare from Newark to Charleston, SC</td>
<td>{'domain': 'travel', 'type': 'cost', 'mode': 'air', 'origin': {'id': 5101798, 'name': 'Newark, NJ, US'}, 'destination': {'id': 4574324, 'name': 'Charleston, SC, US'}}</td>
</tr>
</tbody>
</table>

- Resolves ambiguity and canonicalizes
- (No executor in this domain)
TRAINING DATA

Examples (travel_examples.py)
• travel boston to fr. myers fla
• how do i get from tulsa oklahoma to atlantic city. new jersey by air
• airbus from boston to europe
• cheap tickets to south carolina
• birmingham al distance from indianapolish in
• transportation to the philadelphia airport
• one day cruise from fort lauderdale florida
• directions from washington to canada
• flights from portland or to seattle wa
• honeymoon trip to hawaii

Roles
• Destination
• Origin
• Mode
• Type of information sought
• “Optional” words
• Ordering of phrases isn’t important
PHRASE BAG GRAMMAR

- Query elements can appear in any order
  - Travel locations (to, from)
  - Travel arguments (mode, trigger, request type)
- Optionals can appear anywhere

- Annotators: modules for assigning categories and semantics to specific types of phrases
- Unary compositional rules
- N-ary rules
  - Rule('City', 'new york city')
  - Rule('RouteQuery', 'FromLocation $ToLocation $TravelMode')
  - Optionals
TRAVEL QUERIES—SUMMARY

- Larger, more realistic dataset
- Annotators to “automate” rule definitions
- Rules for phrase-bag grammar with optionals
- Parsing with n-ary rules (CNF not required)
THE PROBLEM

- "which states border texas?"
- "how many states border the largest state?"
- "what is the size of the capital of texas?"
- Large vocabulary
- Lexical and syntactic ambiguity
- Adhere to conventional rules for spelling and syntax
- Semantics with arbitrarily complex compositional structure
- Isomorphic with other domains!
Dataset

- Questions and answers
- Geo880 corpus: [http://www.cs.utexas.edu/users/ml/geo.html](http://www.cs.utexas.edu/users/ml/geo.html)
- “Standard evaluation” for semantic parsing systems
- (Not representative of web search queries)
Knowledge Base

- Small knowledge base covering Geo880 queries
- states: capital, area, population, major cities, neighboring states, highest and lowest points and elevations
- cities: containing state and population
- rivers: length and states traversed
- mountains: containing state and height
- roads: states traversed
- lakes: area, states traversed

https://github.com/mspandit/sippycup
## Semantic Representation: Queries for Graph-Structured Knowledge Base

<table>
<thead>
<tr>
<th>Question</th>
<th>Query</th>
</tr>
</thead>
<tbody>
<tr>
<td>capital of texas</td>
<td>('/state/texas', 'capital')</td>
</tr>
<tr>
<td>rivers that traverse utah</td>
<td>('.and', 'river', ('traverses', '/state/utah'))</td>
</tr>
<tr>
<td>tallest mountain</td>
<td>('.argmax', 'height', 'mountain')</td>
</tr>
</tbody>
</table>
unit3_tests.py
In cases where we put the wrong parse at the top, the top parse had nonsensical semantics with an empty denotation.

👉 Downweight parses with empty denotations
unit3_tests.py
GEOGRAPHY QUERIES—SUMMARY

- Semantic representation: queries for graph-structured knowledge base
SO... WHAT’S NEXT?

1. Visit the Intel® AI Academy for additional resources, training materials and videos related to today’s presentation. software.intel.com/AI


3. Build useful chatbots and voice interfaces using semantic parsers!

4. Check out more examples of Intel AI/Movidius NCS/Intel AI DevCloud in action on Intel’s Developer Network https://devmesh.intel.com/
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