Semantic Parsing

CS221 Section 9: 11/30/2017

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Motivation: From Natural Language to Logic

Alice likes hiking. → $\text{Likes}(\text{alice}, \text{hiking})$

Alice likes geometry. → $\text{Likes}(\text{alice}, \text{geometry})$

Bob likes hiking. → $\text{Likes}(\text{bob}, \text{hiking})$

Bob likes geometry. → $\text{Likes}(\text{bob}, \text{geometry})$

Lots of regularities — can we convert language to logic automatically?

Lambda calculus

- Improves upon first-order logic for increased expressiveness and compositionality.
- Differences between the quantifiers using variable x:
  - $\exists x\, P(x)$ means "There exists an x such that P(x) is true."
  - $\forall x\, P(x)$ means: "For all x, P(x) is true."
  - $\lambda x\, P(x)$ means: "**Given** x, P(x) is true."
- Unlike $\exists$ and $\forall$, which are symbols for the words "exists" and "all", **λ** is a **function**
  - The λ operators allow us to abstract over x. They have no meaning on their own, but allow us to bind the **variable** x to a given **argument** value.

Analogy: Python lambda functions

- Think of lambda functions in Python
- Example:
  - Let P denote “even”. Then $\lambda x\, P(x)$ means “Given x, x is even.”
  - This statement could be true or false.
  - Let the function f denote $\lambda x\, P(x)$. Then we can try this in the Python shell:

```
>>> f = lambda x : x % 2 == 0
>>> f(2)
True
>>> f(3)
False
```

Lambda calculus example 1

- “Given x, x is a student and x likes hiking.”
- x = alice

→ “alice is student and alice likes hiking.”

Function:

$$\lambda x \, \text{Student}(x) \wedge \text{Likes}(x, \text{hiking})$$

Argument:

$$\text{alice}$$

Function application:

$$(\lambda x \, \text{Student}(x) \wedge \text{Likes}(x, \text{hiking}))(\text{alice})$$

$$\text{Student}(\text{alice}) \wedge \text{Likes}(\text{alice}, \text{hiking})$$

Lambda calculus example 2

- "Given y and x, x likes y."
- y = hiking

→ "Given x, x likes hiking."

Function:

$$\lambda y\, \lambda x\, \text{Likes}(x, y)$$

Argument:

$$\text{hiking}$$

Function application:

$$(\lambda y\, \lambda x\, \text{Likes}(x, y))(\text{hiking}) =$$

$$\lambda x\, \text{Likes}(x, \text{hiking})$$

Lambda calculus example 3

- "Given f and x, <u>not</u> f(x)."
- f = "Given y, y likes hiking."
- f(x) = "x likes hiking"

→ "Given x, x does <u>not</u> like hiking"

Function:

$$\lambda f\, \lambda x\, \neg f(x)$$

Argument:

$$\lambda y\, \mathsf{Likes}(y, \mathsf{hiking})$$

Function application:

$$(\lambda f\, \lambda x\, \neg f(x))(\lambda y\, \mathsf{Likes}(y, \mathsf{hiking})) =$$

$$\lambda x\, \neg(\lambda y\, \mathsf{Likes}(y, \mathsf{hiking}))(x) =$$

$$\lambda x\, \neg \mathsf{Likes}(x, \mathsf{hiking})$$

Principle of Compositionality

Key idea: principle of compositionality

The semantics of a sentence is combination of meanings of its parts.

Sentence:

Alice likes hiking. → $\text{Likes}(\text{alice}, \text{hiking})$

Words:

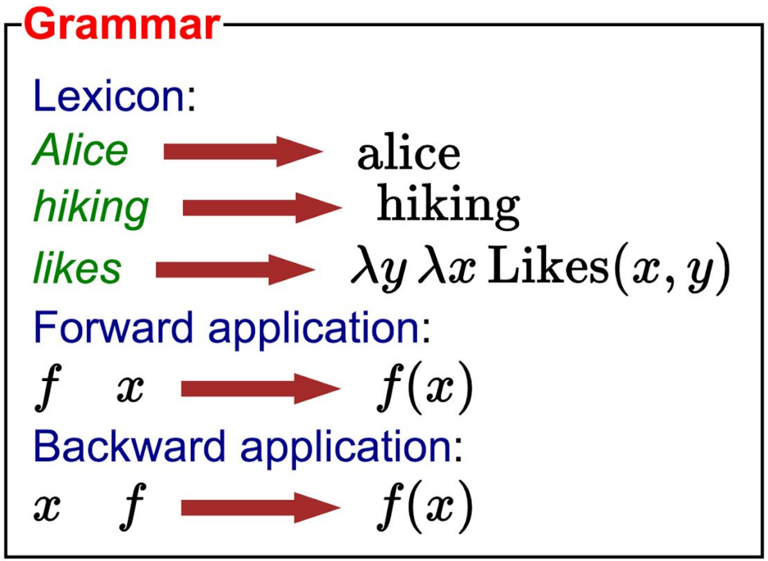
Alice → alice

hiking → hiking

likes → $\lambda y \, \lambda x \, \text{Likes}(x, y)$

Grammar

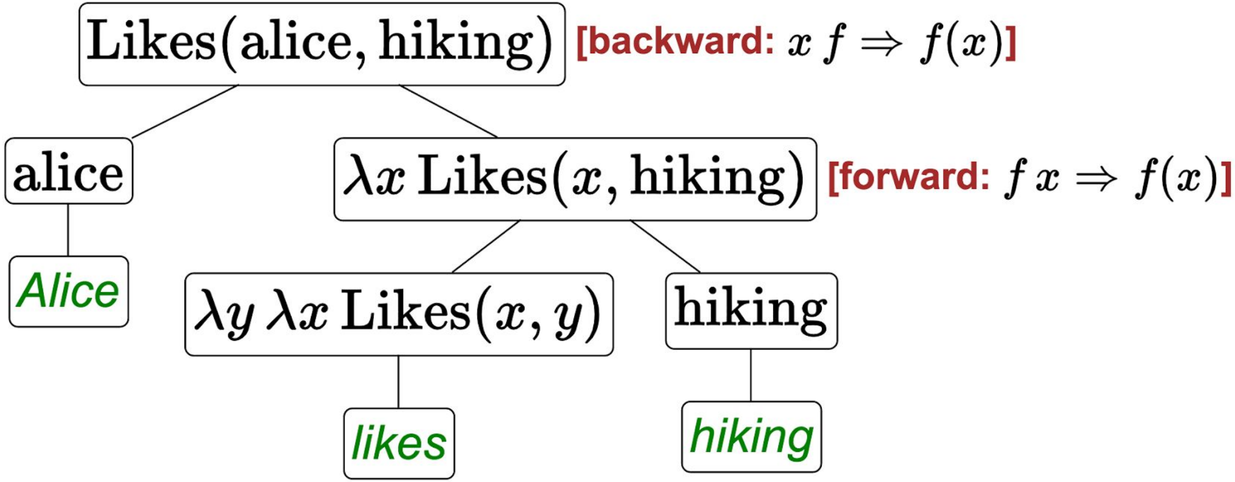
- Set of Rules
- Natural Language → Formulas



Basic Derivation

Leaves: input words

Internal nodes: produced by applying rule to children



Example involving Negation

Alice does not like hiking.

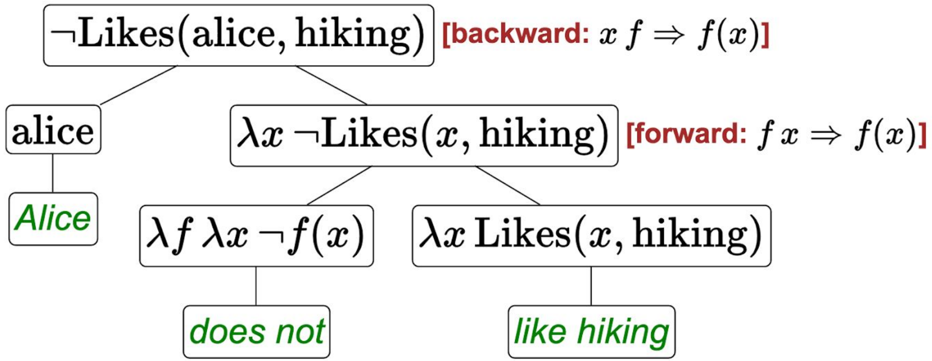
$$\neg \text{Likes}(\text{alice}, \text{hiking})$$

Grammar

...

Negation:

does not → $\lambda f\, \lambda x\, \neg f(x)$



Coordination 1

Alice likes hiking ***and*** *Bob likes swimming.*

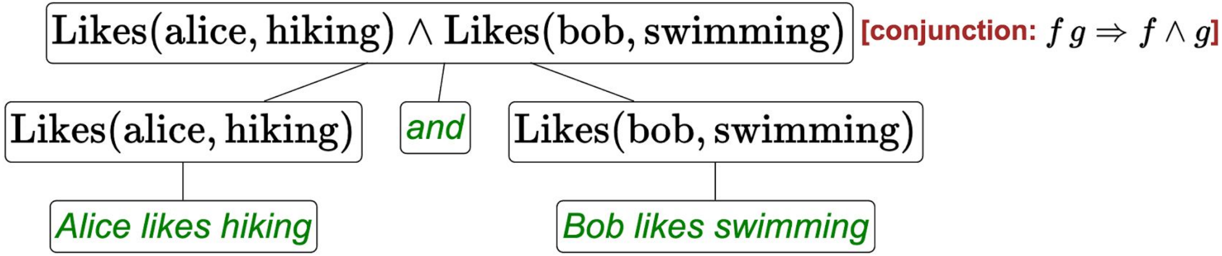
$$\text{Likes}(\text{alice}, \text{hiking}) \wedge \text{Likes}(\text{bob}, \text{swimming})$$

Grammar

...

Coordination:

f *and* $g \longrightarrow f \wedge g$



Coordination 2

*Alice likes hiking **and** hates swimming.*

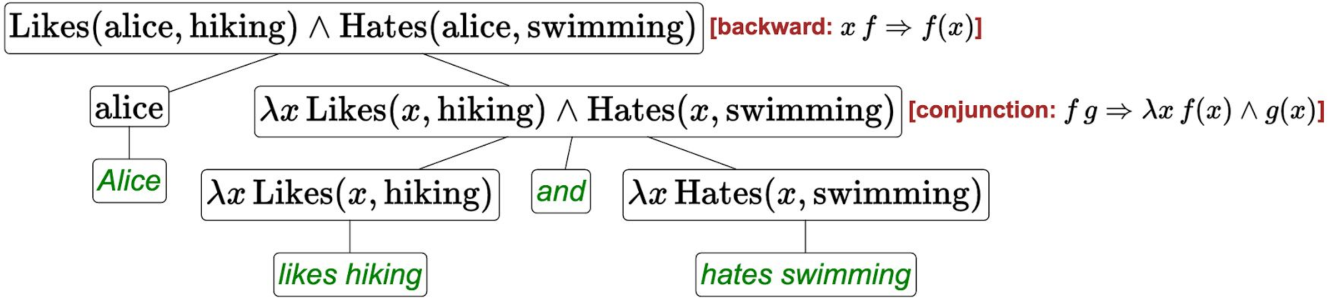
$$\text{Likes}(\text{alice}, \text{hiking}) \wedge \text{Hates}(\text{alice}, \text{swimming})$$

Grammar

...

Coordination:

f *and* g ⟶ $\lambda x\, f(x) \wedge g(x)$



Quantification

Every *student likes hiking.*

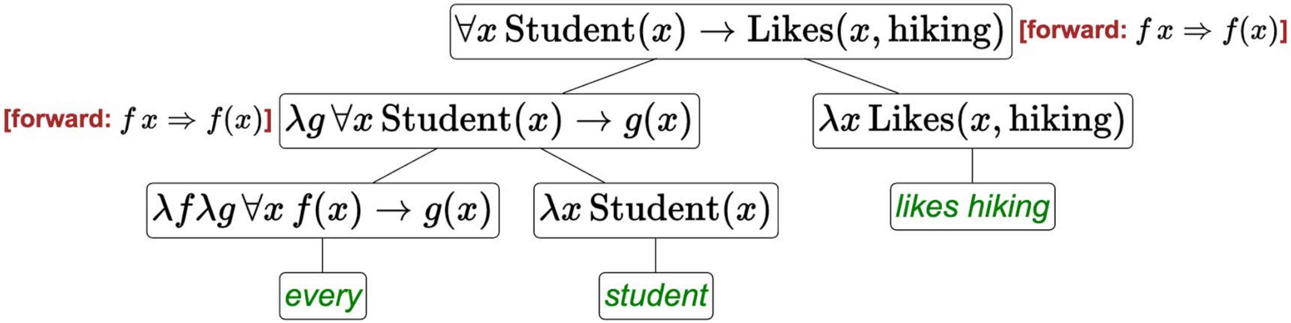
$$\forall x\, \mathrm{Student}(x) \rightarrow \mathrm{Likes}(x, \mathrm{hiking})$$

Grammar

...

Universal quantification:

every ➡ $\lambda f \lambda g \forall x\, f(x) \rightarrow g(x)$



Some sources of ambiguity

Lexical ambiguity:

Alice went to the bank. → $\mathrm{Travel}(\mathrm{alice}, \mathrm{RiverBank})$

Alice went to the bank. → $\mathrm{Travel}(\mathrm{alice}, \mathrm{MoneyBank})$

Scope ambiguity:

Everyone likes someone. → $\forall x\, \exists y\, \mathrm{Likes}(x, y)$

Everyone likes someone. → $\exists y\, \forall x\, \mathrm{Likes}(x, y)$

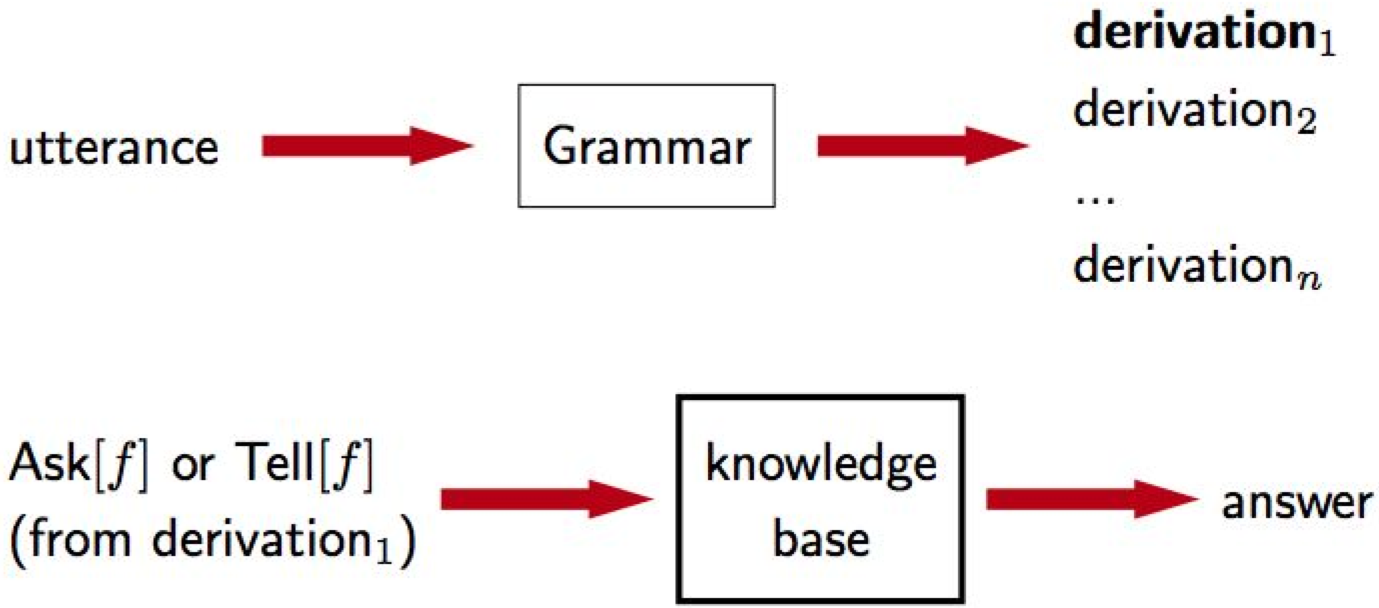
Algorithms

utterance → Grammar → **derivation**$_1$, derivation$_2$, ..., derivation$_n$

- Inference (parsing): construct derivations recursively (dynamic programming)

- Learning: define ranking loss function, optimize with stochastic gradient descent

Putting It Together



Full Understanding of Natural Language: Are We There Yet?

- Do we fully understand the following sentences? Can we generate complete, precise semantics?
- Not yet! This is a **hard** problem.

Logic games from LSAT and GRE

Six sculptures — C, D, E, F, G, H — are to be exhibited in rooms 1, 2, and 3 of an art gallery.

- Sculptures C and E may not be exhibited in the same room.
- Sculptures D and G must be exhibited in the same room.
- If sculptures E and F are exhibited in the same room, no other sculpture may be exhibited in that room.
- At least one sculpture must be exhibited in each room, and no more than three sculptures may be exhibited in any room.

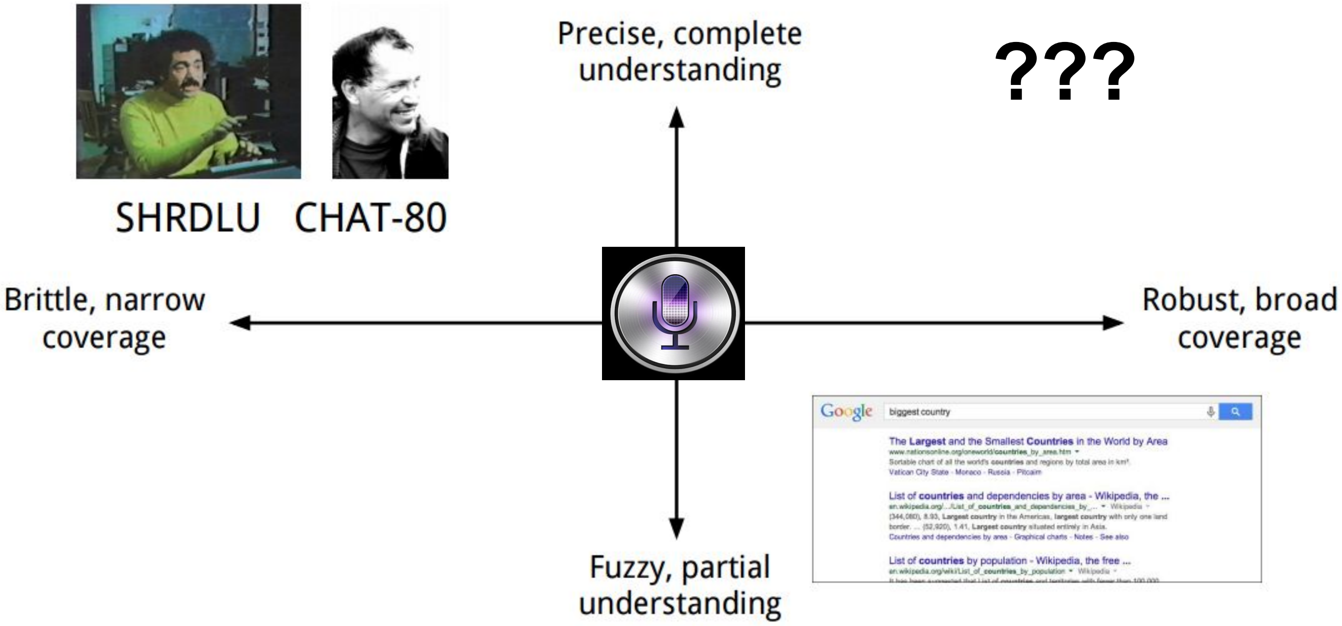
If sculpture D is exhibited in room 3 and sculptures E and F are exhibited in room 1, which of the following may be true?

- Sculpture C is exhibited in room 1.
- Sculptures C and H are exhibited in the same room.
- Sculptures G and F are exhibited in the same room.

Travel reservations

Yes, hi, I need to book a flight for myself and my husband from SFO to Boston. Actually Oakland would be OK too. We need to fly out on Friday the 12th, and then I could come back on Sunday evening or Monday morning, but he won't return until Wednesday the 18th, because he's staying for business. No flights with more than one stop, and we don't want to fly on United because we hate their guts.

Full Understanding of Natural Language: Are We There Yet?



SHRDLU (Winograd 1972)

Check out https://www.youtube.com/watch?v=8SvD-lNg0TA

- Find a block which is taller than the one you are holding and put it into the box.
  - OK.
- How many blocks are not in the box?
  - FOUR OF THEM.
- Is at least one of them narrower than the one which I told you to pick up?
  - YES, THE RED CUBE.

CHAT-80 by Fernando Pereira & David Warren (1979 - 82)

- Could answer questions about geography
- Hand-built lexicon & grammar
- Highly influential NLIDB system
- Proof-of-concept natural language interface to database
- Implemented in Prolog

Things that you could ask CHAT-80

- Is there more than one country in each continent?
- What countries border Denmark?
- What are the countries from which a river flows into the Black_Sea?
- What is the total area of countries south of the Equator and not in Australasia?
- Which country bordering the Mediterranean borders a country that is bordered by a country whose population exceeds the population of India?
- How far is London from Paris?

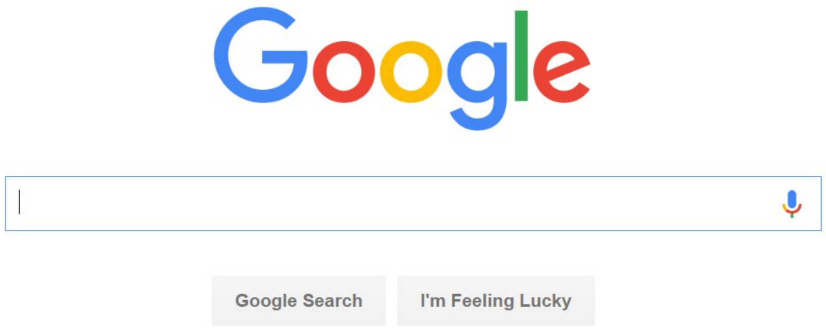
CHAT-80 Demo

- You can run Chat-80 yourself on the corn machines!

```
$ ssh corn.stanford.edu
$ cd /afs/ir/class/cs224n/src/chat/
$ module load sicstus
$ sicstus
? [load].
? hi.
? what is the capital of france?
```

- Sample queries can be found at:
    - /afs/ir/class/cs224n/src/chat/demo
- All the source code is there for your perusal as well

Google



Google

Google | Yes, hi, I need to book a flight for myself and my husband from SFO to B

All · News · Maps · Images · Shopping · More · Settings · Tools

About 1,590,000 results (1.02 seconds)

"t" (and any subsequent words) was ignored because we limit queries to 32 words.

Is there a best day of the week to buy airline tickets? | CheapAir
https://www.cheapair.com/.../travel.../is-there-a-best-day-of-the-week-to-buy-airline-ti...
Oct 24, 2014 - **We** looked at fares that were available each day, regardless of what was **actually** purchased. And **we** found the notion that there is a best day of the week to buy continues to be a myth. As you **can** see below, Wednesdays and Thursdays **have** been the cheapest day to buy, **but** only $3 less on average **than** ...

How Far in Advance Should I book my Flights? | CheapAir
https://www.cheapair.com/blog/travel.../how-far-in-advance-should-i-book-my-flight/
Jan 11, 2013 - For international **flights**, it was still not good to buy **too** early or **too** late, **but** the sweet spot there was about 11-**12** weeks in advance. (The exact ... Contrary to what many **travel** "experts" **have** claimed, no particular day of the week was a consistently less expensive day to buy tickets in 2012. It has become ...

When to ignore our advice and book your flight as early as possible ...
https://www.cheapair.com/.../travel.../when-to-ignore-our-advice-and-book-your-flig...
Apr 11, 2014 - **We** also found that **booking too** early or **too** late **could** cause you to pay more **than** you **have** to and that the "prime **booking** window" where the best fares are available usually ranges ... If you **want** to **travel** on weekends, especially, reasonably priced seats on those **flights can** be extremely hard to **come** by.

When should you buy your airline ticket? Here's what our data has to ...
https://www.cheapair.com/.../travel.../when-should-you-buy-your-airline-ticket-heres-...
Apr 11, 2014 - This **doesn't** necessarily mean to buy early – in fact, most of the time **we** suggest waiting. **But** you **want** to become familiar with the market on your exact **travel** dates so you know what's a good fare, what's not, and what's realistic. If you check **back** frequently, you **will** likely catch fares that are both on the **high** ...

[PDF] **Introduction to semantic parsing**
https://web.stanford.edu/class/cs224u/materials/cs224u-2016-intro-semparse.pdf
by B MacCartney - 2016
May 4, 2016 - **Travel** reservations. **Yes**, **hi**, I **need** to **book** a **flight** for **myself** and **my husband** from **SFO** to **Boston**. **Actually Oakland would** be **OK too**. **We need** to **fly out** on **Friday** the **12th**, and **then** I **could come back** on **Sunday evening** or **Monday morning**, **but he won**'t return until Wednesday the 18th, because **he's** ...

Chatbots

https://cdn.cultofmac.com/wp-content/uploads/2011/11/iphone-4s-siri.jpg

Let’s talk about Carbon Emissions

- Which country had the highest carbon emissions last year?

Carbon Emissions

- You may want to parse the natural language into database query
- Which country had the highest carbon emissions in 2014?

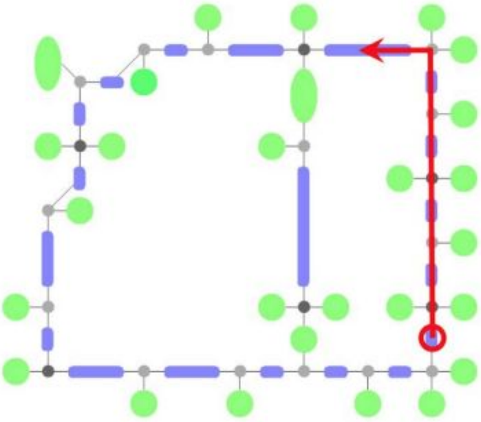
```sql
SELECT   country.name
FROM     country, co2_emissions
WHERE    country.id = co2_emissions.country_id
AND      co2_emissions.year = 2014
ORDER BY co2_emissions.volume DESC
LIMIT    1;
```

Let’s control terminators!!! (while we can :P)

- For a robot control application, you might want a custom-designed procedural language.

Go to the third junction and take a left.

```
(do-sequentially
  (do-n-times 3
    (do-sequentially
      (move-to forward-loc)
      (do-until
        (junction current-loc)
        (move-to forward-loc))))
  (turn-left))
```



Using smartphones through Natural Language

For smartphone voice commands, you might want relatively simple meaning representations, with *intents* and *arguments*:

directions to SF by train

```
(TravelQuery
  (Destination /m/0d6lp)
  (Mode TRANSIT))
```

angelina jolie net worth

```
(FactoidQuery
  (Entity /m/0f4vbz)
  (Attribute /person/net_worth))
```

weather friday austin tx

```
(WeatherQuery
  (Location /m/0vzm)
  (Date 2013-12-13))
```

text my wife on my way

```
(SendMessage
  (Recipient 0x31cbf492)
  (MessageType SMS)
  (Subject "on my way"))
```

play sunny by boney m

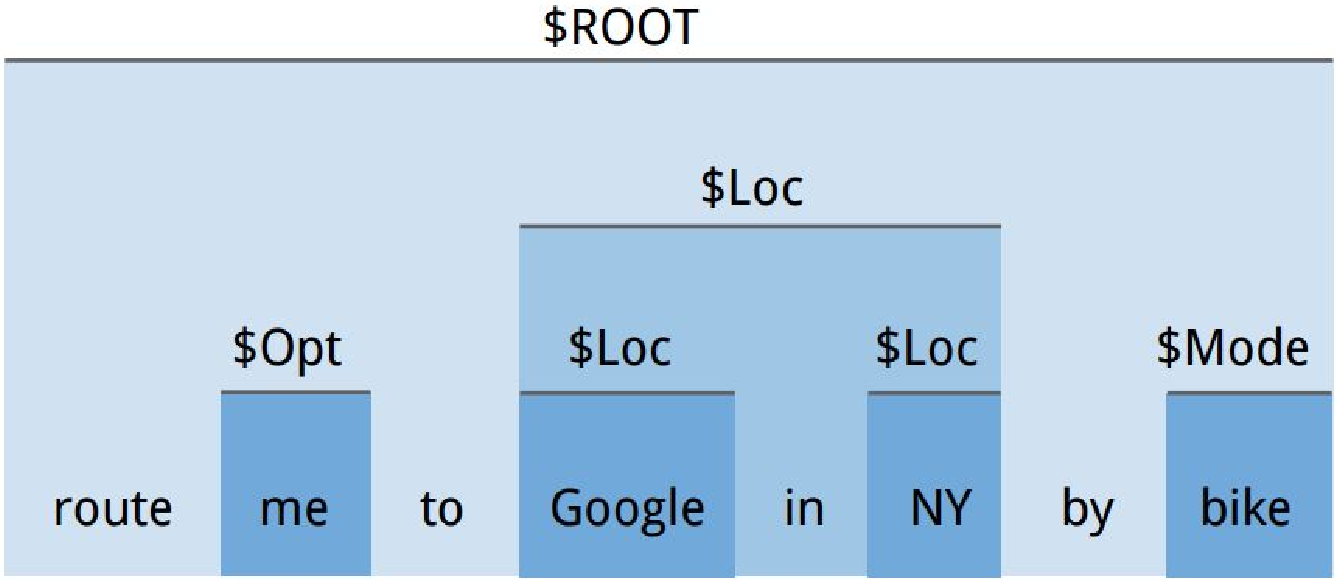
```
(PlayMedia
  (MediaType MUSIC)
  (SongTitle "sunny")
  (MusicArtist /m/017mh))
```

is REI open on sunday

```
(LocalQuery
  (QueryType OPENING_HOURS)
  (Location /m/02nx4d)
  (Date 2013-12-15))
```

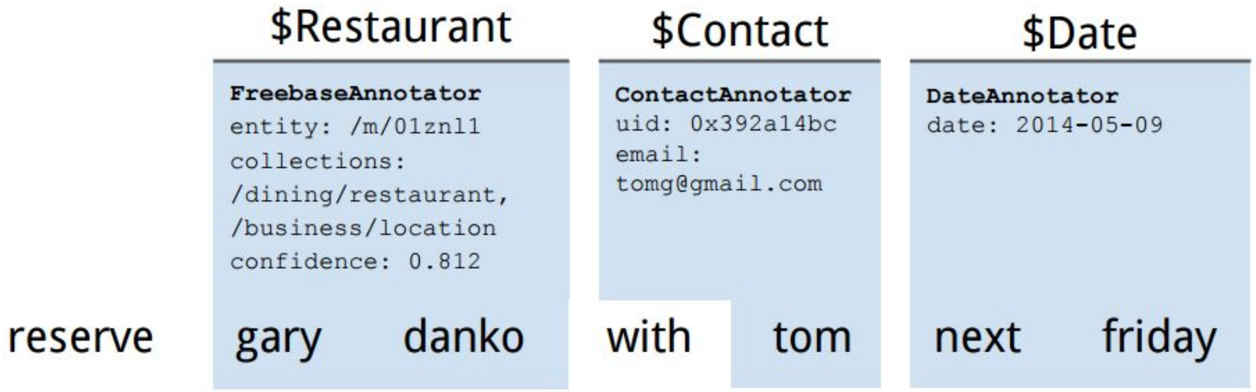
Intent, Argument Classification Problem!

A simple yet elegant parse of sentence



Annotations from Large data

- Don’t want a million rules like: $Loc → NY
- Instead, leverage intelligence of special-purpose annotators



Learning

- If we want to understand natural language completely and precisely, we need to do learning.
  - That is, translate natural language into a formal meaning representation on which a machine can act in a scalable way.

Summary

We map queries into structured representations of meaning using:

- Leverage parsers and annotators for entities...
- Classify intents, arguments from the entities extracted
- Typically requires lots and lots and lots of data!

Demo with SippyCup

- SippyCup is a simple semantic parser, written in Python, created purely for didactic purposes.
- The design favors simplicity and readability over efficiency and performance.
- The goal is to make semantic parsing look easy!
- Examples:
  - Notebook 0: Introduction to Semantic Parsing & SippyCup
  - Notebook 1: Natural Language Arithmetic
  - Notebook 2: Travel Queries
  - Notebook 3: Geography Queries

References

- Prof. Liang’s CS221 Lecture Logic III
- Prof. Potts and Prof. MacCartney’s CS224U Semantic Parsing Lecture
- https://plato.stanford.edu/entries/lambda-calculus/