Natural Language Understanding

- We want to communicate with computers using natural language (spoken and written).
  - unstructured natural language — allow any statements, but make mistakes or failure.
  - controlled natural language — only allow unambiguous statements with fixed vocabulary (e.g., in supermarkets or for doctors).
- There is a vast amount of information in natural language.
- Understanding language to answer questions is more difficult than extracting gestalt properties such as topic, or choosing a web page.
- Many of the problems of AI are explicit in natural language understanding. "AI complete".

Syntax, Semantics, Pragmatics

- Syntax describes the form of language (using a grammar).
- Semantics provides the meaning of language.
- Pragmatics explains the purpose or the use of language (how utterances relate to the world).

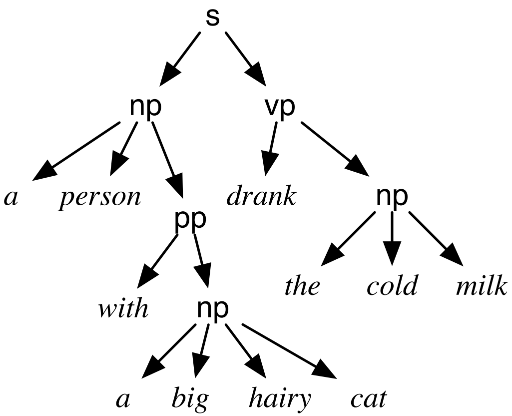
Examples:

- *This lecture is about natural language.*
- *The green frogs sleep soundly.*
- *Colorless green ideas sleep furiously.*
- *Furiously sleep ideas green colorless.*

Beyond N-grams

- *A person with a big hairy cat drank the cold milk.*
- Who or what drank the milk?

Simple parse tree:



Context-free grammar

- A terminal symbol is a string representing a word (perhaps including punctuation and composite words, such as "hot dog" or "Buenos Aires").
- A non-terminal symbol can be rewritten as a sequence of terminal and non-terminal symbols, e.g.,

$$sentence \longmapsto noun\_phrase, verb\_phrase$$

$$verb\_phrase \longmapsto verb, noun\_phrase$$

$$verb \longmapsto [''drank'']$$

- Can be written as a logic program, where a sentence is a sequence of words:

$$sentence(S) \leftarrow noun\_phrase(N), verb\_phrase(V), append(N, V, S).$$

$$verb\_phrase(P) \leftarrow verb(V), noun\_phrase(N), append(V, N, P).$$

To say word "drank" is a verb:

$$verb([''drank'']).$$

Difference Lists

- Non-terminal symbol s becomes a predicate with two arguments, $s(T_1, T_2)$, meaning:
  - T_2 is an ending of the list T_1
  - all of the words in T_1 before T_2 form a sequence of words of the category s.
- Lists T_1 and T_2 together form a difference list.
- "the student" is a noun phrase:

$$noun\_phrase(["the", "student", "passed", "the", "course"], \\ ["passed", "the", "course"])$$

- The words "drank" and "passed" are verbs:

$$verb(["drank" \mid W], W).$$

$$verb(["passed" \mid W], W).$$

Definite clause grammar

The grammar rule

$$sentence \longmapsto noun\_phrase, verb\_phrase$$

represented as: there is a sentence between T_0 and T_2 if there is a noun phrase between T_0 and T_1 and a verb phrase between T_1 and T_2:

$$\begin{aligned}
& sentence(T_0, T_2) \leftarrow \\
& \qquad noun_phrase(T_0, T_1) \wedge \\
& \qquad verb_phrase(T_1, T_2).
\end{aligned}$$

$$\overbrace{\underbrace{T_0 \qquad\qquad\qquad\qquad}_{noun\_phrase}\underbrace{T_1 \qquad\qquad\qquad\qquad}_{verb\_phrase}}^{sentence} T_2$$

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Definite clause grammar rules

The rewriting rule

$$h \longmapsto b_1, b_2, \ldots, b_n$$

says that h is b_1 followed by b_2, ..., followed by b_n:

$$\begin{aligned} & h(T_0, T_n) \leftarrow \\ & \qquad b_1(T_0, T_1) \land \\ & \qquad b_2(T_1, T_2) \land \\ & \qquad \vdots \\ & \qquad b_n(T_{n-1}, T_n). \end{aligned}$$

using the interpretation

$$\overbrace{\underbrace{T_0 \qquad\qquad}_{b_1} \underbrace{T_1 \qquad\qquad}_{b_2} T_2 \cdots \underbrace{T_{n-1} \qquad\quad}_{b_n}}^{h} T_n$$

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Terminal Symbols

Non-terminal h gets mapped to the terminal symbols, $t_1, ..., t_n$:

$$h([t_1, \cdots, t_n \mid T], T)$$

using the interpretation

$$\overbrace{t_1, \cdots, t_n}^{h} T$$

Thus, $h(T_1, T_2)$ is true if $T_1 = [t_1, ..., t_n \mid T_2]$.

Context Free Grammar Example

see
`https://artint.info/3e/resources/ch15/geography_CFG.pl`

(also load `https://artint.info/3e/resources/ch15/geography_DB.pl`)

What will the following query return?

```
noun_phrase(["a","country","that","borders","Chile"], L3).
```

How many answers does the following query have?

```
noun_phrase(["a", "Spanish", "speaking", "country",
             "that", "borders", "Chile"], L3).
```

Example

```
% a noun phrase is a determiner followed by adjectives
% followed by a noun followed by a prepositional phrase.
noun_phrase(L0,L4) :-
   det(L0,L1),
   adjectives(L1,L2),
   noun(L2,L3),
   pp(L3,L4).
% dictionary for determiners
det(L,L).
det(["a"|L],L).
det(["the"|L],L).
% adjectives is a sequence of adjectives
adjectives(L,L).
adjectives(L0,L2) :-
    adj(L0,L1),
    adjectives(L1,L2).
```

Clicker Question

If the query for the grammar rule

`noun_phrase([the,cat,on,the,mat,sat,on,the,hat], R).`

returns with substitution `R=[sat,on,the,hat]`
What is the noun-phrase it found?

A the cat

B the mat

C the cat on the mat

D sat on the hat

E either “the cat”, “the mat” or “the hat”, we can’t tell

Clicker Question

If the query for the grammar rule

```
noun_phrase([the,cat,on,the,mat,sat,on,the,hat], R).
```

returns with `R=[on,the,mat,sat,on,the,hat]`
What is the noun-phrase it found?

A the cat

B the mat

C the cat on the mat

D sat on the hat

E either "the cat", "the mat" or "the hat", we can't tell

Augmenting the Grammar

Two mechanisms can make the grammar more expressive:

- extra arguments to the non-terminal symbols
- arbitrary conditions on the rules.

We have a Turing-complete programming language at our disposal!

Question-answering

- How can we get from natural language directly to the answer?
- Goal: map natural language to a query that is asked of a knowledge base.
- Add arguments representing the individual

  $$noun\_phrase(T_0, T_1, O)$$

  means
  - $T_0 - T_1$ is a difference list forming a noun phrase.
  - The noun phrase refers to the individual O.
- Can be implemented by the parser directly calling the knowledge base.

Example natural language to query

see
https://artint.info/3e/resources/ch15/geography_QA.pl

Noun Phrases

```
% A noun phrase is a determiner followed by adjectives foll
% by a noun followed by an optional modifying phrase.
% They all refer to the same individual.
noun_phrase(L0, L4, Ind) :-
    det(L0, L1, Ind),
    adjectives(L1, L2, Ind),
    noun(L2, L3, Ind),
    omp(L3, L4, Ind).
```

Adjectives provide properties

```
% adj(T0,T1,Entity) is true if T0-T1
% is an adjective that is true of Entity
adj(["large" | L], L, Ind) :- large(Ind).
adj([LangName, "speaking" | L], L, Ind) :-
    language(Ind, Lang), name(Lang, LangName).

% adjectives(T0,T1,Entity) is true if
% T0-T1 is a sequence of adjectives that true of Entity
adjectives(T0,T2,Entity) :-
    adj(T0,T1,Entity),
    adjectives(T1,T2,Entity).
adjectives(T,T,_).
```

Verbs and propositions provide relations

reln($T0$, $T1$, *Subject*, *Object*)

- $T0 - T1$ is a verb or preposition that provides
- a relation that true between *Subject* and *Object*

```
reln(["borders" | L], L, Sub, Obj) :- borders(Sub, Obj).
reln(["bordering" | L], L, Sub, Obj) :- borders(Sub, Obj).
reln(["next", "to" | L], L, Sub, Obj) :- borders(Sub, Obj).
reln(["the", "capital", "of" | L], L, Sub, Obj) :-
     capital(Obj, Sub).
reln(["the", "name", "of" | L], L, Sub, Obj) :-
     name(Obj, Sub).
```

Verbs and propositions provide relations

```
% A  modifying phrase / relative clause is either
% a relation (verb or preposition)
%     followed by a noun_phrase or
% 'that' followed by a relation then a noun_phrase
mp(L0, L2, Subject) :-
    reln(L0, L1, Subject, Object),
    aphrase(L1, L2, Object).
mp(["that" | L0], L2, Subject) :-
    reln(L0, L1, Subject, Object),
    aphrase(L1, L2, Object).

% An optional modifying phrase is either a modifying phrase
omp(L0,L1,E) :-
    mp(L0,L1,E).
omp(L, L, _).
```

Real-world queries

- Want a tokenizer: mapping from strings to sequence of words. `readln` provides a simple one.
- What should the system do with ungrammatical sentences?
- What should the system do with new words?
- What about pronoun references?

  > *The student took many courses. Two computer science courses and one mathematics course were particularly difficult.* The mathematics course...
  >
  > *Who was the captain of the Titanic?*
  >
  > *Was she tall?*

- And other tricky and subtle aspects of English?

  — program them

  — learn them

Question-answering

- How can we get from natural language to a query or to logical statements?
- Goal: map natural language to a query that can be asked of a knowledge base.
- Add arguments representing the individual and the relations about that individual. E.g.,

  $$noun\_phrase(T_0, T_1, O, C_0, C_1)$$

  means
  - $T_0 - T_1$ is a difference list forming a noun phrase.
  - The noun phrase refers to the individual O.
  - C_0 is list of previous relations.
  - C_1 is C_0 together with the relations on individual O given by the noun phrase.

Building a list of constraints on the entity (geography_QA_query.pl)

$noun\_phrase(L0, L4, Entity, C0, C4)$ is true if

- $L0$ and $L4$ are list of words, such that
  - $L4$ is an ending of $L0$
  - the words in $L0$ before $L4$ (written $L0 - L4$) form a noun phrase
- Entity is an individual that the noun phrase is referring to
- C0 is a list such that $C4$ is an ending of $C0$ and $C0 - C4$ contains the constraints imposed by the noun phrase

```
noun_phrase(L0,L4,Entity,C0,C4) :-
    det(L0,L1,Entity,C0,C1),
    adjectives(L1,L2,Entity,C1,C2),
    noun(L2,L3,Entity,C2,C3),
    mp(L3,L4,Entity,C3,C4).
```

Example natural language to query

see
`https://artint.info/3e/resources/ch15/geography_QA.pl`
ALso load
`https://artint.info/3e/resources/ch15/geography_DB.pl`

Context and world knowledge

The student took many courses. Two computer science courses and one mathematics course were particularly difficult. The mathematics course...

Who was the captain of the Titanic?

Was she tall?