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- 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".

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- *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.*
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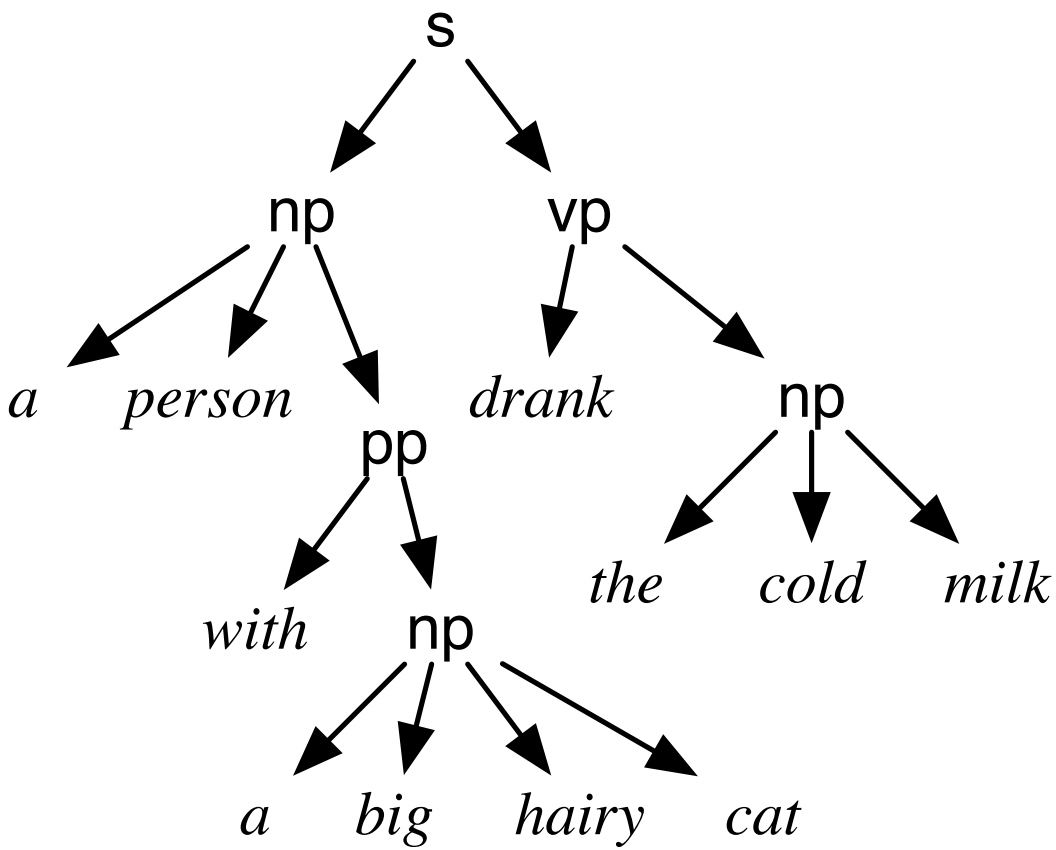
Simple parse tree:



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$$\mathit{sentence} \longmapsto \mathit{noun\_phrase}, \mathit{verb\_phrase}$$

$$\mathit{verb\_phrase} \longmapsto \mathit{verb}, \mathit{noun\_phrase}$$

$$\mathit{verb} \longmapsto [\text{"}\mathit{drank}\text{"}]$$

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

$$verb \longmapsto [\text{"}drank\text{"}]$$

- 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:

$verb([\text{"}drank\text{"}]).$

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
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- "the student" is a noun phrase:

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

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

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

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

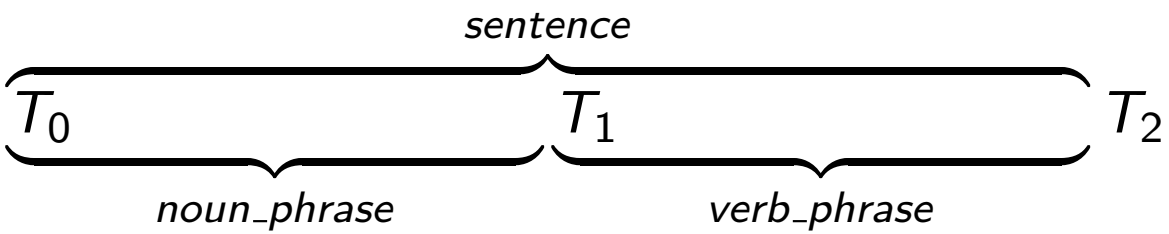
Definite clause grammar

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:

$$sentence(T_0, T_2) \leftarrow$$
$$\quad noun\_phrase(T_0, T_1) \wedge$$
$$\quad verb\_phrase(T_1, T_2).$$



Definite clause grammar rules

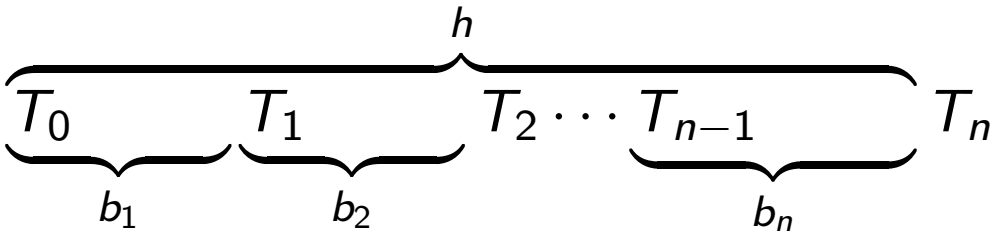
The rewriting rule

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

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

$$h(T_0, T_n) \leftarrow$$
$$b_1(T_0, T_1) \wedge$$
$$b_2(T_1, T_2) \wedge$$
$$\vdots$$
$$b_n(T_{n-1}, T_n).$$

using the interpretation



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).
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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

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

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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.
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- 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).
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% 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).
```

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```
% 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, _).
```

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  — program them
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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)

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