Contents

- Communication
- Phrase Structure Grammar
- Syntactic Analysis
- Perspective
Speech Acts

Speech acts achieve the speaker's goals:

- **Inform**: ``There's a pit in front of you''
- **Query**: ``Can you see the gold?''
- **Command**: ``Pick it up''
- **Promise**: ``I'll share the gold with you''
- **Acknowledge**: ``OK''

Speech act planning requires knowledge of:

- Situation
- Semantic and syntactic conventions
- Hearer's goals, knowledge base, and rationality
Stages in communication (informing)

- **Intention**: S wants to inform H that P
- **Generation**: S selects words W to express P in context C
- **Synthesis**: S utters words W
- **Perception**: H perceives W in context C’
- **Analysis**: H infers possible meanings P₁, … Pₙ
- **Disambiguation**: H infers intended meaning Pᵢ
- **Incorporation**: H incorporates Pᵢ into KB

How could this go wrong?
- **Insincerity**: S doesn't believe P
- **Speech wreck**: ignition failure
- **Ambiguous utterance**
- **Differing understanding of current context C<->C’**
Stages in communication (informing)

Intention:

\[ \text{Know}(H, \neg \text{Alive}(Wumpus, S_3)) \]

Generation:

"The wumpus is dead"

Synthesis:

[thawmpaxsizdehd]

Perception:

"The wumpus is dead"

Analysis:

(Semantic Interpretation):

\[ \neg \text{Alive}(Wumpus, \neg) \]

\[ \text{Tired}(Wumpus, \neg) \]

(Pragmatic Interpretation):

\[ \neg \text{Alive}(Wumpus, S_3) \]

\[ \text{Tired}(Wumpus, S_3) \]

Disambiguation:

\[ \neg \text{Alive}(Wumpus, S_3) \]

Incorporation:

\[ \text{TELL}(\text{KB}, \neg \text{Alive}(Wumpus, S_3)) \]
Speech Acts

- Animals use isolated symbols for sentences
  - restricted set of communicable propositions, no *generative capacity*
- Grammar specifies the compositional structure of complex message (speech, language, music)
- A formal language is a set of strings of terminal symbols
- Each string in the language can be analyzed/generated by the grammar
- The grammar is a set of rewrite rules,
  - e.g.,

\[
S \rightarrow NP \ VP \\
Article \rightarrow \text{the} \mid \text{a} \mid \text{an} \mid \ldots
\]

- Here *S* is the *sentence* symbol, *NP* and *VP* are *nonterminals*, and *the, a ... terminals*
Grammar Types

Regular: \( \text{nonterminal} \rightarrow \text{terminal}[^{\text{nonterminal}}] \)

\[
S \rightarrow aS \\
S \rightarrow \Lambda
\]

Context-free: \( \text{nonterminal} \rightarrow \text{anything} \)

\[
S \rightarrow aSb
\]

Context-sensitive: more nonterminals on right-hand side

\[
ASB \rightarrow AAaBB
\]

Recursively enumerable: no constraints

Natural language probably context-free
The Wumpus Lexicon

Noun → stench | breeze | glitter | nothing
| wumpus | pit | pits | gold | east | ...

Verb → is | see | smell | shoot | feel | stinks
| go | grab | carry | kill | turn | ...

Adjective → right | left | east | south | back | smelly | ...

Adverb → here | there | nearby | ahead
| right | left | east | south | back | ...

Pronoun → me | you | I | it | S/HE | Y’ALL...

Name → John | Mary | Boston | UCB | PAJC | ...

Article → the | a | an | ...

Preposition → to | in | on | near | ...

Conjunction → and | or | but | ...

Digit → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Divided into open and closed classes
The Wumpus Grammar

\[ S \rightarrow NP \ VP \quad \text{l + feel a breeze } \]
\[ \quad \mid S \ Conjunction \ S \quad \text{l feel a breeze + and + l smell a v} \]

\[ NP \rightarrow Pronoun \quad \text{l} \]
\[ \quad \mid Noun \quad \text{pits} \]
\[ \quad \mid Article \ Noun \quad \text{the + wumpus} \]
\[ \quad \mid Digit \ Digit \quad 3 4 \]
\[ \quad \mid NP \ PP \quad \text{the wumpus + to the east} \]
\[ \quad \mid NP \ RelClause \quad \text{the wumpus + that is smelly} \]

\[ VP \rightarrow Verb \quad \text{stinks} \]
\[ \quad \mid VP \ NP \quad \text{feel + a breeze} \]
\[ \quad \mid VP \ Adjective \quad \text{is + smelly} \]
\[ \quad \mid VP \ PP \quad \text{turn + to the east} \]
\[ \quad \mid VP \ Adverb \quad \text{go + ahead} \]

\[ PP \rightarrow Preposition \ NP \quad \text{to + the east} \]
\[ RelClause \rightarrow that \ VP \quad \text{that + is smelly} \]
Grammatical Judgements

Formal language $L_1$ may well differ from natural language $L_2$.

Adjusting is a learning problem.

Real grammars typically 10-500 pages, insufficient for proper English.
Parse Trees
Exhibit the grammatical structure of a sentence

S
  NP
  Pronoun
  I
  VP
  Verb
  shoot
  VP
  Article
  the
  NP
  Noun
  wumpus
Syntax in NLP

Most view syntactic structure as an essential step towards meaning

```
``Mary hit John'' <> ``John hit Mary''
```

```
``And since I was not informed---as a matter of fact, since I did not know that there were excess funds until we, ourselves, in that checkup after the whole thing blew up, and that was, if you'll remember, that was the incident in which the attorney general came to me and told me that he had seen a memo that indicated that there were no more funds.''
```

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Parsing CFGs

Many different parsing algorithms

- Top-down
- Bottom-up
- Chart-parsing (aka CYK algorithm)
  - Dynamic programming
  - $O(n^3)$

[S: [NP :[Pronoun:I]]
 [VP :[VP:[Verb:shoot]]
  [NP:[Article:the][Noun:wumpus]]]]
Top-down parsing

- Initial state: [S: ?]
- Successor function:
  - Select rules for leftmost node in tree with unknown children and apply
  - [S:[S:?][Conjunction:?][S:?]]
  - [S:[NP:?][VP:?]]
- Goal Test:
  - Check whether leaves of the parse tree correspond to (complete) input

Problem for Top-down: left-recursive rules S -> S Conjunction S
infinite loops
Top-down parsing

Successful top-down parse

[S: ?]
[S:[NP:?][VP:?]]
[S:[NP:[Art:?][Noun:?]][VP:?]]
[S:[NP:[Art:The][Noun:wumpus]][VP:?]]
[S:[NP:[Art:The][Noun:wumpus]][VP:[Verb:?]]]
[S:[NP:[Art:The][Noun:wumpus]][VP:[Verb:stinks]]]

Alternative notation

S  [The, wumpus, stinks]
NP VP [The, wumpus, stinks]
Art Noun VP [The, wumpus, stinks]
Noun VP [wumpus, stinks]
VP [stinks]
Verb [stinks]
[] []
Bottom up parsing

- Initial state
  - [the, wumpus, is, dead]
- Successor function
  - If subsequence at pos i matches right-hand of rule then replace by left hand
  - [[Art:the], wumpus, is, dead]
- Goal state:
  - A single state with root S

Problem for Bottom up:
Art -> []
Bottom up

- [the, wumpus, is, dead]
- [[Art:the],wumpus,is,dead]
- [[Art:the][Noun:wumpus],is,dead]
- [[NP:[Art:the][Noun:wumpus]],is,dead]
- [[NP:[Art:the][Noun:wumpus]],[Verb:is],dead]
- [[NP:[Art:the][Noun:wumpus]],[VP:[Verb:is]],dead]
- [[NP:[Art:the][Noun:wumpus]],[VP:[Verb:is]],[Adj:dead]]
- [[NP:[Art:the][Noun:wumpus]],[VP:[VP:[Verb:is]]],[Adj:dead]]]
- [S:[[[NP:[Art:the][Noun:wumpus]],[VP:[VP:[Verb:is]]],[Adj:dead]]]]
# Bottom up parsing

<table>
<thead>
<tr>
<th>step</th>
<th>list of nodes</th>
<th>subsequence</th>
<th>rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>INIT</td>
<td>the wumpus is dead</td>
<td>the</td>
<td>Article $\rightarrow$ the</td>
</tr>
<tr>
<td>2</td>
<td>Article wumpus is dead</td>
<td>wumpus</td>
<td>Noun $\rightarrow$ wumpus</td>
</tr>
<tr>
<td>3</td>
<td>Article Noun is dead</td>
<td>Article Noun</td>
<td>NP $\rightarrow$ Article Noun</td>
</tr>
<tr>
<td>4</td>
<td>NP is dead</td>
<td>is</td>
<td>Verb $\rightarrow$ is</td>
</tr>
<tr>
<td>5</td>
<td>NP Verb dead</td>
<td>dead</td>
<td>Adjective $\rightarrow$ dead</td>
</tr>
<tr>
<td>6</td>
<td>NP Verb Adjective</td>
<td>Verb</td>
<td>VP $\rightarrow$ Verb</td>
</tr>
<tr>
<td>7</td>
<td>NP VP Adjective</td>
<td>VP Adjective</td>
<td>VP $\rightarrow$ VP Adjective</td>
</tr>
<tr>
<td>8</td>
<td>NP VP</td>
<td>NP VP</td>
<td>S $\rightarrow$ NP VP</td>
</tr>
<tr>
<td>Goal</td>
<td>S</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chart parsing

- Have the students in B.Sc. Informatik take the exam of AI.
- Have the students in B.Sc. Informatik taken the exam of AI?
- Double work
  - Dynamic programming - combine bottom-up and top-down
- Chart:
  - N+1 vertices
  - Labeled edges, e.g. $[0, 2 \stackrel{S \rightarrow NP}{\rightarrow} VP]$
    - Denotes that from 0 to 2 we have a NP, and if we find a VP, from 2 to k then we have an S from 0 to k
Chart parsing

- **Initialization**
  - Add edge $[0,0 \text{ S' -> * S}]$
  - Call scanner on all words

- **Convention**:
  - **non-terminal** - upper case
  - **sequence** - lower case

- **Add edge** $[i,j \text{ A -> b * c}]
  - if c is empty then call extender on edge
  - else call predictor on edge

- **Predictor** $[i,j \text{ A -> b * C E}]$
  - top-down
  - With (all) rules C -> d
  - Add edge $[i,j \text{ A -> b * d E}]$

- **Extender** $[j,k \text{ B -> c *}]$
  - bottom-up
  - With (all) edges $[i,j \text{ A -> d* B e}]$
  - Add edge $[i,k \text{ A -> d c * e}]$

- **Scanner** $[j,k \text{ A -> b * D c}]$
  - bottom-up
  - Word of type D at position k
  - Add edge $[j,k+1 \text{ A -> b D * c}]$
function CHART-PARSE(words, grammar) returns chart

chart ← array[0...LENGTH(words)] of empty lists
ADD-EDGE([0, 0, S' → • S])
for i ← from 0 to LENGTH(words) do
  SCANNER(i, words[i])
return chart

procedure ADD-EDGE(edge)
  /* Add edge to chart, and see if it extends or predicts another edge. */
  if edge not in chart[END(edge)] then
    append edge to chart[END(edge)]
    if edge has nothing after the dot then EXTENDER(edge)
    else PREDICTOR(edge)

procedure SCANNER(j, word)
  /* For each edge expecting a word of this category here, extend the edge. */
  for each [i, j, A → α • B β] in chart[j] do
    if word is of category B then
      ADD-EDGE([i, j+1, A → α B • β])
  
procedure PREDICTOR([i, j, A → α • B β])
  /* Add to chart any rules for B that could help extend this edge */
  for each (B → γ) in REWRITES-FOR(B, grammar) do
    ADD-EDGE([j, j, B → • γ])

procedure EXTENDER([j, k, B → γ •])
  /* See what edges can be extended by this edge */
  e_B ← the edge that is the input to this procedure
  for each [i, j, A → α • B' β] in chart[j] do
    if B = B' then
      ADD-EDGE([i, k, A → α e_B • β])
A completed chart

Diagram details:
- a:S'/S
- b:S/NP VP
- c:NP/Pronoun
- d:NP
- e:S/VP
- f:VP/Verb
- g:VP/VP NP
- h:VP
- i:VP/NP
- k:NP
- l:VP
- m:S
- feel
- it

Numbers:
- 0
- 1
- 2
- 3
# Chart Parse Trace

<table>
<thead>
<tr>
<th>Edge</th>
<th>Procedure</th>
<th>Derivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>INITIALIZER</td>
<td>$[0, 0, S' \rightarrow \bullet S]$</td>
</tr>
<tr>
<td>b</td>
<td>PREDICTOR(a)</td>
<td>$[0, 0, S \rightarrow \bullet NP \ VP]$</td>
</tr>
<tr>
<td>c</td>
<td>PREDICTOR(b)</td>
<td>$[0, 0, NP \rightarrow \bullet Pronoun]$</td>
</tr>
<tr>
<td>d</td>
<td>SCANNER(c)</td>
<td>$[0, 1, NP \rightarrow Pronoun \bullet]$</td>
</tr>
<tr>
<td>e</td>
<td>EXTENDER(b,d)</td>
<td>$[0, 1, S \rightarrow NP \bullet VP]$</td>
</tr>
<tr>
<td>f</td>
<td>PREDICTOR(e)</td>
<td>$[1, 1, VP \rightarrow \bullet Verb]$</td>
</tr>
<tr>
<td>g</td>
<td>PREDICTOR(e)</td>
<td>$[1, 1, VP \rightarrow \bullet VP \ NP]$</td>
</tr>
<tr>
<td>h</td>
<td>SCANNER(f)</td>
<td>$[1, 2, VP \rightarrow Verb \bullet]$</td>
</tr>
<tr>
<td>i</td>
<td>EXTENDER(g,h)</td>
<td>$[1, 2, VP \rightarrow VP \bullet NP]$</td>
</tr>
<tr>
<td>j</td>
<td>PREDICTOR(g)</td>
<td>$[2, 2, NP \rightarrow \bullet Pronoun]$</td>
</tr>
<tr>
<td>k</td>
<td>SCANNER(j)</td>
<td>$[2, 3, NP \rightarrow Pronoun \bullet]$</td>
</tr>
<tr>
<td>l</td>
<td>EXTENDER(i,k)</td>
<td>$[1, 3, VP \rightarrow VP \ NP \bullet]$</td>
</tr>
<tr>
<td>m</td>
<td>EXTENDER(e,l)</td>
<td>$[0, 3, S \rightarrow NP \ VP \bullet]$</td>
</tr>
</tbody>
</table>

**Figure 22.9** Trace of a parse of “0 I 1 feel 2 it 3.” For each edge a-m, we show the procedure used to derive the edge from other edges already in the chart. Some edges were omitted for brevity.
Definite Clause Grammars

- A form of unification based grammar
- Nonterminals become atomic expressions
  - $s(\text{Num}) \rightarrow \text{np}(\text{Num}), \text{vp}(\text{Num})$
  - $\text{Num}$ is a variable
  - Binds to singular and plural
- Employ unification during parsing.
- Directly executable in Prolog
- Rules directly translate to (definite) clause logic
- Next slides employ Prolog notation
  - Running examples with e.g. YAP prolog or SWI prolog
Non-terminals with arguments

sentence  \(\rightarrow\) noun_phrase\((N)\), verb_phrase\((N)\).
noun_phrase  \(\rightarrow\) article\((N)\), noun\((N)\).
verb_phrase\((N)\)  \(\rightarrow\) intransitive_verb\((N)\).
article\((\text{singular})\)  \(\rightarrow\) [a].
article\((\text{singular})\)  \(\rightarrow\) [the].
article\((\text{plural})\)  \(\rightarrow\) [the].
noun\((\text{singular})\)  \(\rightarrow\) [turtle].
noun\((\text{plural})\)  \(\rightarrow\) [turtles].
intransitive_verb\((\text{singular})\)  \(\rightarrow\) [sleeps].
intransitive_verb\((\text{plural})\)  \(\rightarrow\) [sleep].
Case Marking

pronoun(singular,nominative) --> [he]; [she]
pronoun(singular,accusative) --> [him]; [her]
pronoun(plural,nominative) --> [they]
pronoun(plural,accusative) --> [them]

sentence --> np(Number,nominative), vp(Number)
vp(Number) --> v(Number), np(X,accusative)
np(Number,Case) --> pronoun(Number,Case)
np(Number,X) --> det, n(Number)

He sees her. She sees him. They see her.
But not Them see he.
Principles DCG Parsing

- **Given**
  - $u, l_1, \ldots, l_n$ (goal)
  - $t \rightarrow t_1, \ldots, t_m$ (**renamed**)

- **Generate**
  - $(t_1, \ldots, t_m, l_1, l_2, \ldots, l_n) \Theta$
  - Where $\Theta = \text{mgu}(u, t)$
Top down parsing with DCG

sentence  
np(Num,nom), vp(Num)  
pronoun(Num,nom), vp(Num)  

\[ \Theta = \{ \text{Num} = \text{sing} \} \]  
pronoun(sing,nom) --> [he]  

vp(sing)  

\[ \Theta' = \{ \text{Number} = \text{sing} \} \]  
vp(Number) --> v(Number), np(X,accusative)  

v(sing), np(X,accusative)  
np(X,accusative)  

\[ \Theta'' = \{ X = \text{sing} \} \]  
np(sing,accusative) --> [her]  
pronoun(sing,accusative)  
[]

[He, sees, her]  
[He, sees, her]  
[He, sees, her]  
[he]  
[sees, her]  
[her]  
[her]  
[]
Subcategorization

\[
\begin{array}{ll}
vp & \rightarrow v(1). \\
vp & \rightarrow v(2), \text{ np.} \\
vp & \rightarrow v(3), \text{ np, np.} \\
vp & \rightarrow v(4), s.
\end{array}
\]

<table>
<thead>
<tr>
<th>Verb</th>
<th>Complement</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep</td>
<td>None</td>
<td>The cat slept</td>
</tr>
<tr>
<td>Chase</td>
<td>One NP</td>
<td>The cat chased the dog</td>
</tr>
<tr>
<td>Give</td>
<td>Two NP</td>
<td>John gave Bill the book</td>
</tr>
<tr>
<td>Say</td>
<td>sentence</td>
<td>John said he loved Mary.</td>
</tr>
</tbody>
</table>
Constructing parse trees

\[
\text{sentence}(s(NP,VP)) \rightarrow \text{noun_phrase}(NP), \text{verb_phrase}(VP).
\]
\[
\text{noun_phrase}(np(N)) \rightarrow \text{proper_noun}(N).
\]
\[
\text{noun_phrase}(np(Art,Adj,N)) \rightarrow \text{article}(Art), \text{adjective}(Adj), \text{noun}(N).
\]
\[
\text{noun_phrase}(np(Art,N)) \rightarrow \text{article}(Art), \text{noun}(N).
\]
\[
\text{verb_phrase}(vp(IV)) \rightarrow \text{intransitive_verb}(IV).
\]
\[
\text{verb_phrase}(vp(TV,NP)) \rightarrow \text{transitive_verb}(TV), \text{noun_phrase}(NP).
\]
\[
\text{article}(art(the)) \rightarrow [the].
\]
\[
\text{adjective}(adj(lazy)) \rightarrow [lazy].
\]
\[
\text{adjective}(adj(rapid)) \rightarrow [rapid].
\]
\[
\text{proper_noun}(pn(achilles)) \rightarrow [achilles].
\]
\[
\text{noun}(n(turtle)) \rightarrow [turtle].
\]
\[
\text{intransitive_verb}(iv(sleeps)) \rightarrow [sleeps].
\]
\[
\text{transitive_verb}(tv(beats)) \rightarrow [beats].
\]

?-phrase(sentence(T),[achilles,beats,the,lazy,turtle])
T = s(np(np(achilles)),
    vp(tv(beats),
        np(art(the),
            adj(lazy),
            n(turtle))))
Semantic Interpretation

\[
\begin{align*}
\text{np}(\text{fido}) & \rightarrow [\text{fido}] . \\
\text{np}(\text{felix}) & \rightarrow [\text{felix}] . \\
\text{v}(X^{\text{slept}(X)}) & \rightarrow [\text{slept}] . \\
\text{v}(Y^{(X^{\text{chased}(X,Y)})}) & \rightarrow [\text{chased}] . \\
\text{s}(\text{Pred}) & \rightarrow \text{np}(\text{Subj}) , \text{vp}(\text{Subj}^{\text{Pred}}) . \\
\text{vp}(\text{Subj}^{\text{Pred}}) & \rightarrow \text{v}(\text{Subj}^{\text{Pred}}) . \\
\text{vp}(\text{Subj}^{\text{Pred}}) & \rightarrow \text{v}(\text{Obj}^{(\text{Subj}^{\text{Pred}})}) , \text{np}(\text{Obj}) . \\
\?\text{-phrase}(s(X),[\text{fido, chased, felix}]). \\
X = \text{chased}(\text{fido},\text{felix})
\end{align*}
\]
Lambda Expressions

\( X^{\text{slept}(X)} \) stands for \( \lambda X. \text{slept}(X) \)
\( Y^{(X^{\text{chased}(X,Y)})} \) stands for \( \lambda Y \lambda X. \text{chased}(X,Y) \)

These lambda-expressions denote relationships. They can be instantiated by unification.

With unification:
\( X^{\text{slept}(X)} \) with \( X=\text{fido} \) yields \( \text{fido}^{\text{slept}(\text{fido})} \)
unify \( \text{fido}^{\text{slept}(\text{fido})} \) with \( X^R \)
Yields \( R=\text{slept}(\text{fido}) \)

In lambda-calculus:
\( (\lambda X. \text{slept}(X)) \) \( \text{fido} \) gives \( \text{slept}(\text{fido}) \)
Natural Language Processing

- Complex process
  - Requiring knowledge, reasoning and AI in general
- Grammars to represent natural languages
- Parsing techniques for syntactic analysis
- DCG add expressive power to CFGs
  - Convenient in practice
  - Unification based grammars