

Computational Linguistics (INF2820 — Parsing)

$S \rightarrow NP VP; S \rightarrow S PP; S \rightarrow VP$

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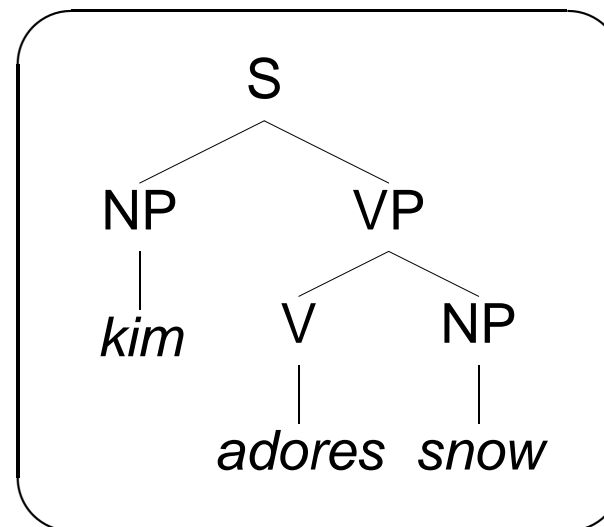
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Background: Trees as Bracketed Sequences

- Trees can be encoded as sequences (*dominance plus precedence*):

```
(S (NP kim)
   (VP (V adored)
        (NP snow)))
```



- the `first()` element (at each level) represents the tree root (or mother);
- all other elements (i.e. the `rest()`) correspond to immediate daughters.



Mildly Mathematically: Context-Free Grammars

- Formally, a *context-free grammar* (CFG) is a quadruple: $\langle C, \Sigma, P, S \rangle$
- C is the set of categories (aka *non-terminals*), e.g. $\{S, NP, VP, V\}$;
- Σ is the vocabulary (aka *terminals*), e.g. $\{\text{Kim, snow, saw, in}\}$;
- P is a set of category rewrite rules (aka *productions*), e.g.

S \rightarrow NP VP
VP \rightarrow V NP
NP \rightarrow Kim
NP \rightarrow snow
V \rightarrow saw

- $S \in C$ is the *start symbol*, a filter on complete ('sentential') results;
- for each rule ' $\alpha \rightarrow \beta_1, \beta_2, \dots, \beta_n$ ' $\in P$: $\alpha \in C$ and $\beta_i \in C \cup \Sigma$; $1 \leq i \leq n$.

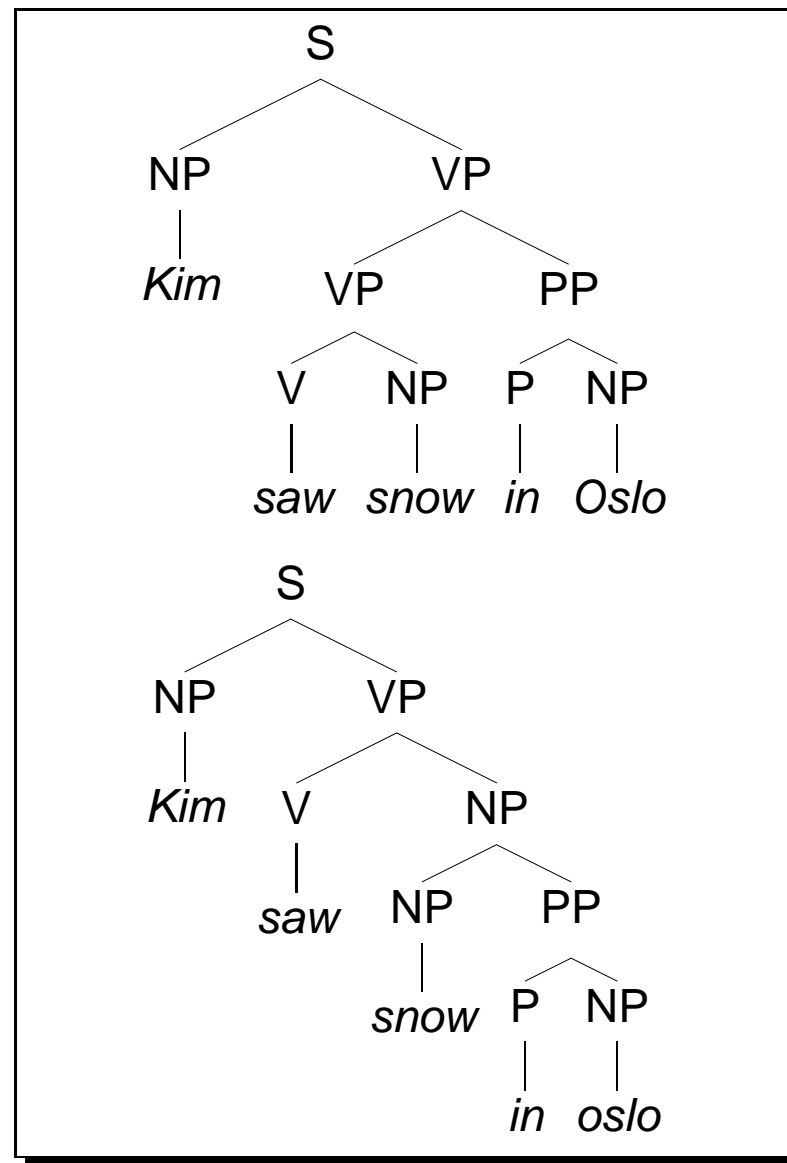


Parsing: Recognizing the Language of a Grammar

- $S \rightarrow NP VP$
- $VP \rightarrow V NP$
- $VP \rightarrow VP PP$
- $NP \rightarrow NP PP$
- $PP \rightarrow P NP$
- $NP \rightarrow Kim \mid snow \mid Oslo$
- $V \rightarrow saw$
- $P \rightarrow in$

All Complete Derivations

- are rooted in the start symbol S ;
- label internal nodes with categories $\in C$, leafs with words $\in \Sigma$;
- instantiate a grammar rule $\in P$ at each local subtree of depth one.



A Simple-Minded Parsing Algorithm

Control Structure

- top-down: given a parsing goal α , use all grammar rules that rewrite α ;
- successively instantiate (extend) the right-hand sides of each rule;
- for each β_i in the RHS of each rule, recursively attempt to parse β_i ;
- termination: when α is a prefix of the input string, parsing succeeds.

(Intermediate) Results

- Each result records a (partial) tree and remaining input to be parsed;
- complete results consume the full input string and are rooted in S ;
- whenever a RHS is fully instantiated, a new tree is built and returned;
- all results at each level are combined and successively accumulated.



The Recursive Descent Parser

```
(defun parse (input goal)
  (if (equal (first input) goal)
      (let ((edge (make-edge :category (first input))))
        (list (make-parse :edge edge :input (rest input))))
      (loop
        for rule in (rules-deriving goal)
        append (extend-parse (rule-lhs rule) nil (rule-rhs rule) input))))
```

```
(defun extend-parse (goal analyzed unanalyzed input)
  (if (null unanalyzed)
      (let ((edge (make-edge :category goal :daughters analyzed)))
        (list (make-parse :edge edge :input input)))
      (loop
        for parse in (parse input (first unanalyzed))
        append (extend-parse
                  goal (append analyzed (list (parse-edge parse)))
                  (rest unanalyzed)
                  (parse-input parse)))))
```

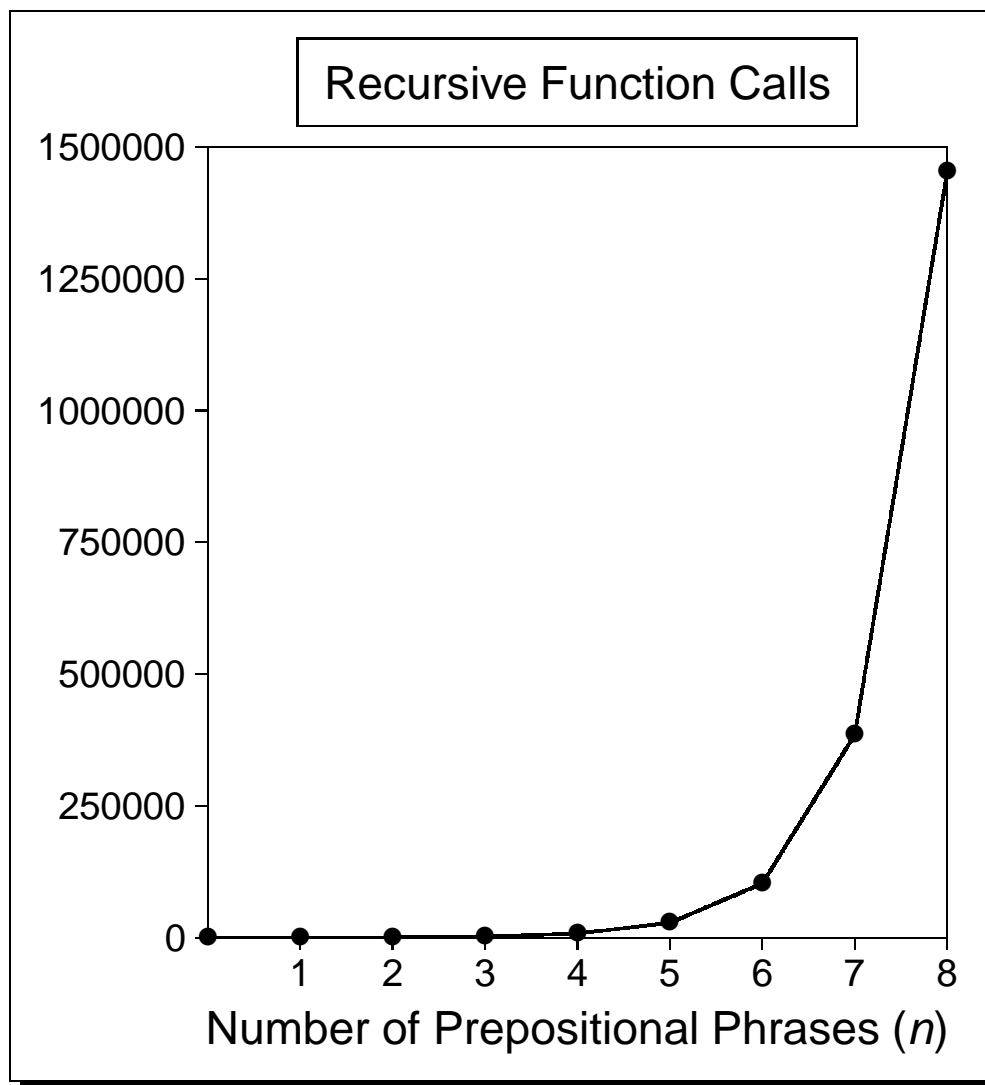


A Closer Look at the Calling Sequence

```
SSP(18): (parse '(kim adored snow) 's)
parse(): input: (KIM ADORED SNOW); goal: S
  parse(): input: (KIM ADORED SNOW); goal: NP
    parse(): input: (KIM ADORED SNOW); goal: KIM
    parse(): input: (KIM ADORED SNOW); goal: SANDY
    parse(): input: (KIM ADORED SNOW); goal: SNOW
  parse(): input: (ADORED SNOW); goal: VP
    parse(): input: (ADORED SNOW); goal: V
      parse(): input: (ADORED SNOW); goal: LAUGHED
      parse(): input: (ADORED SNOW); goal: ADORED
    parse(): input: (ADORED SNOW); goal: V
      parse(): input: (ADORED SNOW); goal: LAUGHED
      parse(): input: (ADORED SNOW); goal: ADORED
    parse(): input: (SNOW); goal: NP
  ...
```



Quantifying the Complexity of the Parsing Task



Kim adores snow (in Oslo)ⁿ

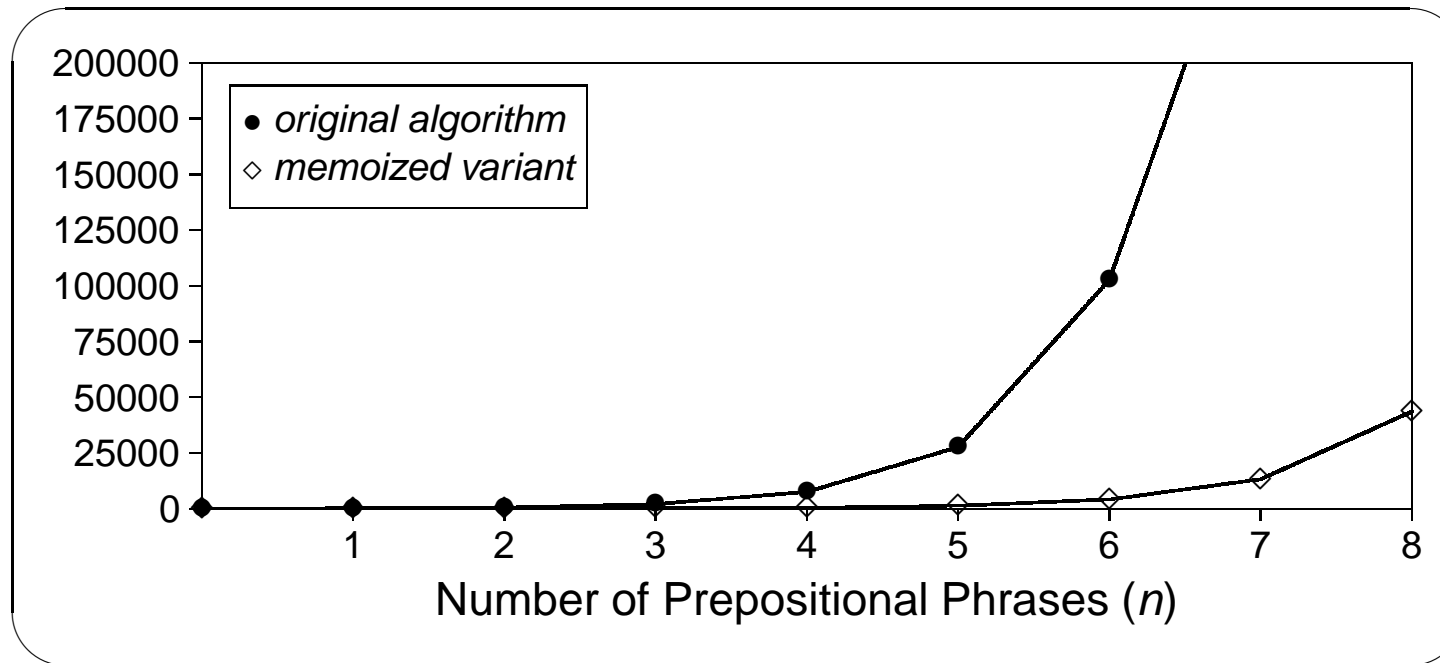
<i>n</i>	trees	calls
0	1	46
1	2	170
2	5	593
3	14	2,093
4	42	7,539
5	132	27,627
6	429	102,570
7	1430	384,566
8	4862	1,452,776
⋮	⋮	⋮



Memoization: Remember Earlier Results

Dynamic Programming

- The function call (parse (adored snow) V) executes two times;
 - *memoization*—record parse() results for each set of arguments;
- requires abstract data type, efficient indexing on *input* and *goal*.



Top-Down vs. Bottom-Up Parsing

Top-Down (Goal-Oriented)

- Left recursion (e.g. a rule like 'VP \rightarrow VP PP') causes infinite recursion;
 - grammar conversion techniques (eliminating left recursion) exist, but will typically be undesirable for natural language processing applications;
- assume bottom-up as basic search strategy for remainder of the course.

Bottom-Up (Data-Oriented)

- unary (left-recursive) rules (e.g. 'NP \rightarrow NP') would still be problematic;
- lack of parsing goal: compute all possible derivations for, say, the input *adores snow*; however, it is ultimately rejected since it is not sentential;
- availability of partial analyses desirable for, at least, some applications.



Chart Parsing — Specialized Dynamic Programming

Basic Notions

- Use *chart* to record partial analyses, indexing them by string positions;
- count inter-word vertices; CKY: chart row is *start*, column *end* vertex;
- treat multiple ways of deriving the same category for some substring as *equivalent*; pursue only once when combining with other constituents.

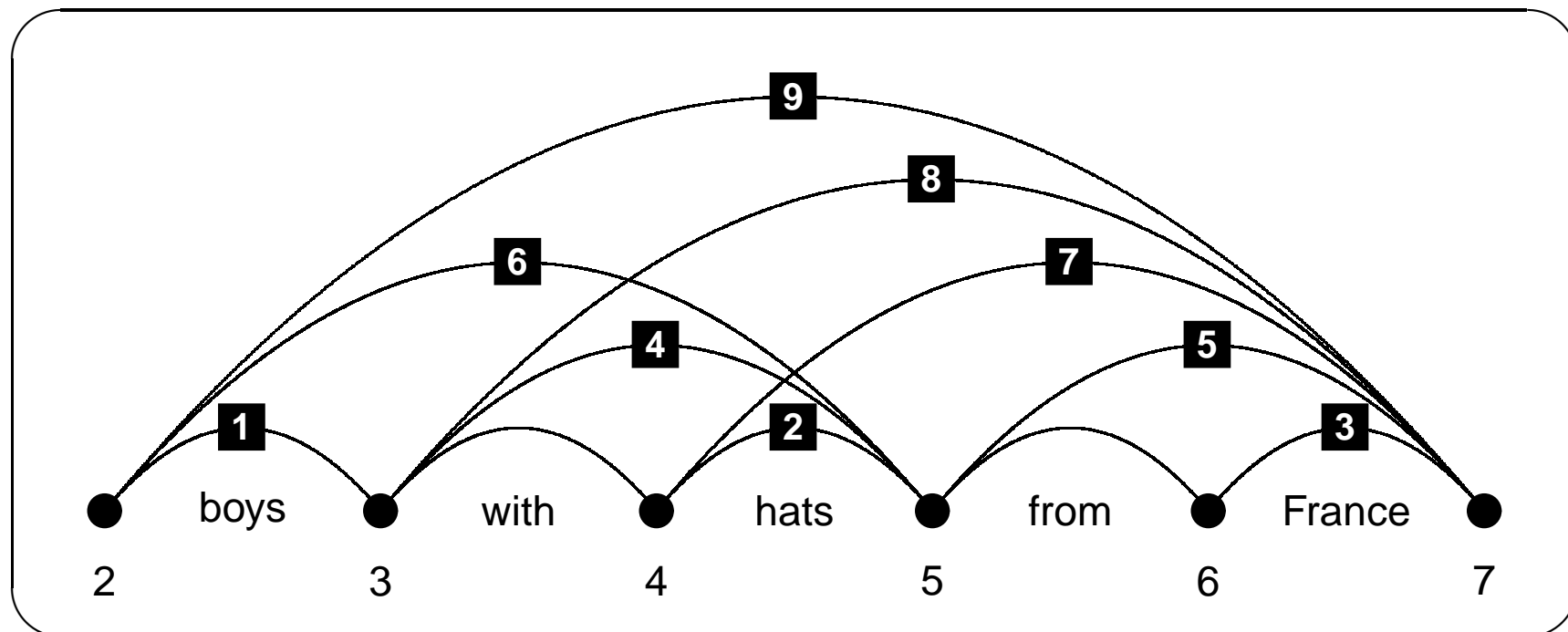
Key Benefits

- Dynamic programming (memoization): avoid recomputation of results;
- efficient indexing of constituents: no search by start or end positions;
- compute *parse forest* with exponential ‘extension’ in *polynomial* time.



Bounding Ambiguity — The Parse Chart

- For many substrings, more than one way of deriving the same category;
- NPs: **1** | **2** | **3** | **6** | **7** | **9**; PPs: **4** | **5** | **8**; **9** \equiv **1** + **8** | **6** + **5**;
- *parse forest* — a single item represents multiple trees [Billot & Lang, 89].



The CKY (Cocke, Kasami, & Younger) Algorithm

```

for ( $0 \leq i < |input|$ ) do
   $chart_{[i,i+1]} \leftarrow \{\alpha \mid \alpha \rightarrow input_i \in P\};$ 
for ( $1 \leq l < |input|$ ) do
  for ( $0 \leq i < |input| - l$ ) do
    for ( $1 \leq j \leq l$ ) do
      if ( $\alpha \rightarrow \beta_1 \beta_2 \in P \wedge \beta_1 \in chart_{[i,i+j]} \wedge \beta_2 \in chart_{[i+j,i+l+1]}$ ) then
         $chart_{[i,i+l+1]} \leftarrow chart_{[i,i+l+1]} \cup \{\alpha\};$ 

```

$[0,2] \leftarrow [0,1] + [1,2]$

...

$[0,5] \leftarrow [0,1] + [1,5]$

$[0,5] \leftarrow [0,2] + [2,5]$

$[0,5] \leftarrow [0,3] + [3,5]$

$[0,5] \leftarrow [0,4] + [4,5]$

	1	2	3	4	5
0	NP		S		S
1		V	VP		VP
2			NP		NP
3				P	PP
4					NP



Limitations of the CKY Algorithm

Built-In Assumptions

- *Chomsky Normal Form* grammars: $\alpha \rightarrow \beta_1\beta_2$ or $\alpha \rightarrow \gamma$ ($\beta_i \in C$, $\gamma \in \Sigma$);
- breadth-first (aka exhaustive): always compute all values for each cell;
- rigid control structure: bottom-up, left-to-right (one diagonal at a time).

Generalized Chart Parsing

- Liberate order of computation: no assumptions about earlier results;
- *active edges* encode partial rule instantiations, ‘waiting’ for additional (adjacent and passive) constituents to complete: $[1, 2, VP \rightarrow V \bullet NP]$;
- parser can fill in chart cells in *any* order and guarantee completeness.

