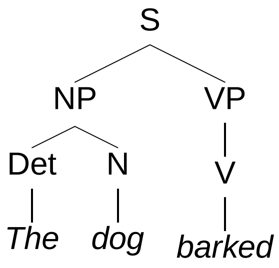

$$\begin{bmatrix} \texttt{LTOP} & h_1 \\ \texttt{INDEX} & e_2 \\ \texttt{RELS} & \left\langle \begin{bmatrix} \textit{prpstn\_m\_rel} & \\ \texttt{LBL} & h_1 \\ \texttt{MARG} & h_3 \end{bmatrix} \begin{bmatrix} \textit{def\_q\_rel} & \\ \texttt{LBL} & h_4 \\ \texttt{ARG0} & x_5 \\ \texttt{RSTR} & h_6 \\ \texttt{BODY} & h_7 \end{bmatrix} \begin{bmatrix} \textit{“dog\_n\_rel”} & \\ \texttt{LBL} & h_8 \\ \texttt{ARG0} & x_5 \end{bmatrix} \begin{bmatrix} \textit{“bark\_v\_rel”} & \\ \texttt{LBL} & h_9 \\ \texttt{ARG0} & e_2 \\ \texttt{ARG1} & x_5 \end{bmatrix} \right\rangle \\ \texttt{HCONS} & \langle h_3 =_q h_9,\ h_6 =_q h_8 \rangle \end{bmatrix}$$

Computational Linguistics (INF2820 — Syntax)

$S \longrightarrow NP\ VP;\ \ S \longrightarrow S\ PP;\ \ S \longrightarrow VP$

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Candidate Theories of Grammar (1 of 3)

Language as a Set of Strings

The dog barks.
The angry dog barks.
The fierce dog barks.
The fierce angry dog barks.
The angry fierce dog barks.
The dog chased a cat.
A dog chased the cat.
The dog chased a black cat.
The dog chased a young cat.
The dog of my neighbours chased a cat.
A dog chased the cat of my neighbours.
The cat of my neighbours was chased by a dog.
...

Grammatical Categories (1 of 2)

Word Classes or Parts of Speech (PoS)

cat, *dog*, *neighbour(s)*, ...	**noun (N)**
adore, *bark(s)*, *chase(d)*, *was*, ...	**verb (V)**
fierce, *angry*, *black*, *young*, ...	**adjective (A)**
quickly, *probably*, *not*, ...	**adverb (Adv)**
a, *the*, *my*, *that*, ...	**determiner (D)**
of, *by*, *on*, *at*, *under*, ...	**preposition (P)**
she, *mine*, *those*, *what*, ...	**pronoun (Pro)**
and, *neither* ... *nor*, *because*, ...	**conjunction (C)**

$$\textit{the} \left\{\begin{array}{c}\textit{cat}\\ \textit{dog}\\ {}^{*}\textit{adore}\end{array}\right\} \qquad \textit{Kim likes to} \left\{\begin{array}{c}\textit{bark}\\ \textit{chase dogs}\\ {}^{*}\textit{cat}\end{array}\right\} \qquad \textit{a} \left\{\begin{array}{c}\textit{fierce}\\ \textit{angry}\\ {}^{*}\textit{quickly}\end{array}\right\} \textit{cat}$$

Candidate Theories of Grammar (2 of 3)

Language as a Sequence of Word Classes

cat, *dog*, *neighbour(s)*, ...	**noun (N)**
adore, *bark(s)*, *chase(d)*, *was*, ...	**verb (V)**
fierce, *angry*, *black*, *young*, ...	**adjective (A)**
a, *the*, *my*, *that*, ...	**determiner (D)**
of, *by*, *on*, *at*, *under*, ...	**preposition (P)**

Regular Expressions

$$\mathrm{D}^{?}\ \mathrm{A}^{*}\ \mathrm{N}^{+}\ \mathrm{V}\ \left(\mathrm{D}^{?}\ \mathrm{A}^{*}\ \mathrm{N}^{+}\right)^{*}$$

Candidate Theories of Grammar (2 of 3)

Language as a Sequence of Word Classes

cat, *dog*, *neighbour(s)*, ...	**noun (N)**
adore, *bark(s)*, *chase(d)*, *was*, ...	**verb (V)**
fierce, *angry*, *black*, *young*, ...	**adjective (A)**
a, *the*, *my*, *that*, ...	**determiner (D)**
of, *by*, *on*, *at*, *under*, ...	**preposition (P)**

Regular Expressions

$$\boxed{\mathsf{D}^{?}\ \mathsf{A}^{*}\ \mathsf{N}^{+}\ \mathsf{V}\left(\mathsf{D}^{?}\ \mathsf{A}^{*}\ \mathsf{N}^{+}\right)^{*}}$$

$$\boxed{\mathsf{D}^{?}\ \mathsf{A}^{*}\ \mathsf{N}^{+}\left(\mathsf{P}\ \mathsf{D}^{?}\ \mathsf{A}^{*}\ \mathsf{N}^{+}\right)^{*}\ \mathsf{V}\left(\mathsf{D}^{?}\ \mathsf{A}^{*}\ \mathsf{N}^{+}\ \left(\mathsf{P}\ \mathsf{D}^{?}\ \mathsf{A}^{*}\ \mathsf{N}^{+}\right)^{*}\ \right)^{*}}$$

Candidate Theories of Grammar (3 of 3)

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. $\{$Kim, snow, saw, in$\}$;
- P is a set of category rewrite rules (aka *productions*), e.g.

S → NP VP
VP → V NP
NP → Kim
NP → snow
V → saw

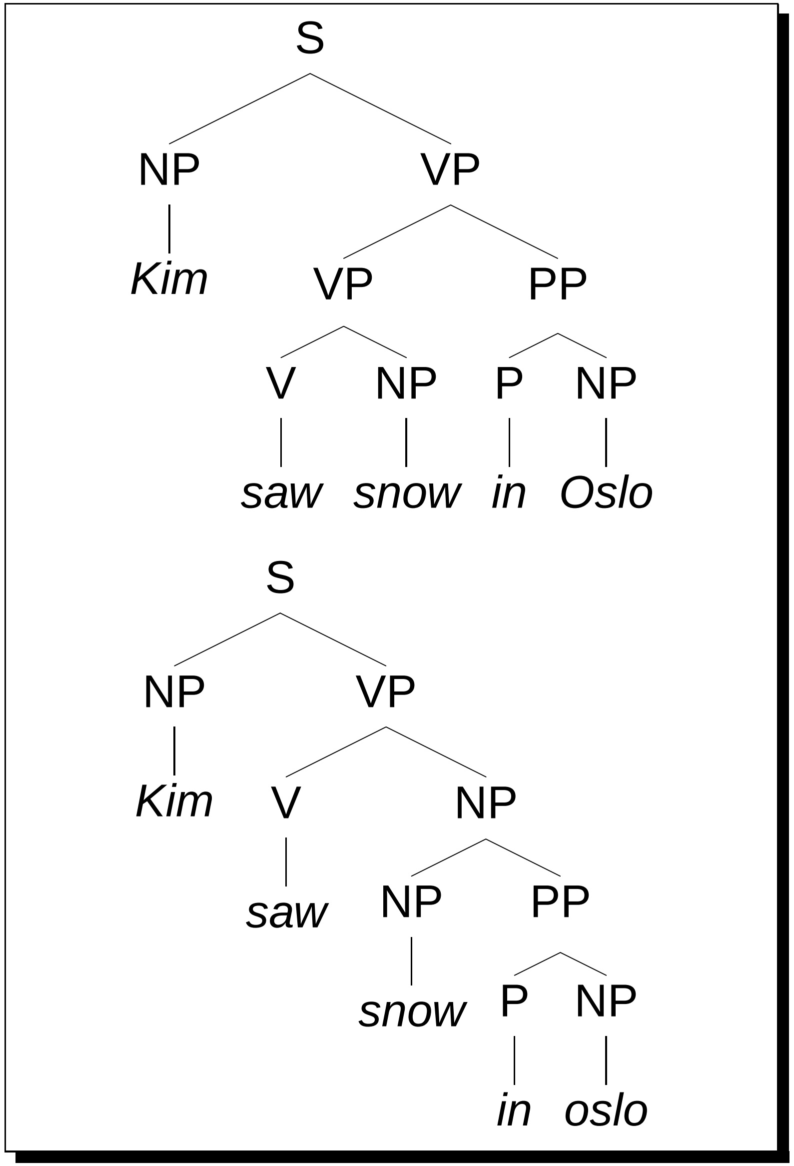
- $S \in C$ is the *start symbol*, a filter on complete (‘sentential’) results;
- for each rule ‘$\alpha \rightarrow \beta_1, \beta_2, ..., \beta_n$’ $\in P$: $\alpha \in C$ and $\beta_i \in C \cup \Sigma$; $1 \leq i \leq n$.

Parsing: Recognizing the Language of a Grammar

S → NP VP
VP → V NP
VP → VP PP
NP → NP PP
PP → P NP
NP → Kim | snow | Oslo
V → saw
P → 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)))))
```