CS321 Languages and Compiler Design I

Winter 2012

Lecture 7

PARSING

A **parser** is a program that, given an input sentence, “recognizes” whether or not that sentence is in the language of a given grammar.

Works by reconstructing a **derivation** for the sentence.

Parser “constructs” parse tree:

- **explicitly** – actual data structure is built; or
- **implicitly** – “semantic actions” are invoked at points corresponding to nodes in the tree, but no tree is actually built.

All parsers read input **left-to-right**, but they differ in how tree is constructed: **top-down** vs. **bottom-up**.

Any context-free grammar can be parsed by a (nondeterministic) pushdown automaton (NFA + stack), but not necessarily by a deterministic one (much less an efficient one).

Top-down Parsing

Idea: construct parse tree by starting at start symbol and "guessing" each derivation until we reach a string that matches input.

Example Grammar:

$$S \rightarrow \texttt{if}\ E\ \texttt{then}\ S\ \texttt{else}\ S \mid \texttt{while}\ E\ \texttt{do}\ S \mid \texttt{print} \mid \epsilon$$
$$E \rightarrow \texttt{true} \mid \texttt{false} \mid \texttt{id}$$

Token string:

`if` $\texttt{id}_{\texttt{b}}$ `then while true do else print`

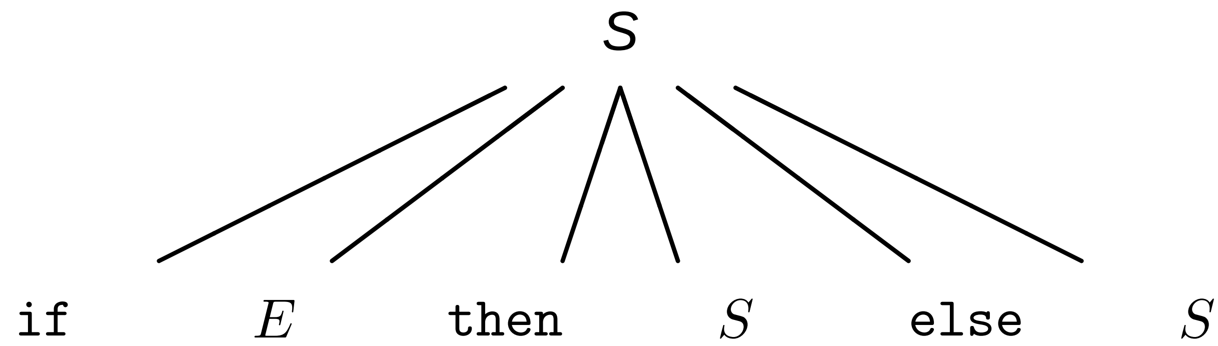
Tree:

$$S$$

Input: `if` $\texttt{id}_{\texttt{b}}$ `then while true do else print`

Action: Guess for S

Tree:

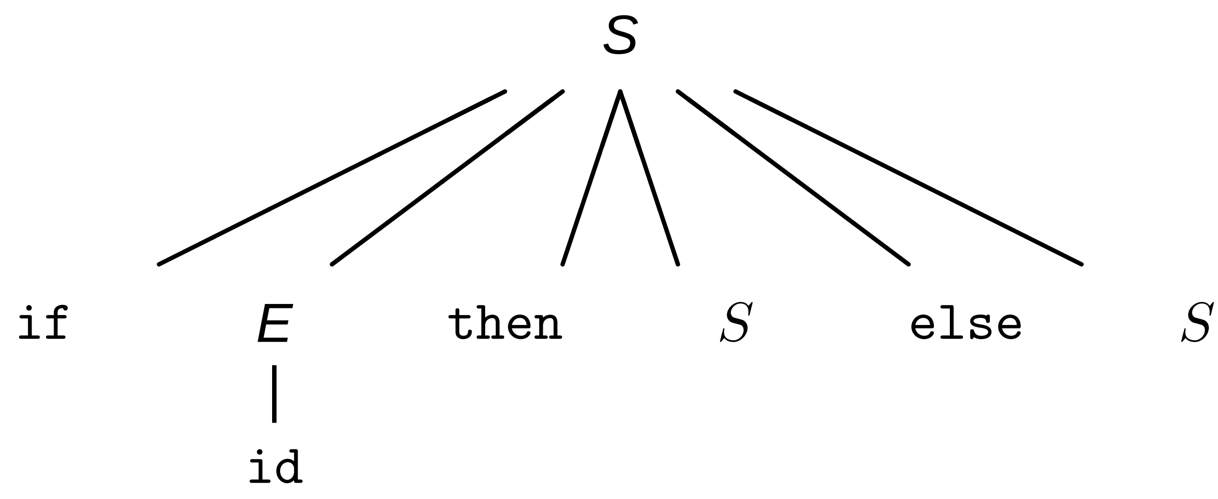


Input: `if` $\texttt{id}_{\texttt{b}}$ `then while true do else print`

Action:

`if` matches; guess for E

Tree:

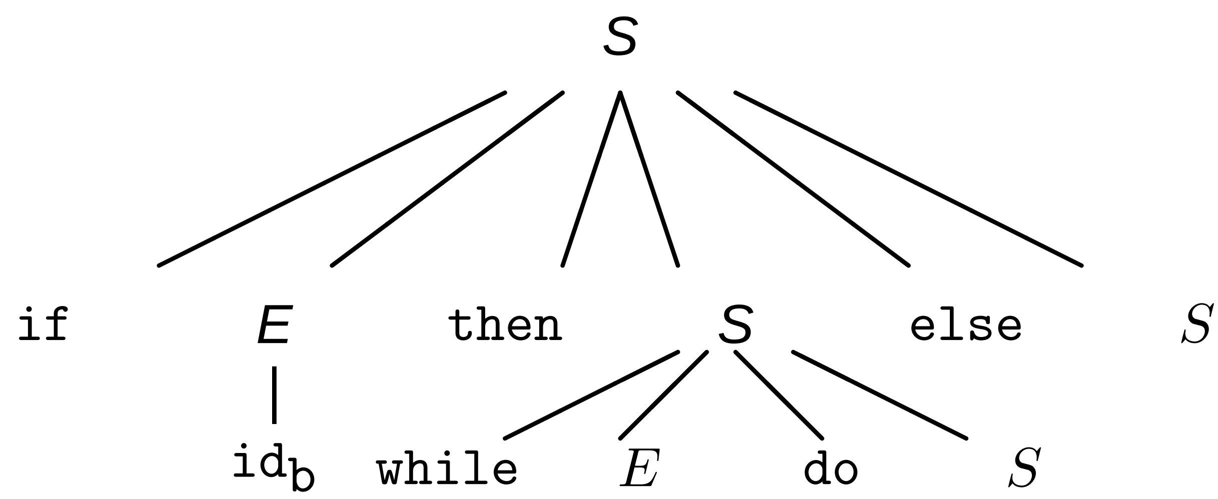


Input: $\mathtt{id_b}$ `then while true do else print`

Action:

$\mathtt{id_b}$ matches; `then` matches; guess for S

Tree:

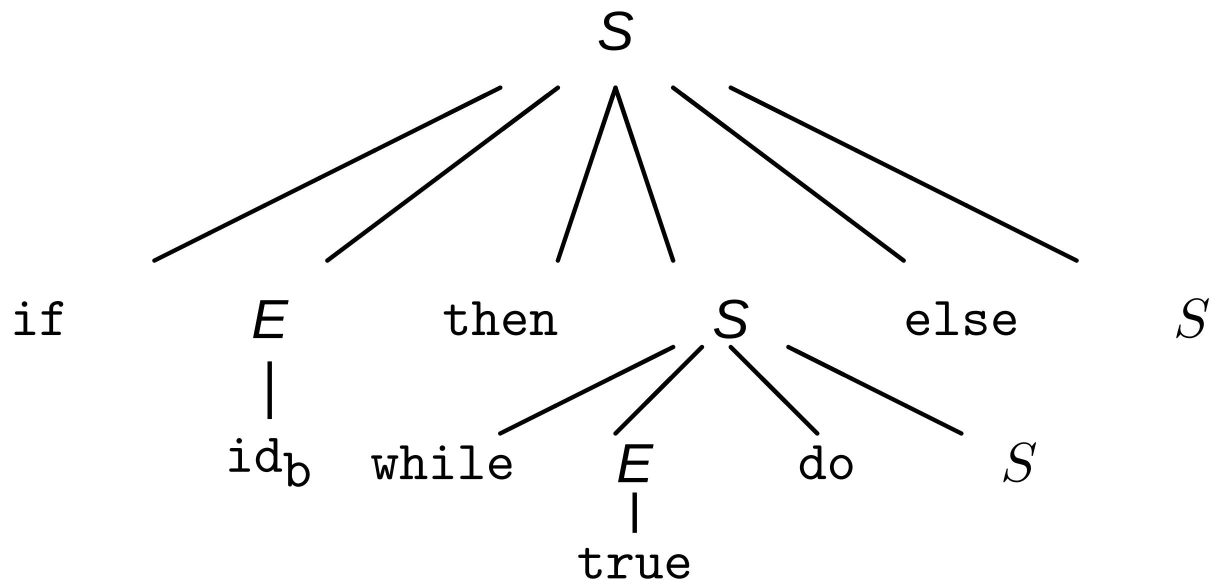


Input: `while true do else print`

Action:

`while` matches; guess for E

Tree:

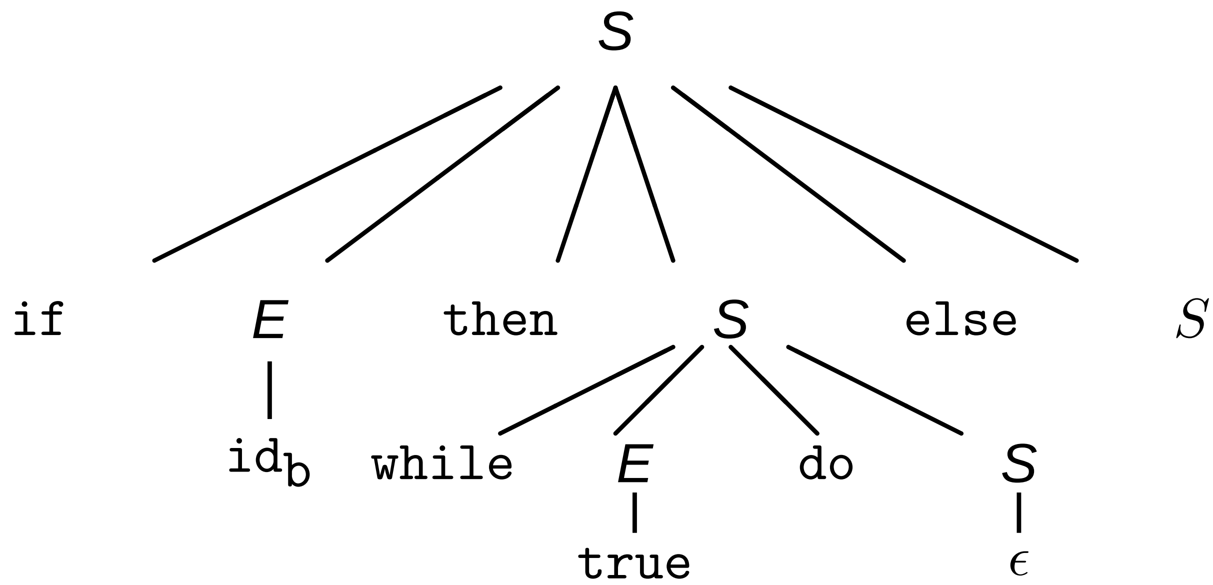


Input: `true do else print`

Action:

`true` matches; `do` matches; guess for S

Tree:

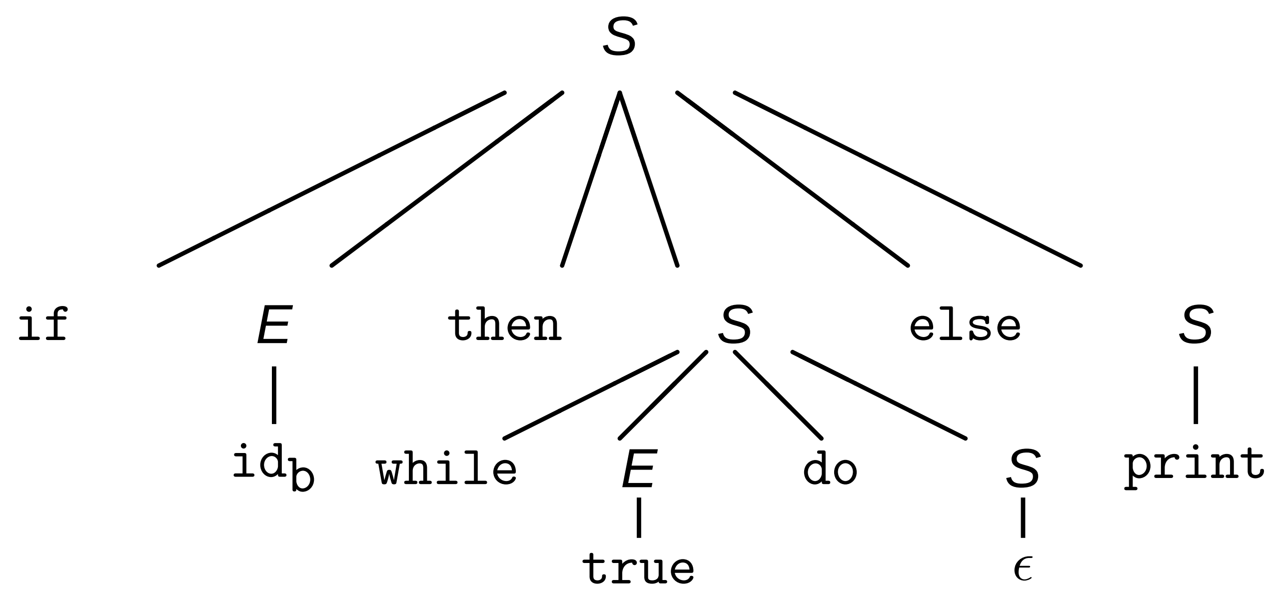


Input: `else print`

Action:

ϵ matches; `else` matches; guess for S

Tree:



Input: `print`

Action:

`print` matches; input exhausted; done.

RECURSIVE-DESCENT PARSING

Implementation of top-down parser using a **recursive** procedure for each non-terminal.

For many languages, can make perfect guesses (avoid back-tracking) by using 1-symbol **lookahead**. I.e., if

$A \rightarrow \alpha_1 | \alpha_2 | \ \ldots | \alpha_n$

choose correct α_i by looking at **first** symbol it derives.

(If ϵ is an alternative, choose it last.)

This approach is also called **predictive parsing**

Recursive-descent parsers are easy to write by hand and reasonably efficient.

Often must massage grammar into suitable form (more later).

Not all languages can be parsed this way.

Recursive-Descent Example

For the same grammar as before:

$$S \rightarrow \texttt{if}\ E\ \texttt{then}\ S\ \texttt{else}\ S \mid \texttt{while}\ E\ \texttt{do}\ S \mid \texttt{print}\ \epsilon$$
$$E \rightarrow \texttt{true} \mid \texttt{false} \mid \texttt{id}$$

We write one function to parse expressions, and another to parse statements.

Each function returns normally if it successfully parsed; otherwise it calls `error()`, which we assume issues an error message and terminates the parser.

For simplicity in this example, the parser functions don't return anything.

We assume that `lex()` returns the next token and advances the lexical analyzer's token stream.

```
void e() {
   if (tok == TRUE || tok == FALSE || tok == ID)
     tok = lex();
   else error();
}
```

```
void s() {
  if (tok == IF) {
    tok = lex();  /* get next input token */
    e();
    if (tok == THEN) {
      tok = lex();
      s();  /* recursive call! */
      if (tok == ELSE) {
        tok = lex();
        s();
      } else error(); /* issue error message */
    } else error();
  } else if (tok == WHILE) {
    tok = lex();
    e();
    if (tok == DO) {
      tok = lex();
      s();
    } else error();
  } else if (tok == PRINT) {
    tok = lex();
  } else
  /* epsilon case falls out */
}
```

PROBLEMS FOR RECURSIVE-DESCENT PARSING

• Left recursion: a derivation

$A \stackrel{*}{\Rightarrow} A\alpha$

causes parser to loop!

Solution: **Remove** left recursion from grammar.

• Need to backtrack (inefficient) because one-symbol lookahead can't "guess" correctly, e.g.:

$$
\begin{array}{lll}
S & \rightarrow & V \; \texttt{:=} \; \texttt{int} \\
V & \rightarrow & \texttt{alpha} \; \texttt{'['} \; \texttt{int} \; \texttt{']'} \; | \; \texttt{alpha}
\end{array}
$$

Possible inputs: `x := 77` or `x[2] := 17`.

Which alternative should we choose for V ?

Solution: **Left-factor** the grammar.

• These problems arise naturally in expression grammars. (Can usually prevent them in statement grammars by careful language design.)

Eliminating Immediate Left Recursion

Replace left-recursive productions of the form

$A \rightarrow A\alpha \mid \beta$

which generate sentences of the form

β, $\beta\alpha$, $\beta\alpha\alpha$, ...

by the **right-recursive** productions

$$\begin{array}{lcl} A & \rightarrow & \beta A' \\ A' & \rightarrow & \alpha A' \mid \epsilon \end{array}$$

Yields different parse trees but same language:

Left-Recursion Removal in Arithmetic Expressions

For a simplified expression grammar:

$$
\begin{array}{lcl}
E & \rightarrow & E \texttt{ + } T \mid E \texttt{ - } T \mid T \\
T & \rightarrow & T \texttt{ * } F \mid T \texttt{ / } F \mid F \\
F & \rightarrow & \texttt{(} E \texttt{)} \mid \texttt{id}
\end{array}
$$

becomes

$$
\begin{array}{lcl}
E & \rightarrow & T\ E' \\
E' & \rightarrow & \texttt{+ } T\ E' \mid \texttt{- } T\ E' \mid \epsilon \\
T & \rightarrow & F\ T' \\
T' & \rightarrow & \texttt{* } F\ T' \mid \texttt{/ } F\ T' \mid \epsilon \\
F & \rightarrow & \texttt{(} E \texttt{)} \mid \texttt{id}
\end{array}
$$

But note that the desired left-associativity has been lost!

Eliminating all left-recursion

Consider
$$
\begin{aligned}
S &\rightarrow Aa \mid b \\
A &\rightarrow Sc \mid d
\end{aligned}
$$

Non-terminal S is left-recursive in two steps:

$S \Rightarrow Aa \Rightarrow Sca \Rightarrow Aaca \Rightarrow Scaca \Rightarrow \ldots$

Fairly General Algorithm

(Works unless $A \stackrel{+}{\Rightarrow} A$ or $A \rightarrow \epsilon$. Fully general algorithm exists, but is complicated!)

- arrange non-terminals in some order $A_1, \ldots, A_n$.
- for i = 1 to n do
  - for j = 1 to i-1 do
    - for any production $A_i \rightarrow A_j \alpha$
      replace it by substituting definition of A_j into r.h.s.,
      i.e., by changing it to
      $A_i \rightarrow \beta_1 \alpha \mid \ \ldots \ \mid \ \beta_m \alpha$
      where current productions for A_j are
      $A_j \rightarrow \beta_1 \mid \ \ldots \ \mid \ \beta_m$
  - eliminate any immediate left-recursion in A_i

Example: Consider a grammar with the non-terminals ordered as follows:

$$\begin{array}{llll} (1) & S & \rightarrow & Pa \mid b \\ (2) & P & \rightarrow & Sc \mid Rd \\ (3) & R & \rightarrow & Se \mid f \end{array}$$

Step i=2,j=1: In-line (1) into (2), giving

$$\begin{array}{llll} (2) & P & \rightarrow & Pac \mid bc \mid Rd \end{array}$$

and then remove immediate left-recursion, giving

$$\begin{array}{llll} (2) & P & \rightarrow & bcP' \mid RdP' \\ (2') & P' & \rightarrow & acP' \mid \epsilon \end{array}$$

Step i=3,j=1: Inline (1) into (3), giving

$$\begin{array}{llll} (3) & R & \rightarrow & Pae \mid be \mid f \end{array}$$

Step i=3,j=2: Inline new (2) into new (3), giving

$$\begin{array}{llll} (3) & R & \rightarrow & bcP'ae \mid RdP'ae \mid be \mid f \end{array}$$

and then remove immediate left-recursion, giving

$$\begin{array}{llll} (3) & R & \rightarrow & bcP'aeR' \mid beR' \mid fR' \\ (3') & R' & \rightarrow & dP'aeR' \mid \epsilon \end{array}$$

LEFT-FACTORING

Easy to remove common prefixes by left-factoring, creating new non-terminals.

Change

$$V \rightarrow \alpha\beta \mid \alpha\gamma$$

to

$$\begin{aligned} V &\rightarrow \alpha V' \\ V' &\rightarrow \beta \mid \gamma \end{aligned}$$

Example:

$$\begin{aligned} S &\rightarrow V \ \texttt{:=}\ \texttt{int} \\ V &\rightarrow \texttt{alpha}\ \texttt{'['}\ \texttt{int}\ \texttt{']'} \mid \texttt{alpha} \end{aligned}$$

becomes

$$\begin{aligned} S &\rightarrow V \ \texttt{:=}\ \texttt{int} \\ V &\rightarrow \texttt{alpha}\ V' \\ V' &\rightarrow \texttt{'['}\ \texttt{int}\ \texttt{']'} \mid \epsilon \end{aligned}$$

Expression Parsing Using Recursive Descent (I)

Recall grammar of arithmetic expressions after removal of left recursion:

$$
\begin{aligned}
E &\rightarrow TE' \\
E' &\rightarrow \texttt{+}\ TE' \mid \epsilon \\
T &\rightarrow FT' \\
T' &\rightarrow \texttt{*}\ FT' \mid \epsilon \\
F &\rightarrow \texttt{(}E\texttt{)} \mid \texttt{id}
\end{aligned}
$$

This leads directly to this code for E and E' (T and T' are similar):

```
e() {
  t();
  e1();
}

e1() {
  if (tok == '+') {
    tok = lex(); t(); e1();
  }
  /* epsilon case falls through */
}
```

EXPRESSION PARSING USING RECURSIVE-DESCENT (II)

We can simplify this code (and improve its performance) by turning the recursions into iterations, e.g.:

```
e1() {
  if (tok == '+') {
    tok = lex(); t(); e1();
  }
  /* epsilon case falls through */
}
```

becomes:

```
e1() {
  while (tok == '+') {
    tok = lex(); t();
  }
}
```


Expression parsing using recursive-descent (III)

We then inline functions that are (now) called only once, e.g.:

```
e() {  t(); e1(); }
```

becomes:

```
e() {
  t();
  while (tok == '+') {
    tok = lex(); t();
  }
}
```

Performing the same transformation on `t` and `t1`, and adding the usual recursive descent code for `f`, we get...

EXPRESSION PARSING USING RECURSIVE-DESCENT (IV)

```
e() {
  t();
  while (tok == '+') { lex(); t(); }
}

t() {
  f();
  while (tok == '*') { lex(); f(); }
}

f() {
  if (tok == ID)
    lex();
  else if (tok == '(') {
    lex();
    e();
    if (tok == ')')
      lex();
    else error();
  else error();
}
```