CS321 Languages and Compiler Design I

Fall 2010

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:

$S \rightarrow$ `if` E `then` S `else` $S \mid$ `while` E `do` $S \mid$ `print` $\mid \epsilon$

$E \rightarrow$ `true` $\mid$ `false` $\mid$ `id`

Token string:

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

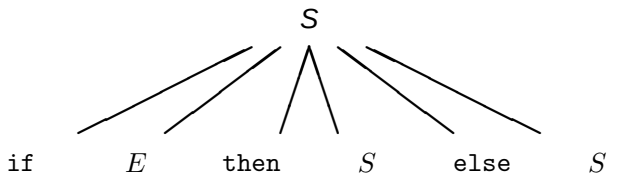
Tree:

S

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

Action: Guess for S

Tree:

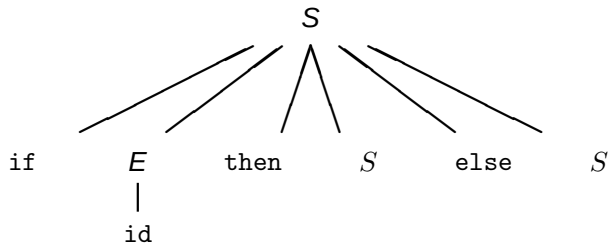


Input: `if` $\texttt{id}_b$ `then while true do else print`

Action:

`if` matches; guess for E

Tree:

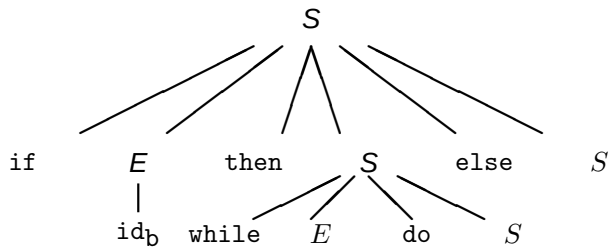


Input: $\texttt{id}_\texttt{b}$ `then while true do else print`

Action:

$\texttt{id}_\texttt{b}$ matches; `then` matches; guess for S

Tree:

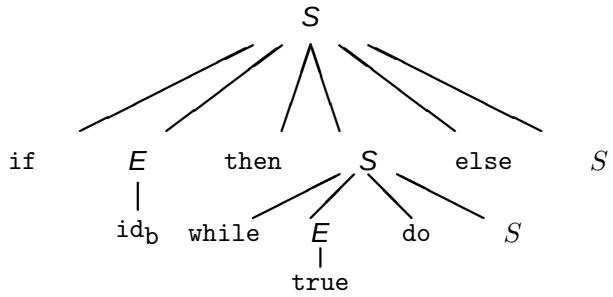


Input: `while true do else print`

Action:

`while` matches; guess for E

Tree:

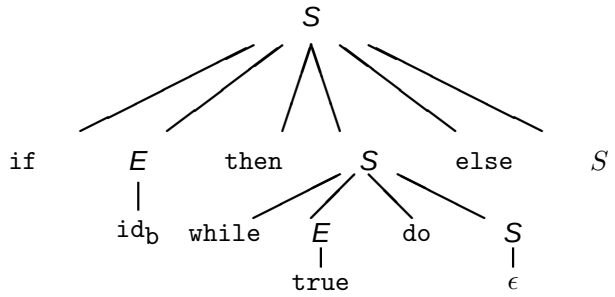


Input: `true do else print`

Action:

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

Tree:

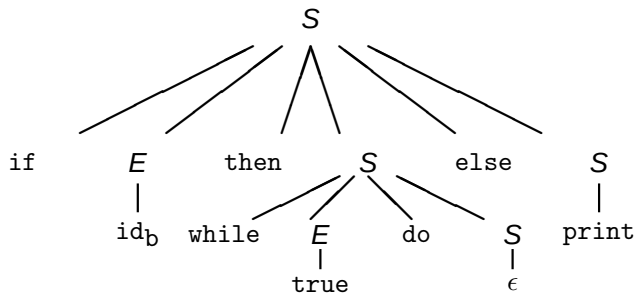


Input: `else print`

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:

$S \rightarrow$ `if` E `then` S `else` S | `while` E `do` S | `print` ϵ

$E \rightarrow$ `true` | `false` | `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.:

$S \rightarrow V$ `:= int`

$V \rightarrow$ `alpha '[' int ']'` | `alpha`

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

$\beta, \beta\alpha, \beta\alpha\alpha, \ldots$

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:

$E \rightarrow E$ `+` $T \mid E$ `-` $T \mid T$

$T \rightarrow T$ `*` $F \mid T$ `/` $F \mid F$

$F \rightarrow$ `(` E `)` | `id`

becomes

$E \rightarrow T\ E'$

$E' \rightarrow$ `+` $T\ E' \mid$ `-` $T\ E' \mid \epsilon$

$T \rightarrow F\ T'$

$T' \rightarrow$ `*` $F\ T' \mid$ `/` $F\ T' \mid \epsilon$

$F \rightarrow$ `(` E `)` | `id`

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

ELIMINATING ALL LEFT-RECURSION

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

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:

(1) $S \rightarrow Pa \mid b$
(2) $P \rightarrow Sc \mid Rd$
(3) $R \rightarrow Se \mid f$

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

(2) $P \rightarrow Pac \mid bc \mid Rd$

and then remove immediate left-recursion, giving

(2) $P \rightarrow bcP' \mid RdP'$
(2') $P' \rightarrow acP' \mid \epsilon$

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

(3) $R \rightarrow Pae \mid be \mid f$

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

(3) $R \rightarrow bcP'ae \mid RdP'ae \mid be \mid f$

and then remove immediate left-recursion, giving

(3) $R \rightarrow bcP'aeR' \mid beR' \mid fR'$
(3') $R' \rightarrow dP'aeR' \mid \epsilon$

LEFT-FACTORING

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

Change

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

to

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

Example:

$S \rightarrow V$ `:= int`
$V \rightarrow$ `alpha '[' int ']'` $\mid$ `alpha`

becomes

$S \rightarrow V$ `:= int`
$V \rightarrow$ `alpha` V'
$V' \rightarrow$ `'[' int ']'` $\mid \epsilon$

EXPRESSION PARSING USING RECURSIVE DESCENT (I)

Recall grammar of arithmetic expressions after removal of left recursion:

$E \rightarrow TE'$
$E' \rightarrow$ `+` $TE' \mid \epsilon$
$T \rightarrow FT'$
$T' \rightarrow$ `*` $FT' \mid \epsilon$
$F \rightarrow$ `(`E`)` $\mid$ `id`

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();
}
```