Top-down Parsing

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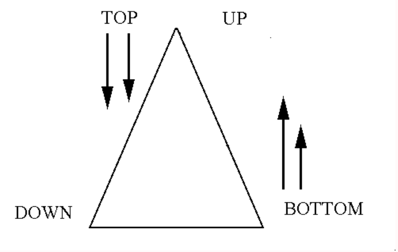
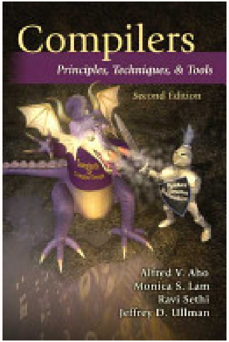


1. Resources



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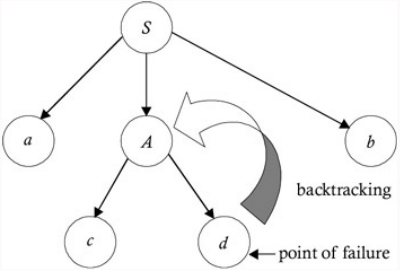
2. Introduction

- The goal of parsing is <u>not</u> the generation of sentences, but the <u>recognition</u> of them.
- This implies that the generating steps that lead to the construction must be deduced from the finished sentence.
- top-down is simplest parsing technique
- Simple implementations of top-down do not terminate in the presence of left recursion
- Tow-down with backtracking may have exponential complexity
- e.g.: recursive descent, and LL(k)

2.1. How it works

- Start with start symbol
- Try to regenerate the sentence by applying productions.
- Determine production by looking at next terminal in sentence.



2.2. Intuition

- Try to find a leftmost derivation by scanning input from left to right (LL).
- by searching for parse trees,
- using a top-down expansion of the grammar rules!
- Tokens are consumed from left to right.

3. Recursive Descent Parsing

- Def: Top-down approach to syntax analysis where a set of recursive procedures is used to process the input.
- One procedure is associated with each non-terminal
- **Predictive** recursive descent: the look-ahead symbol must unambiguously determine the flow of control through the procedure body.
- The body of the procedure mimics the body of the chosen non-terminal.
- Left recursive grammars lead to infinite recursion and must be transformed

4. Example: Balanced Parens

Consider the following grammar:

S : '(' S ')' S

One non-terminal in grammar $\Rightarrow$ one function:

```
void S() const {
  if ( nextToken == '(' ) {
    match('(');
    S();
    match(')');
    S();
  }
```

Note the static variable in the code!

5. Example: Infix to Postfix translator

We can use the expression grammar:

```
expr    : expr '+' term
        | expr '-' term
        | term
term    | DIGIT
```

Except that left recursion ⇒ infinit loop!

5.1. Removal of Left Recursion

Given a grammar with left recursion:

$$\begin{array}{lll} A & : & A\ \alpha \\ & | & A\ \beta \\ & | & \gamma \end{array}$$

We get the following with left recursion removed:

$$\begin{array}{lll} A & : & \gamma\ R \\ R & : & \alpha\ R \\ & | & \beta\ R \\ & | & \lambda \end{array}$$

5.2. Transformed Expression Grammar without left recursion

expr	:	term rest
rest	:	'+' term rest
	|	'-' term rest
	|	λ
term	:	DIGIT

5.3. Transformed expression grammar with semantic actions

```
expr   : term rest

rest   : '+' term { print('+'); } rest
       | '-' term { print('-'); } rest
       | λ
term   : DIGIT { print(DIGIT); }
```

5.4. Pseudo-code for translator

```
void expr() {
  term(); rest;
}

void rest() {
  if (lookahead == '+') {
    match('+'); term(); print('+'); rest();
  }
  else if (lookahead == '-') {
    match('-'); term(); print('-'); rest();
  }
  else {} // do nothing
}

void term() {
  if (lookahead is a digit) {
    t = lookahead; match(lookahead); print(t);
  }
  else report("syntax error");
}
```

6. Table-driven Parsing

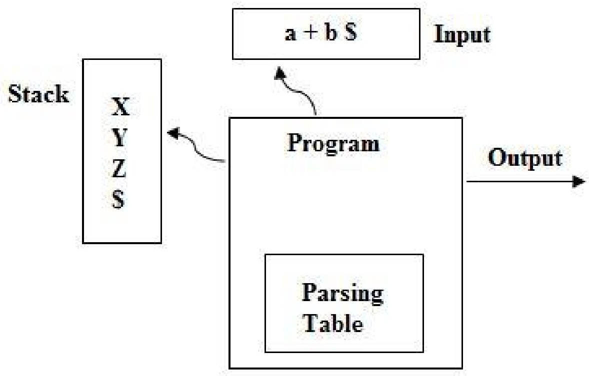


Fig 2.6 Model of a predictive parser

6.1. Writing a Grammar

1. Grammars can describe most, but not **all** of the syntax.

2. For example: CFG cannot specify that an ID must be declared before it's used.

3. Tokens accepted by parser form a **superset** of the language.

4. Subsequent phases must analyze parser output to ensure compliance of rules not checked by parser (p. 209 of the dragon book).

6.2. Re-Writing a Grammar

- Some grammars are not in the proper form for a given parsing algorithm.
- For example, some transformations are needed to enable top-down parsing:
  - Left factor
  - Left recursion
  - Ambiguity

6.3. Consider expression grammar

$$\text{E} \quad : \text{E '+' E} \mid \text{E '*' E} \mid \text{(E)} \mid \text{ID}$$

Eliminate ambiguity:

$$\begin{array}{ll} \text{E} & : \text{E '+' T} \mid \text{T} \\ \text{T} & : \text{T '*' F} \mid \text{F} \\ \text{F} & : \text{(E)} \mid \text{ID} \end{array}$$

Eliminate left recursion to get G':

$$\begin{array}{ll} \text{E} & : \text{T } E' \\ E' & : \text{'+' T } E' \mid \epsilon \\ \text{T} & : \text{F } T' \\ T' & : \text{'*' F } T' \mid \epsilon \\ \text{F} & : \text{(E)} \mid \text{ID} \end{array}$$

7. First and Follow

1. Useful for construction of both Top-down and Bottom-up parsers
2. The First and Follow is associated with a grammar G
3. In Top-down parsing, First and Follow help decide which production to apply, based on next input.
4. During recovery, sets of tokens in Follow can dictate how far ahead to skip.

7.1. How First and Follow predict

- Consider production $A \Rightarrow \alpha \mid \beta$, where FIRST($\alpha$) and FIRST($\beta$) are disjoint sets.

- We can choose rhs of A by looking at next input symbol a, since a can be $\in$ either FIRST(α) or FIRST(β), but <u>not</u> both.

7.2. To compute FIRST(X)

Apply the following rules until no more terminals or ϵ can be added to any FIRST set:

1. If X is a terminal, then FIRST(X) = {X}.
2. If X is a non-terminal and $X \Rightarrow Y_1 Y_2 \ldots Y_k$ is a production for some $k \geq 1$, then place a in FIRST(X) if for some i, a $\in$ FIRST(Y_i), and ϵ is $\in$ all of FIRST(Y_1), ...,FIRST(Y_{i-1}); In other words: $Y_1 \ldots Y_{i-1} \Rightarrow \epsilon$.
   (a) If $\epsilon \in$ FIRST(Y_j) for all j=1,2,...,k then add ϵ to FIRST(X).
   (b) E.g., everything in FIRST(Y_1) is $\in$ FIRST(X); if Y_1 does not derive ϵ, add no more.
3. If $X \rightarrow \epsilon$ is a production, add ϵ to FIRST(X)

7.3. To compute FOLLOW(A)

For all non-terminals A, apply the following rules until nothing can be added to any FOLLOW sets:

1. Place \$ in FOLLOW(S), where S is start symbol and \$ is end marker.
2. If there is a production $A \rightarrow \alpha B \beta$, then everything in FIRST(β) except ϵ is in FOLLOW(B).
3. If there is a production $A \rightarrow \alpha B$, or a production $A \rightarrow \alpha B \beta$, where FIRST($\beta$) contains ϵ, then everything in FOLLOW(A) is in FOLLOW(B).

7.4. Compute First and Follow for G'

1. FIRST(E) = FIRST(T) = FIRST(F) = { '(', ID}
2. FIRST(E') = { '+', ϵ }
3. FIRST(T') = { '*', ϵ }
4. FOLLOW(E) = FOLLOW(E') = { ')', \$ }
5. FOLLOW(T) = FOLLOW(T') = { '+', ')', \$ }
6. FOLLOW(F) = { '+', '*', ')', \$ }

7.5. Construction of parse table

- INPUT: Grammar G
- OUTPUT: Parse table M
- METHOD: For each production $A \to \alpha$:

  1. For each terminal α in First(A), add $A \to \alpha$ to M[A, a].
  2. If $\epsilon \in$ FIRST(α), then for each terminal b in Follow(A), add $A \to \alpha$ to M[A, b].

     If $\epsilon \in$ FIRST(α) and \$ $\in$ FOLLOW(A), then add $A \to \alpha$ to M[A, \$].

- If after performing above, there is no production at all in M[A, α], then set M[A, α] to error (empty entry in table)

8. Algorithm for table-driven Parser

- INPUT: a string w, and a parse table M for grammar G.
- OUTPUT: if $w \in L(G)$, a leftmost derivation of w, or *error*.
- METHOD: Initially, the parser is in a configuration with $w\$$ in the input buffer and the start symbol S on the top of the stack, above \$.

  The algorithm on next page uses table M to produce a predictive parse for the input.

8.1. Pseudo-code for table-driven parser

```
set ip to point to first symbol w;
set X to the top stack symbol;
while ( X != $ ) { // stack is not empty
  if ( X is a ) pop the stack and advance ip;
  else if ( X is a terminal ) error();
  else if ( M[X, a] is an error entry ) error();
  else if ( M[X, a] = X—>Y1 Y2...Yk ) {
    output the production X—>Y1 Y2...Yk;
    pop the stack;
    push Yk, Yk-1, ..., Y1 onto stack; Y1 on top;
  }
  set X to the top stack symbol;
}
```