CSE 504 Compiler Design

Top-Down Parsing (Predictive Parsing)

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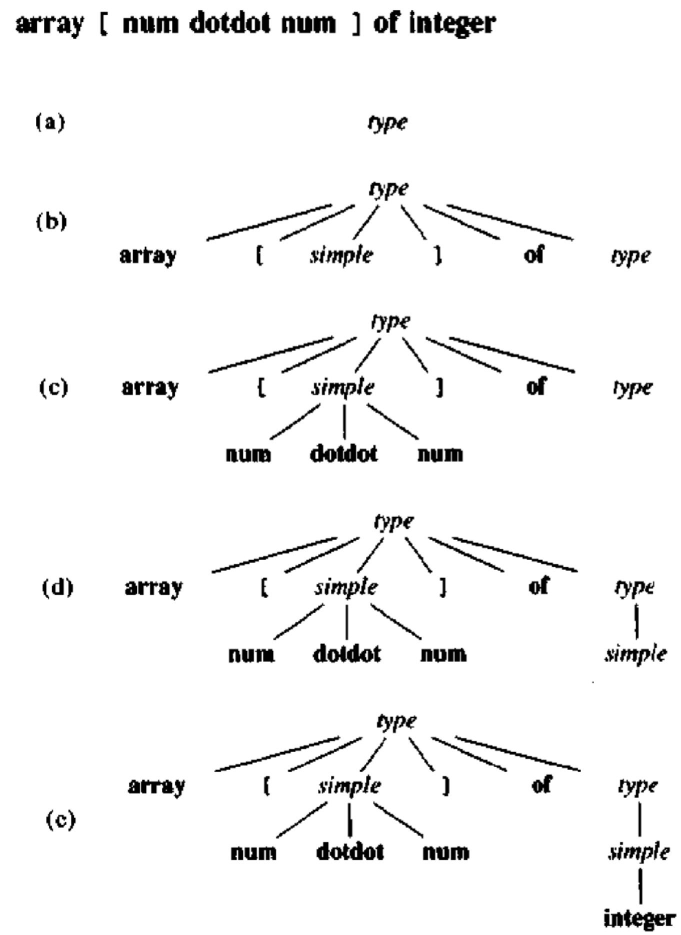
Parsing

- Parsing is the process of determining if a string of tokens can be generated by a grammar
- For any context-free grammar, there is a parser that can parse a string of n tokens in $O(n^3)$ times.
- For programming languages, we can generally construct a grammar that can be parsed quickly (in linear time).
- Top-Down parsing
  - Build parse trees from the root node to leave nodes.
  - Simple (parsers can be made manually), but limited.
- Bottom-Up parsing
  - Build parse trees from leaves towards the root.
  - More complex (parsers are generated from software tools), but more generic.

Top-Down Parsing

- Start from the root, labeled with the starting nonterminal, repeatedly perform the following two steps.
    - At node n, labeled with nonterminal A, select one of the productions for A and construct children at n for the symbols on the RHS of the production.
    - Find the next node at which a subtree is to be constructed.

```
type   → simple
       | ↑ id
       | array [ simple ] of type
simple → integer
       | char
       | num dotdot num
```



Predictive Parsing

- Recursive Decent Parsing
  - A top-down parsing method.
  - For each nonterminal of a grammar, associate a procedure and execute it to process the input.
- Predictive Parsing
  - A recursive decent parsing method.
  - The lookahead symbol unambiguously determines the procedure for each nonterminal.
  - In the next example, we use an additional procedure match to advance the next input token if the argument matches the lookahead symbol.

Pseudo-code for a predictive parser

```
procedure type ;
begin
    if lookahead is in { integer, char, num } then
        simple
    else if lookahead = '↑' then begin
        match('↑'); match(id)
    end
    else if lookahead = array then begin
        match(array); match('['); simple ; match(']'); match(of); type
    end
    else error
end;
```

```
procedure simple ;
begin
    if lookahead = integer then
        match(integer)
    else if lookahead = char then
        match(char)
    else if lookahead = num then begin
        match(num); match(dotdot); match(num)
    end
    else error
end;
```

```
procedure match(t : token);
begin
    if lookahead = t then
        lookahead := nexttoken
    else error
end;
```

Predictive Parsing: procedure FIRST

- Predictive parsing relies on what first symbols can be generated by the RHS of a production.
- FIRST(α)
  - Let α be the RHS of a production for nonterminal A
  - FIRST(α) returns the set of tokens that appear as the first symbol of the strings generated from α.
  - For recursive decent parsing without backtracking, if there are more than one productions, their FIRST sets must be disjoint.
    - E.g. for A -> α | β, FIRST(α) ∩ FIRST(β) = ∅
  - Example:

$$\text{FIRST}(\textit{simple}) = \{\ \textbf{integer},\ \textbf{char},\ \textbf{num}\ \}$$

$$\text{FIRST}(\uparrow \textbf{id}) = \{\ \uparrow\ \}$$

$$\text{FIRST}(\textbf{array}\ [\ \textit{simple}\ ]\ \textbf{of}\ \textit{type}) = \{\ \textbf{array}\ \}$$

Designing a Predictive Parser

- The procedures for nonterminals do two things

1. Decide which production to use by looking at the lookahead and FIRST(α).
   - If there are conflicts, we cannot parse the grammar with this parsing method.
   - If lookahead doesn't appear in any of the FIRST sets, use the ϵ-Production.
2. Procedures mimic the RHS of a production
   - Nonterminals result in a call to the procedure for the nonterminal.
   - Tokens matching the lookahead results in reading the next input.
   - If the token does not match the lookahead, an error is declared.

Designing a Predictive Parser: Extension to a syntax directed translation

1. Construct a predictive parser, ignoring the actions in productions
2. Copy the action from the translation scheme to the parser
   - If an action appears after a grammar symbol X, copy the action after implementing X.
   - If an action appears at the beginning of a production, copy it before implementing the production.

Left Recursion

- A problem with left-recursive grammars
  - Infinite recursion will occur in recursive decent parsers.
  - `expr -> expr + term`
  - The leftmost symobl on the RHS is the same as the LHS of the production
  - The parser may look like

```
procedure expr;
begin
    if lookhaed is in FIRST('expr + term') then
    begin
        expr; match('+'); term;
    end
end
```

Fixing the Left Recursion Problem

- Change Left Recursive Grammar to Right Recursive one
  - `A -> A α | β`
  - `A -> β R`
`R -> α R | ϵ`
- Example
  - `expr -> expr + term | term`
  - `A = expr, α = + term, β = term`
  - `expr -> term rest`
`rest -> + term rest | ϵ`

Adapting the Translation Scheme

- If semantic actions are in left recursive productions, carry them along in the production
- Example

```
expr -> expr + term { print('+') }
expr -> expr - term { print('-') }
expr -> term
term -> 0 { print('0') }
…
term -> 9 { print('9') }
```

=>

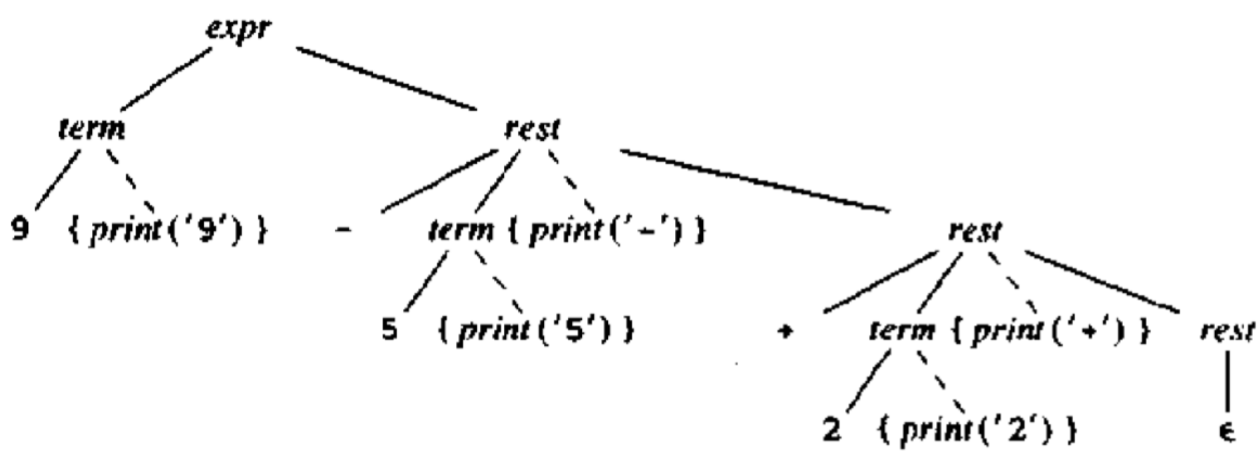
```
expr -> term rest
rest -> + term { print('+') } rest
rest -> - term { print('-') } rest
rest -> ϵ
term -> 0 { print('0') }
…
term -> 9 { print('9') }
```

- A -> A α | A β | γ
- A -> γ R
  R -> α R | β R | ϵ

A = expr,
α = + term { print('+') },
β = - term { print('-') },
γ = term

Adapting the Translation Scheme

- Example: Translation of 9-5+2 into 95-2+



Procedures for expr, term, and rest

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

rest()
{
      if (lookahead == '+') {
            match('+'); term(); putchar('+'); rest();
      }
      else if (lookahead == '-') {
            match('-'); term(); putchar('-'); rest();
      }
      else ;
}
```

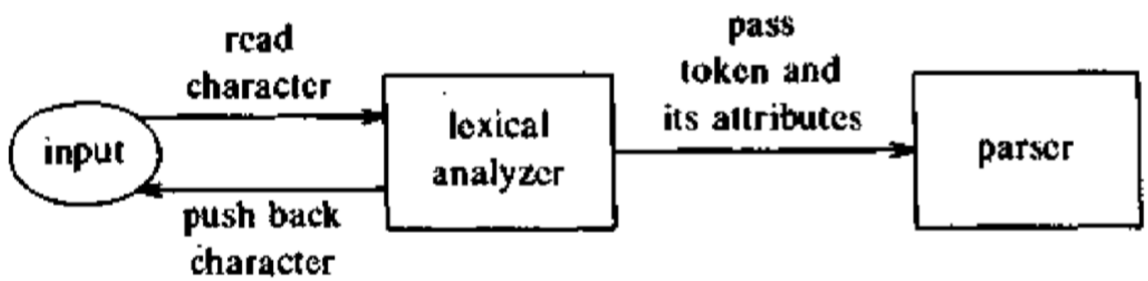
```
term()
{
      if (isdigit(lookahead)) {
            putchar(lookahead); match(lookahead);
      }
      else error();
}
```

Lexical Analyzer

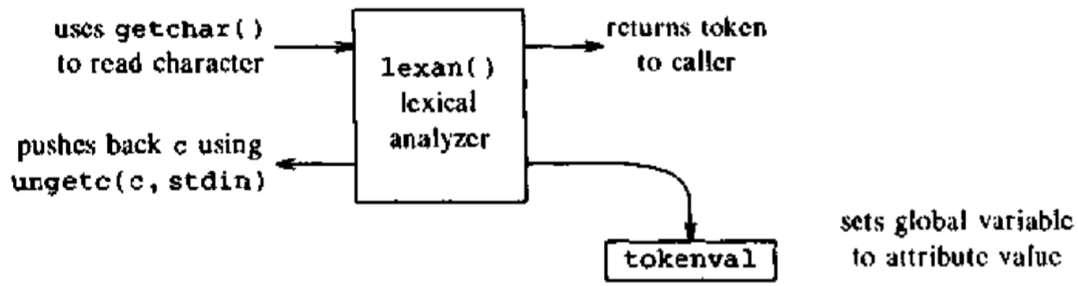
- It converts input to a stream of tokens.
- Lexeme: a sequence of input characters that comprise a single token.
- Insulates parser from the lexeme representation of tokens.
- Frees parsers from removing white space and comments.
  - Removing white spaces from the grammar can be unnecessarily complex.
- For numbers, return num and its value as an attribute.
- For identifiers, return id and its symboltable entry as an attribute.
- For keywords, need to check if a lexeme is a keyword or an identifier.
  - Easier if the keywords are reserved.

Interface to Lexical Analyzer

- In some situations, the lexical analyzer has to read some characters ahead before it can decide.
  - e.g. to distinguish >= and >, after reading > the lexical analyzer needs to read one more character.
  - The extra characters have to be pushed back onto the input.
- The parser hold the produced tokens and their attributes in a token buffer.
  - Commonly the buffer holds just one token and a procedure call from the parser to the lexical analyzer would work.



A Lexical Analyzer



- Updating the grammar and semantic actions for the factor
  - factor -> (expr)
          | NUM { print (NUM.value) }
- Procedure for factor

```
factor()
{
        if (lookahead == '(') {
                match('('); expr(); match(')');
        }
        else if (lookahead == NUM) {
                printf(" %d ", tokenval); match(NUM);
        }
        else error();
}
```

Symbol Table

- Stores information about various source language constructs.
  - lexeme for the id,
  - type of the id (e.g. procedure, variable, label),
  - its position in storage, …
- Interface
  - `insert(s, t):` returns index of the new entry for string s, token t.
  - `lookup(s):` returns index of the entry for string s, or an invalid index if s is not found.