CS419 Compilers Construction

A Simple One-Pass Compiler [Chapter 2]

Lecture 7

Edited by Dr. Ismail Hababeh

Adapted from slides by Dr. Mohammad Daoud

German Jordanian University

Originally from slides by Dr. Robert A. Engelen

Postfix Notation

- The Postfix notation is used to represent algebraic expressions without using parenthesis ( ).
- The expressions written in postfix form are evaluated faster compared to infix notation as parenthesis are not required in postfix.

Postfix Notation Rules

- If E is an expression of the form $\mathbf{E_1}$ **op** $\mathbf{E_2}$, where **op** is any binary operator, then the postfix notation for E is $\mathbf{E_1E_2op}$, where $\mathbf{E_1}$ and $\mathbf{E_2}$ are the operands
- IF E is variable or constant, then the postfix notation for E is E itself.
- The postfix notation for (E) is the same as the postfix notation for E.
- Examples:
  - The postfix notation for (9-5) +2 is 95-2+
  - The postfix notation for 9-(5+2) is 952+-

Postfix Notation

- To read the postfix notation, repeatedly scan the postfix string from the left until an operator is found, then evaluate the operator on the operands.
- Example: Evaluate the following postfix notation expression 952+-3*

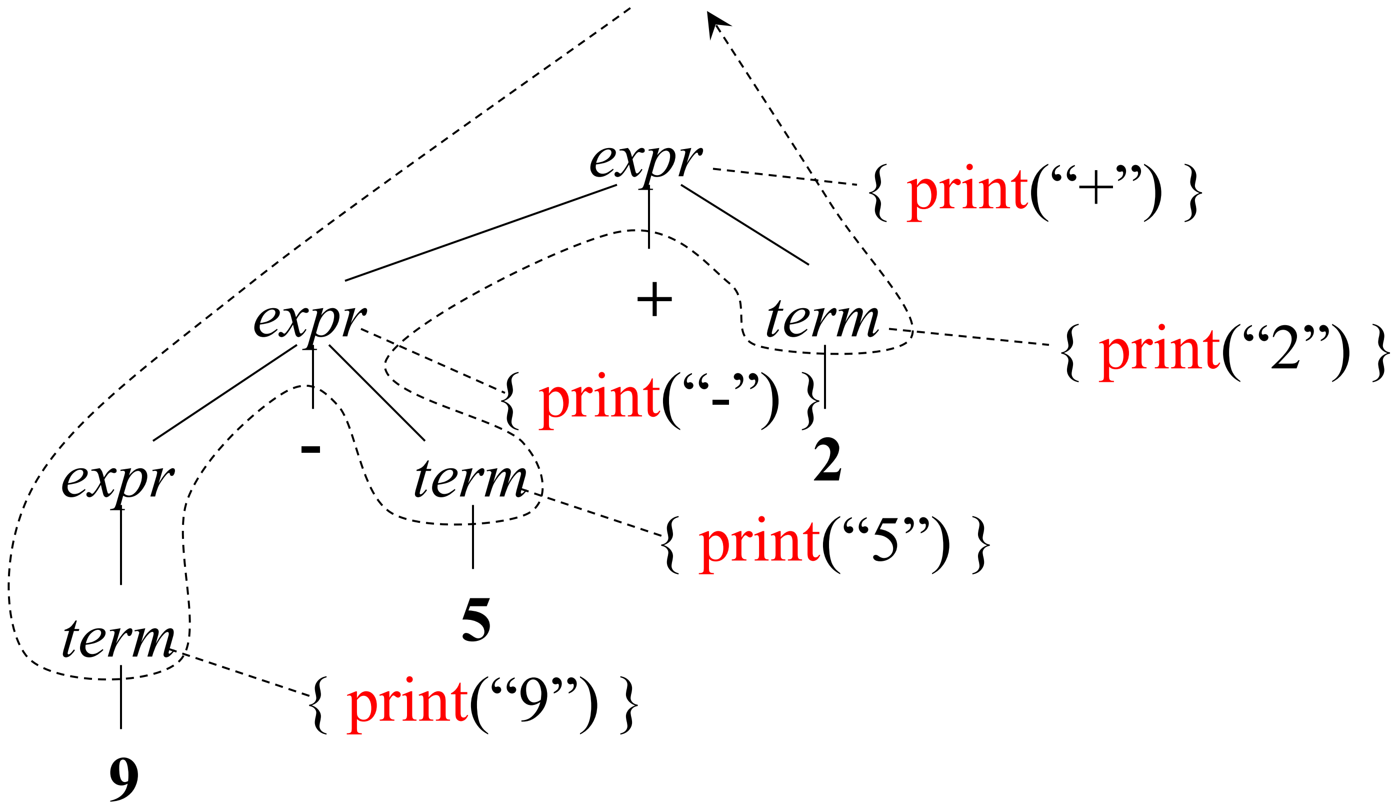
  Solution: (9-(5+2))*3 = 6
- Syntax-Directed Translation is used to translate infix expressions, for example, (9-5)+2 to postfix notation 95-2+ , evaluate expressions and build syntax trees for programming constructs.

Syntax-Directed Translation - Example

- Translate the infix expression 9-5+2 into postfix notation 95-2+ using the following productions.

$expr \rightarrow expr + term$	{ print("+") }	Print is performed without the need to store attributes.
$expr \rightarrow expr - term$	{ print("-") }	*semantic actions*
$expr \rightarrow term$		attaches program
$term \rightarrow \mathbf{0}$	{ print("0") }	fragments to productions
$term \rightarrow \mathbf{1}$	{ print("1") }	in a grammar
…	…	
$term \rightarrow \mathbf{9}$	{ print("9") }	

Translation Scheme Parse Tree - Example



Translates the infix **9-5+2** into postfix **95-2+**

FIRST of Production

FIRST(α) is the set of terminals that appear as the first symbols of one or more strings generated from production (α). FIRST used to write a predictive parser.

Example: $type \rightarrow simple$
$\quad | \ \textbf{\^{} id}$
$\quad | \ \textbf{array [} \ simple \ \textbf{] of} \ type$
$simple \rightarrow \textbf{integer}$
$\quad | \ \textbf{char}$
$\quad | \ \textbf{num dot num}$

FIRST(*simple*) = { **integer**, **char**, **num** }
FIRST(**^ id**) = { **^** }
FIRST(*type*) = { **integer**, **char**, **num**, **^**, **array** }

Using FIRST - Example

$$
\begin{aligned}
\mathit{expr} &\rightarrow \mathit{term\ rest} \\
\mathit{rest} &\rightarrow +\ \mathit{term\ rest} \\
&\quad \mid -\ \mathit{term\ rest} \\
&\quad \mid \varepsilon \\
\mathit{term} &\rightarrow 0 \mid 1 \mid \ldots \mid 9
\end{aligned}
$$

procedure *rest*();
begin
  if *lookahead* in FIRST(+ *term rest*) **then**
    match('+'); *term*(); *rest*()
  else if *lookahead* in FIRST(- *term rest*) **then**
    match('-'); *term*(); *rest*()
  else return
end;

Note: When a nonterminal A has two (or more) productions as in

$$
\begin{aligned}
A &\rightarrow \alpha \\
&\mid \beta
\end{aligned}
$$

Then FIRST (α) and FIRST(β) must be disjoint for predictive parsing to work. Why? Ambiguity!

Left Factoring

When more than one production for nonterminal *A* starts with the same symbols, then FIRST sets are not disjoint and lead to ambiguity.

Example:

$$\begin{aligned} stmt &\rightarrow \textbf{if}\ expr\ \textbf{then}\ stmt \\ &\mid \textbf{if}\ \text{expr}\ \textbf{then}\ stmt\ \textbf{else}\ stmt \end{aligned}$$

How can we solve the FIRST ambiguity?
By using *left factoring*:

$$\begin{aligned} stmt &\rightarrow \textbf{if}\ \text{expr}\ \textbf{then}\ stmt\ opt\_else \\ opt\_else &\rightarrow \textbf{else}\ stmt \\ &\mid \varepsilon \end{aligned}$$

Left Recursion

When a production for nonterminal A starts with a self reference (*left recursive productions*) then a predictive parser loops forever

$$
\begin{aligned}
A &\rightarrow A\ \alpha \\
&\ \ |\ \beta \\
&\ \ |\ \gamma
\end{aligned}
$$

Solution: eliminate *left recursive productions* by systematically rewriting the grammar using (*right recursive productions)*

$$
\begin{aligned}
A &\rightarrow \beta\ R \\
&\ \ |\ \gamma\ R \\
R &\rightarrow \alpha\ R \\
&\ \ |\ \varepsilon
\end{aligned}
$$

Left Recursion Problem

Translate from simple arithmetic expressions into postfix form. Start with the syntax-directed translation scheme.

Problem! left recursion !

$expr \rightarrow expr + term$	{ print("+") }
$expr \rightarrow expr - term$	{ print("-") }
$expr \rightarrow term$	
$term \rightarrow \mathbf{0}$	{ print("0") }
$term \rightarrow \mathbf{1}$	{ print("1") }
…	…
$term \rightarrow \mathbf{9}$	{ print("9") }

Left Recursion Elimination

$expr \rightarrow expr + term$ { print("+") }
$expr \rightarrow expr$ **-** $term$ { print("-") }
$expr \rightarrow term$
$term \rightarrow \mathbf{0}$ { print("0") }
$term \rightarrow \mathbf{1}$ { print("1") }
… …
$term \rightarrow \mathbf{9}$ { print("9") }

It is only for matching

left recursion elimination:

$expr \rightarrow term\ rest$
$rest \rightarrow + term$ { print("+") } $rest$ | **-** $term$ { print("-") } $rest$ | ε
$term \rightarrow \mathbf{0}$ { print("0") }
$term \rightarrow \mathbf{1}$ { print("1") }
…
$term \rightarrow \mathbf{9}$ { print("9") }

Translate Infix Expressions into Postfix Form

Program to translate infix expressions into postfix form.

$expr \rightarrow term\ rest$

$rest \rightarrow +\ term\ \{\ \text{print}(\text{“+”})\ \}\ rest$
$\quad\mid\ -\ term\ \{\ \text{print}(\text{“-”})\ \}\ rest$
$\quad\mid\ \varepsilon$

$term \rightarrow \mathbf{0}\ \{\ \text{print}(\text{“0”})\ \}$
$term \rightarrow \mathbf{1}\ \{\ \text{print}(\text{“1”})\ \}$
...
$term \rightarrow \mathbf{9}\ \{\ \text{print}(\text{“9”})\ \}$

```
main()
{    lookahead = getchar();
     expr();
}
expr()
{    term();
     while (1) /* optimized by inlining rest()
                  and removing recursive calls */
     {    if (lookahead == '+')
          {    match('+'); term(); putchar('+');
          }
          else if (lookahead == '-')
          {    match('-'); term(); putchar('-');
          }
          else break;
     }
}
term()
{    if (isdigit(lookahead))
     {    putchar(lookahead); match(lookahead);
     }
     else error();
}
match(int t)
{    if (lookahead == t)
          lookahead = getchar();
     else error();
}
error()
{    printf("Syntax error\n");
     exit(1);
}
```

Reading One Character Ahead

- Reading ahead is required to differentiate numbers as 1 from 10 or operators as < from <=
- One-character read-ahead is usually used a variable called *peek* to hold the next input character
- Reading ahead is perform only when it is required
  - Example: the operator * is identified without reading ahead, therefore *peek* is set to blank

Reading Constants

- Constants are allowed by creating a terminal symbol, **num**
- When the lexical analyzer encounters a sequence of digits in the input stream, it creates a token consisting of the terminal **num** and the integer-valued attribute computed for the digits:

token : <**num**, attribute>

- Example:

The input **123** is transformed into a token <**num**, 123>

Reading Constants Algorithm

To compute a constant value consists of a sequence of digits:

```
if(peek holds a digit)
{   v = 0;
 do{
      v = v*10 + integer value of digit peek;
      peek = next input character;
}while (peek holds a digit);
      return token <num, v>;
}
```

Reading Keywords and Identifiers

- Language keywords, such as for, do, if, … etc. are fixed character strings.
- Language keywords are reserved, and hence they cannot be used as identifiers
- Character strings are also used as identifiers to name variables, arrays, functions, ….
- The parser treats identifiers as terminals.
- When the lexical analyzer encounters an identifier in the input stream, it creates a token consisting of the terminal **id** and its lexeme.
- Example: the input **count = count + increment**

  is transformed into the following tokens

  <**id**, “count”> <“=“> <**id**, “count”> <“+”> <**id**, “increment”>

Reading Identifiers

When the lexical analyzer reads a string that could form an identifier, it checks the symbol table*:

- If the symbol table includes the lexeme, it returns the identifier token from the table.
- Otherwise, it inserts a token with terminal **id** in the symbol table and returns the token with terminal **id.**

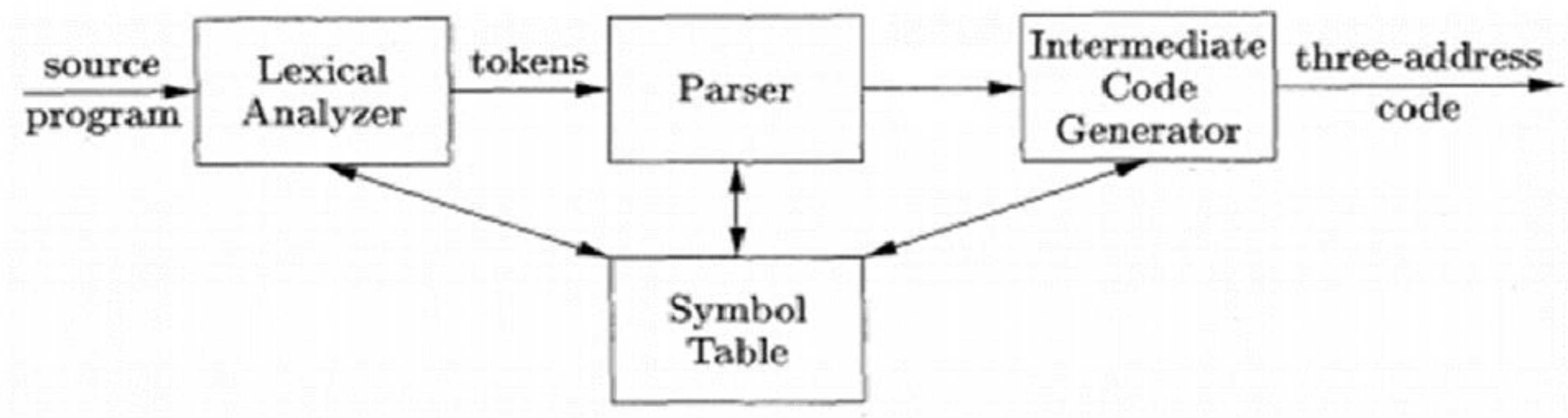
*Symbol Table is a data structure used by the compiler to keep track of identifiers used in the source program. Symbol table is used at compile-time but not used at run time.

Reading Identifiers Algorithm

```
if(peek holds a letter)
{// collect letters and/or digits into a buffer b
    s = string formed from the characters in buffer b;
  // The Lexical Analyzer lookup s in the symbol table
  // If the symbol table has an entry for s, then the
  // token retrieved by lookup is returned
    w = token returned by lookup(s);
    if( w != null) return w;
  // If the table does not contain an entry for s, then
  // the token <id, s> is inserted in the table
    else{
    insert(s, t); // t is the token that holds s
    return token <id, s>;
    }
```

Symbol Table Entry

The **symbol table** is accessible to all phases of the compiler



A model of a compiler front-end Pass

Symbol Table Entry

Each entry in the symbol table contains a string and a token value:

```
struct entry
{   char *lexptr; // lexeme (string)
    int tokenvalue;
};
struct entry symtable[];
```

`insert(s,t)`: inserts new entry for string **`s`** token **`t`**

`lookup(s)`: returns array index to entry for string **`s`** or returns 0 if s is not found

The symbol table is initialized with the reserved keywords and their tokens

Possible Symbol table implementations:
- simple C code
- hashtables