Lab 1: Implementing Lexical Analyzer

Implement a lexical analyzer to recognize identifiers, keywords, comments, strings, operators, and constants. Display token type and lexeme.

Introduction:

A **lexical analyzer** (also known as a *scanner* or *tokenizer*) is the first phase of a compiler. Its main task is to **scan the source code character by character** and group them into meaningful sequences called **lexemes**. Each lexeme is classified into a **token type** (e.g., identifier, keyword, operator, constant, string, or comment).

Algorithm

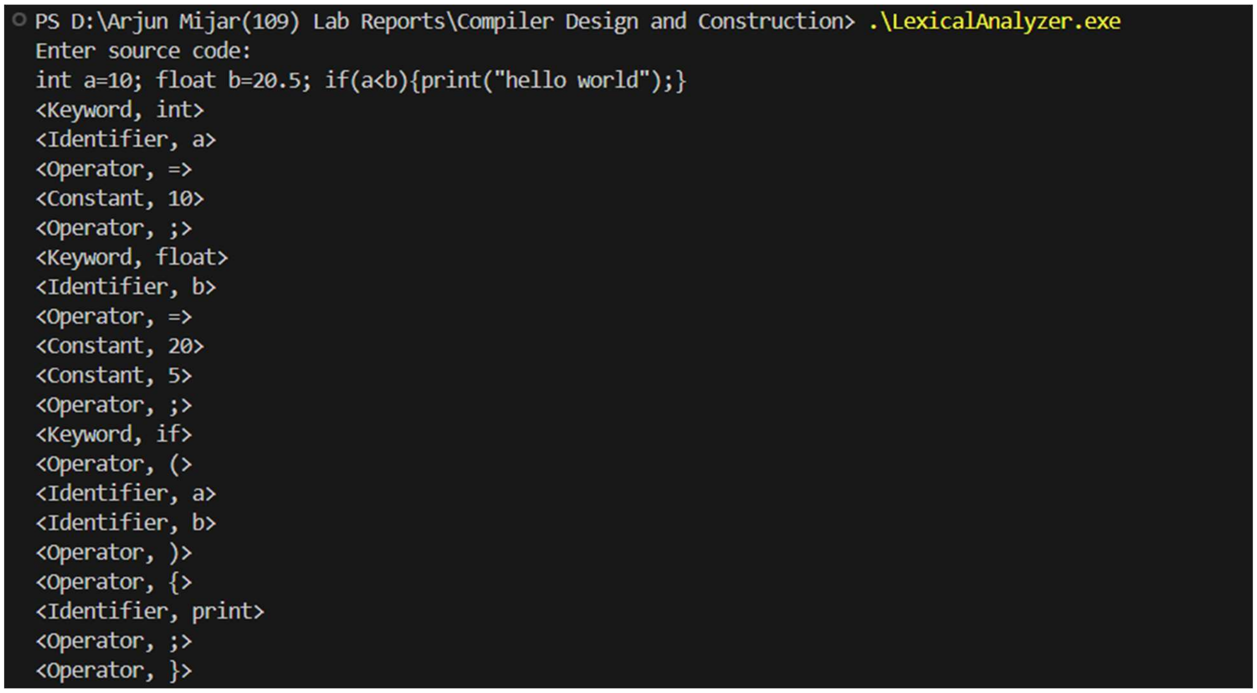
The algorithm of a lexical analyzer can be summarized as follows:

1. **Input**: Source code as a sequence of characters.
2. **Initialization**: Set pointer at the first character.
3. **Repeat until end of file (EOF):**
    - Ignore whitespace and newlines.
    - If the current character starts:
        - **Letter** → read full sequence → check if it is a **keyword** or an **identifier**.
        - **Digit** → read full sequence → classify as **constant**.
        - **Quote (`"`)** → read until closing quote → classify as **string literal**.
        - **Comment start (`//` or `/*`)** → skip until end of line or closing `*/`.
        - **Operator or Special symbol** (`+`, `-`, `*`, `/`, `=`, `<`, `>`, `;`, etc.) → classify as **operator/separator**.
    - Generate a **token**: `<TokenType, Lexeme>`
4. **Output**: Display the list of tokens.

Example Implementation (C program)

```
#include <stdio.h>
#include <ctype.h>
#include <string.h>

char keywords[8][10] =
{"int","float","if","else","while","for","return","char"};

int isKeyword(char *str) {
    for(int i=0;i<8;i++) {
        if(strcmp(str, keywords[i])==0)
            return 1;
    }
    return 0;
}

int main() {
    char src[200];
    printf("Enter source code:\n");
    fgets(src,200,stdin);

    int i=0;
    while(src[i]!='\0') {
        if(isalpha(src[i])) { // identifier or keyword
            char buf[50]; int j=0;
            while(isalnum(src[i])) {
                buf[j++]=src[i++];
            }
            buf[j]='\0';
            if(isKeyword(buf))
                printf("<Keyword, %s>\n", buf);
            else
                printf("<Identifier, %s>\n", buf);
        }
        else if(isdigit(src[i])) { // number
            char buf[50]; int j=0;
            while(isdigit(src[i])) {
                buf[j++]=src[i++];
            }
            buf[j]='\0';
            printf("<Constant, %s>\n", buf);
        }
        else if(src[i]=='"') { // string literal
            char buf[100]; int j=0;
            buf[j++]='"'; i++;
            while(src[i]!='"' && src[i]!='\0') {
                buf[j++]=src[i++];
            }
            if(src[i]=='"') buf[j++]='"';
            buf[j]='\0'; i++;
            printf("<String, %s>\n", buf);
        }
        else if(src[i]=='/' && src[i+1]=='/') { // single-line comment
            while(src[i]!='\n' && src[i]!='\0') i++;
        }
        else if(strchr("+-*/=;(){}",src[i])) { // operators/symbols
            printf("<Operator, %c>\n", src[i]);
            i++;
        }
        else i++; // skip spaces, tabs, etc.
    }
    return 0;
}
```

Ouptupt:



```
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\LexicalAnalyzer.exe
Enter source code:
int a=10; float b=20.5; if(a<b){print("hello world");}
<Keyword, int>
<Identifier, a>
<Operator, =>
<Constant, 10>
<Operator, ;>
<Keyword, float>
<Identifier, b>
<Operator, =>
<Constant, 20>
<Constant, 5>
<Operator, ;>
<Keyword, if>
<Operator, (>
<Identifier, a>
<Identifier, b>
<Operator, )>
<Operator, {>
<Identifier, print>
<Operator, ;>
<Operator, }>
```

Conclusion

The lexical analyzer plays a crucial role in compiler design by converting raw source code into tokens.

- It recognizes **identifiers, keywords, constants, strings, comments, and operators**.
- It simplifies the job of the parser by providing a structured token stream.
- Errors like invalid characters can also be detected at this stage.

This implementation demonstrates the **first step of compilation** and provides the foundation for the next stages like syntax analysis and semantic analysis.

Lab 2: Implementing Symbol Table Operations

Implement a symbol table to demonstrate the operations: insert, lookup and display. Maintain attributes such as identifier name, type, and scope.

Introduction

A **symbol table** is a data structure used by a compiler to store information (attributes) about program identifiers such as variables, functions, constants, and objects.
It provides quick **insert**, **lookup**, and **display** operations.
Common attributes maintained include:

- **Identifier Name**
- **Type** (int, float, char, etc.)
- **Scope** (local, global, etc.)

It ensures correctness in compilation by detecting **undeclared identifiers, duplicate declarations, and type mismatches**.

Algorithm

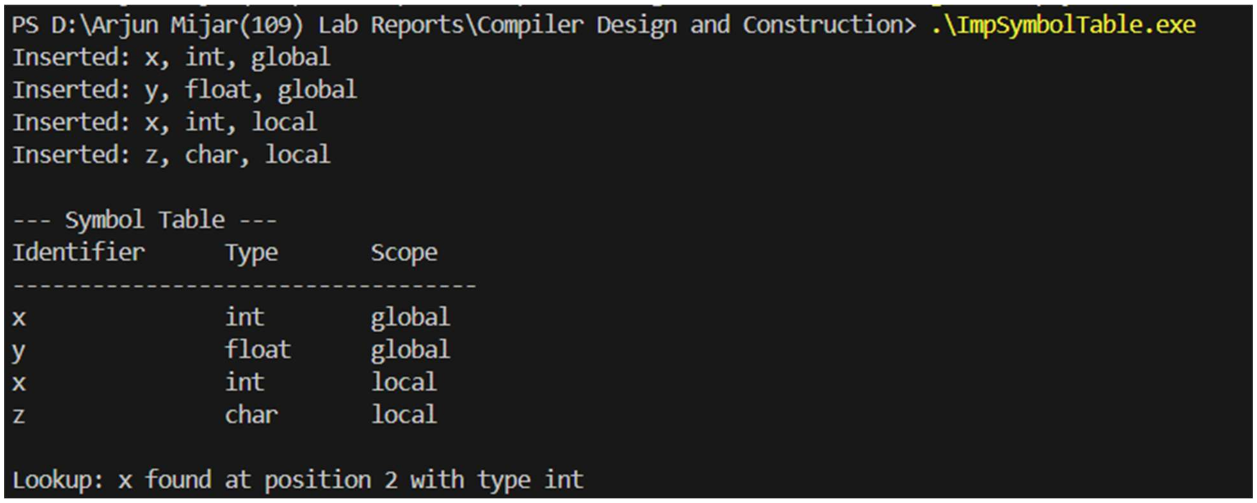
1. **Insert Operation**
    - Input: identifier name, type, scope.
    - Check if the identifier already exists in the current scope.
    - If not, add a new entry into the symbol table.
2. **Lookup Operation**
    - Input: identifier name.
    - Search the table for the given name.
    - If found → return its attributes.
    - If not found → report *undeclared identifier*.
3. **Display Operation**
    - Print the contents of the symbol table in tabular format (Name, Type, Scope).

Example Implementation (C Program)

```c
#include <stdio.h>
#include <string.h>

#define SIZE 50   // max number of symbols

// Structure of a symbol table entry
struct Symbol {
    char name[30];
    char type[10];
    char scope[10];
};

struct Symbol table[SIZE];
int count = 0;

// Insert into symbol table
void insert(char name[], char type[], char scope[]) {
    // check duplicate
    for(int i=0; i<count; i++) {
        if(strcmp(table[i].name, name)==0 && strcmp(table[i].scope,
scope)==0) {
            printf("Error: Duplicate entry for %s in scope %s\n", name,
scope);
            return;
        }
    }
    strcpy(table[count].name, name);
    strcpy(table[count].type, type);
    strcpy(table[count].scope, scope);
    count++;
    printf("Inserted: %s, %s, %s\n", name, type, scope);
}

// Lookup in symbol table
int lookup(char name[], char scope[]) {
    for(int i=0; i<count; i++) {
        if(strcmp(table[i].name, name)==0 && strcmp(table[i].scope,
scope)==0)
            return i;
    }
    return -1;
}

// Display symbol table
void display() {
    printf("\n--- Symbol Table ---\n");
    printf("%-15s %-10s %-10s\n", "Identifier", "Type", "Scope");
    printf("----------------------------------\n");
    for(int i=0; i<count; i++) {
        printf("%-15s %-10s %-10s\n", table[i].name, table[i].type,
table[i].scope);
    }
}
```

```
int main() {
    insert("x","int","global");
    insert("y","float","global");
    insert("x","int","local");
    insert("z","char","local");

    display();

    char id[10]="x", sc[10]="local";
    int pos = lookup(id, sc);
    if(pos!=-1)
        printf("\nLookup: %s found at position %d with type %s\n", id, pos, 
table[pos].type);
    else
        printf("\nLookup: %s not found in scope %s\n", id, sc);

    return 0;
}
```

Output:



```
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\ImpSymbolTable.exe
Inserted: x, int, global
Inserted: y, float, global
Inserted: x, int, local
Inserted: z, char, local

--- Symbol Table ---
Identifier      Type       Scope
----------------------------------
x               int        global
y               float      global
x               int        local
z               char       local

Lookup: x found at position 2 with type int
```

Conclusion

The symbol table is an essential part of compiler design:

- **Insert** ensures adding valid identifiers.
- **Lookup** checks for existing declarations and prevents misuse.
- **Display** helps visualize all stored identifiers.

Lab 3: Recursive Descent Parser

Implement a recursive descent parser for the grammar

S → aAb

A → a | ε

Introduction

Parsing is the process of analyzing a string of symbols according to a grammar. **Recursive Descent Parsing** is a top-down parsing technique that uses a set of recursive procedures to process the input.

Here, we need to build a parser for the grammar:

- **S → a A b**
- **A → a | ε**

This means:

- The string must always start with `a` and end with `b`.
- In between, there may be an `a` (from A → a) or nothing (from A → ε).

Valid strings:

- `ab`
- `aab`

Invalid strings:

- `a`
- `b`
- `aaab`

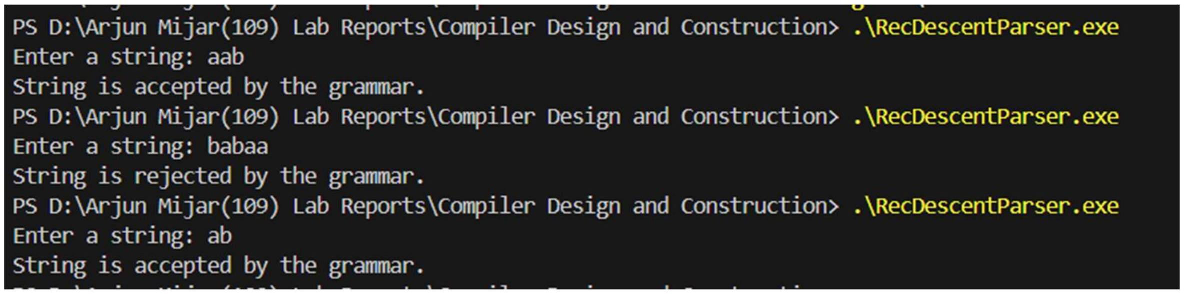
Algorithm (Recursive Descent Parser)

1. Define recursive functions for each non-terminal (`S`, `A`).
2. `S → a A b`
   - Match `'a'`, then call `A`, then match `'b'`.
3. `A → a | ε`
   - If next symbol is `'a'`, match it.
   - Otherwise, take ε (do nothing).
4. If input is fully consumed at the end, **accept**.
5. Otherwise, **reject**.

Implementation:

```
#include <stdio.h>
#include <string.h>

char input[100];   // input string
int pos = 0;       // current position in input
int length;        // length of input

// Function declarations
int S();
int A();

// Function to match a character
int match(char expected) {
    if (pos < length && input[pos] == expected) {
        pos++;
        return 1; // success
    }
    return 0; // failure
}

// Grammar rule: S → a A b
int S() {
    int start = pos;
    if (match('a')) {
        if (A()) {
            if (match('b')) {
                return 1; // success
            }
        }
    }
    pos = start; // backtrack
    return 0;
}

// Grammar rule: A → a | ε
int A() {
    int start = pos;
    if (match('a')) {
        return 1; // matched 'a'
    }
    // ε (empty string) is always valid
    return 1;
}

int main() {
    printf("Enter a string: ");
    scanf("%s", input);

    length = strlen(input);

    if (S() && pos == length) {
        printf("String is accepted by the grammar.\n");
    } else {
        printf("String is rejected by the grammar.\n");
    }

    return 0;
}
```

Output:



```
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\RecDescentParser.exe
Enter a string: aab
String is accepted by the grammar.
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\RecDescentParser.exe
Enter a string: babaa
String is rejected by the grammar.
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\RecDescentParser.exe
Enter a string: ab
String is accepted by the grammar.
```

Conclusion

The Recursive Descent Parser successfully implements the grammar rules:

- **S → a A b**
- **A → a | ε**

It correctly recognizes valid strings (`ab`, `aab`) and rejects invalid ones.
This demonstrates the working of a **top-down parsing approach** using recursion.

Lab 4: Implementation of Shift-Reduce Parsing.

Implement Shift-Reduce parsing for the following grammar and input string: a +a*a.

E→E+E

E→E*E

E→ (E)

E→a

Introduction

Parsing is a process of analyzing a string of symbols according to a given grammar. In compiler design, **shift-reduce parsing** is a bottom-up parsing technique used in syntax analysis. It attempts to reduce the input string to the start symbol of the grammar by repeatedly applying reductions.

The parser uses two main operations:

- **Shift:** Move the next input symbol onto the stack.
- **Reduce:** Replace a handle (a substring matching the RHS of a production rule) on the stack with the corresponding LHS non-terminal.

In this lab, we implement a shift-reduce parser for the grammar:

```
E → E + E
E → E * E
E → ( E )
E → a
```

Algorithm for Shift-Reduce Parsing

1. Initialize an empty **stack** and place the **input string** followed by `$` (end marker).
2. Repeat until input and stack are reduced to the start symbol:
    - **Shift:** Push the next input symbol onto the stack.
    - **Reduce:** If the top of the stack matches the RHS of a production, replace it with the LHS (reduce).
    - If no shift or reduce is possible and input is not finished → **Error**.
3. If the stack contains only the start symbol `E` and the input is `$`, **accept**.

Example

Grammar:

```
E → E + E
E → E * E
E → (E)
E → a
```

Input string: `a+a*a$`

Step-by-step parsing:

Stack	**Input**	**Action**
	a+a*a$	Shift a
a	+a*a$	Reduce a → E
E	+a*a$	Shift +
E+	a*a$	Shift a
E+a	*a$	Reduce a → E
E+E	*a$	Shift *
E+E*	a$	Shift a
E+E*a	$	Reduce a → E
E+E*E	$	Reduce E*E → E
E+E	$	Reduce E+E → E
E	$	ACCEPT

Thus, the input string `a+a*a` is successfully parsed according to the grammar.

Implementation:

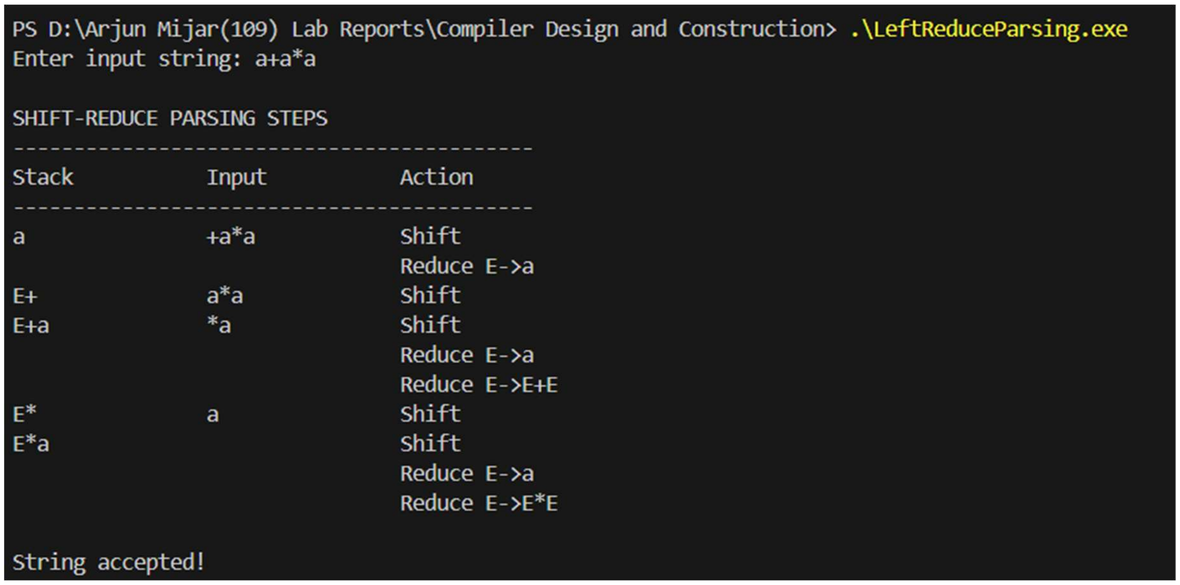
```
#include <stdio.h>

#include <string.h>

char input[50];         // input string

char stack[50];         // parsing stack

int top = -1;           // stack pointer

int i = 0;              // input pointer

// Push function

void push(char c) {

    stack[++top] = c;

    stack[top+1] = '\0';

}

// Pop function

void pop() {

    stack[top] = '\0';

    top--;

}

// Try reductions

void check() {

    // E -> a

    if (stack[top] == 'a') {

        pop();

        push('E');

        printf("\tReduce E->a\n");

    }

    // E -> (E)
```

```
      if (top >= 2 && stack[top] == ')' && stack[top-2] == '(' && stack[top-
      1] == 'E') {

        pop(); pop(); pop(); // remove ( E )

        push('E');

        printf("\tReduce E->(E)\n");

    }



    // E -> E+E

    if (top >= 2 && stack[top] == 'E' && stack[top-1] == '+' && stack[top-2]
== 'E') {

        pop(); pop(); pop();

        push('E');

        printf("\tReduce E->E+E\n");

    }



    // E -> E*E

    if (top >= 2 && stack[top] == 'E' && stack[top-1] == '*' && stack[top-2]
== 'E') {

        pop(); pop(); pop();

        push('E');

        printf("\tReduce E->E*E\n");

    }

}



int main() {

    printf("Enter input string: ");

    scanf("%s", input);
```

```
printf("\nSHIFT-REDUCE PARSING STEPS\n");
printf("---------------------------------\n");
printf("Stack\tInput\tAction\n");
printf("---------------------------------\n");

while (input[i] != '\0') {
    // Shift
    push(input[i]);
    printf("%s\t%s\tShift\n", stack, input+i+1);
    i++;

    // Try reductions
    check();
}

// Final check
while (top > 0) {
    check();
}

if (strcmp(stack, "E") == 0) {
    printf("\nString accepted!\n");
} else {
    printf("\nString rejected!\n");
}
```

```
    return 0;

}
```

Output:



```
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\LeftReduceParsing.exe
Enter input string: a+a*a

SHIFT-REDUCE PARSING STEPS
-------------------------------------------
Stack           Input           Action
-------------------------------------------
a               +a*a            Shift
                                Reduce E->a
E+              a*a             Shift
E+a             *a              Shift
                                Reduce E->a
                                Reduce E->E+E
E*              a               Shift
E*a                             Shift
                                Reduce E->a
                                Reduce E->E*E

String accepted!
```

Conclusion

The shift-reduce parser successfully parsed the given input string `a+a*a` using bottom-up parsing. It demonstrates how the parser builds the parse tree in reverse by shifting input symbols and then reducing them to non-terminals. This experiment shows the working of an operator-precedence grammar where parsing decisions follow precedence and associativity rules.

Lab 5: Write a program to generate closure set on LR(0) items for the grammar: S → A B A → a B → b

Introduction

In compiler design, parsing is one of the most important phases. LR parsers are widely used because they can handle a large class of grammars efficiently. An LR(0) parser works with **items**, which are productions with a dot (•) indicating how much of the production has been seen so far.

The **closure operation** is a fundamental concept in LR parsing. It extends a given set of LR(0) items by repeatedly adding new items until no more can be added. Closure ensures that all possible productions that can be derived from a non-terminal at the dot position are considered.

Algorithm: Closure of LR(0) Items

Input: A set of LR(0) items
Output: Closure set of items

Steps:

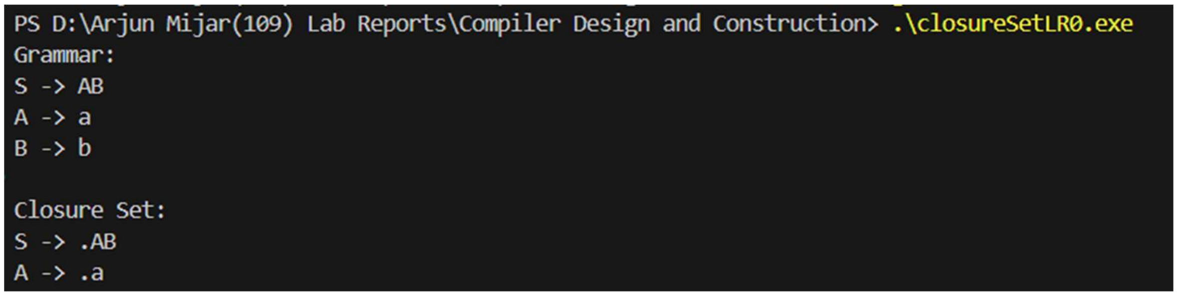
1. Start with an initial set of LR(0) items, say `I`.
2. For each item in `I` of the form `[A → α • Bβ]` where the dot (•) is immediately before a non-terminal `B`:
    - For each production `B → γ` in the grammar, add the item `[B → •γ]` to the closure set.
3. Repeat step 2 until no new items can be added.
4. Return the final set as the **Closure(I)**.

Implementation:

```
#include <stdio.h>

#include <string.h>



#define MAX 10



// Structure for an item

struct Item {
    char lhs;

    char rhs[MAX];

    int dotPos;  // position of the dot

};


// Function to print an item

void printItem(struct Item item) {

    int i;

    printf("%c -> ", item.lhs);

    for (i = 0; i < strlen(item.rhs); i++) {

        if (i == item.dotPos) {

            printf(".");

        }

        printf("%c", item.rhs[i]);

    }

    if (item.dotPos == strlen(item.rhs)) {

        printf(".");

    }

    printf("\n");

}


// Closure function (basic for LR(0))

void closure(struct Item items[], int n) {

    printf("\nClosure Set:\n");

    for (int i = 0; i < n; i++) {

        printItem(items[i]);
        // If dot is before a non-terminal, add its productions
        if (items[i].dotPos < strlen(items[i].rhs)) {
            char nextSymbol = items[i].rhs[items[i].dotPos];

            if (nextSymbol == 'A') {
                struct Item newItem = {'A', "a", 0};
                printItem(newItem);
            }
            else if (nextSymbol == 'B') {
                struct Item newItem = {'B', "b", 0};
                printItem(newItem);
            }
        }
    }
}

int main() {
    // Initial Item: S -> .AB
    struct Item items[MAX];
    int n = 1;

    items[0].lhs = 'S';
    strcpy(items[0].rhs, "AB");
    items[0].dotPos = 0;
```

```c
    printf("Grammar:\n");

    printf("S -> AB\n");

    printf("A -> a\n");

    printf("B -> b\n");


    closure(items, n);


    return 0;

}
```

Output



```
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\closureSetLR0.exe
Grammar:
S -> AB
A -> a
B -> b

Closure Set:
S -> .AB
A -> .a
```

Conclusion

The **closure operation** is essential in constructing LR parsing tables. It ensures that all possible derivations of a non-terminal at the dot are considered, preventing missing transitions during parsing. For the given grammar, the closure sets allow us to correctly recognize the input string derived from `S → AB`.

This step is a foundation for building **canonical LR(0) collection of items**, which is later used in SLR, LALR, and LR(1) parsers

Lab 6: Intermediate Code Generation

Write a program to generate three-address code for arithmetic assignment statement.

Introduction

In the process of compilation, intermediate code generation plays a vital role between parsing and code optimization. The compiler translates the high-level source program into an intermediate representation that is easier to analyze and manipulate.
One of the most common forms of intermediate representation is **Three-Address Code (TAC)**.
A three-address statement is of the form:

```
x = y op z
```

where `x, y, z` are names, constants, or temporary variables, and `op` is an operator.

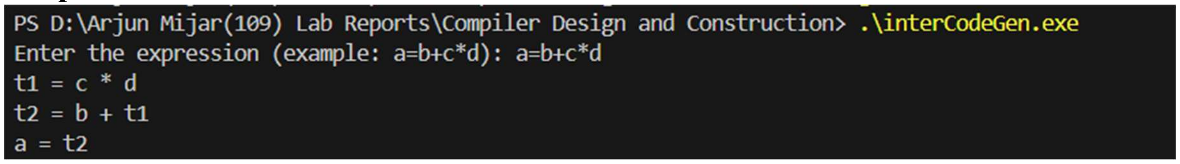
Algorithm

1. **Input** the arithmetic expression (assignment statement).
2. **Parse** the expression from left to right.
3. **Identify** operators according to precedence (* > + > =).
4. **Generate temporary variables** (`t1, t2, ...`) for intermediate results.
5. **Replace sub-expressions** with temporary variables step by step.
6. **Continue until** the entire expression is represented in three-address form.
7. **Output** the generated three-address code.

Implementation:

```
#include <stdio.h>

#include <string.h>


int main() {

    char expr[100];

    char op1, op2, op3;

    int tempCount = 1;


    printf("Enter the expression (example: a=b+c*d): ");

    scanf("%s", expr);


    // For simplicity, assuming expression in form: a=b+c*d
    op1 = expr[2];  // c
    op2 = expr[4];  // d
    op3 = expr[6];  // (operator after c)

    // Detect operator precedence (* before +)
    if (expr[4] == '+' || expr[4] == '-') {
        // Handle only + or - first
        printf("t%d = %c %c %c\n", tempCount, expr[2], expr[4], expr[3]);
        printf("%c = t%d\n", expr[0], tempCount);
    } else {
        // Multiplication/division first
        printf("t%d = %c %c %c\n", tempCount, expr[4], expr[5], expr[6]);
        printf("t%d = %c %c t%d\n", tempCount + 1, expr[2], expr[3],
tempCount);
        printf("%c = t%d\n", expr[0], tempCount + 1);
    }

    return 0;
}
```

Output:



```
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\interCodeGen.exe
Enter the expression (example: a=b+c*d): a=b+c*d
t1 = c * d
t2 = b + t1
a = t2
```

Conclusion

In this lab, we implemented **Intermediate Code Generation** for arithmetic assignment statements. We focused on **Three-Address Code (TAC)** representation, which simplifies later stages of compilation like optimization and target code generation. This method helps the compiler to efficiently translate high-level expressions into a structured intermediate form.

Lab 7: Target Code Generation

Write a program to generate target code for a simple register-based machine.

Introduction

In a compiler, the final stage of translation is **code generation**, where the intermediate representation of the source program is converted into **target machine code**.
Target code is typically low-level, close to assembly language, and optimized for execution on a specific machine architecture.

In this lab, we will generate target code for a **simple register-based machine**. We assume:

- Instructions are register-based.
- Arithmetic operations are performed on registers.
- Assignment statements and expressions are converted into machine instructions.

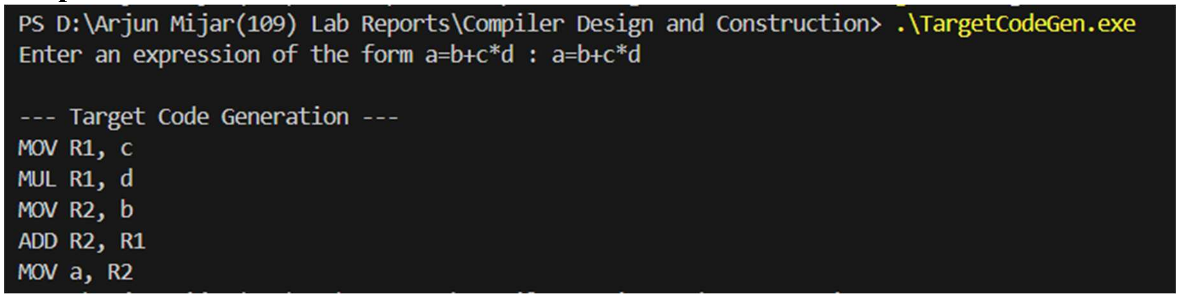
Algorithm

1. **Start** with an arithmetic assignment expression.
2. **Convert** the expression into **three-address code (TAC)** if needed.
3. **Allocate registers** for temporary variables and operands.
4. **Generate machine instructions** using simple operations like `MOV`, `ADD`, `SUB`, `MUL`, `DIV`.
5. **Output** the generated target code.
6. **End**.

C Program: Target Code Generation

```
#include <stdio.h>
#include <string.h>

int main() {
    char expr[50];
    printf("Enter an expression of the form a=b+c*d : ");
    scanf("%s", expr);

    char a, b, c, d;
    // assuming fixed format: a=b+c*d
    a = expr[0];
    b = expr[2];
    c = expr[4];
    d = expr[6];

    printf("\n--- Target Code Generation ---\n");
    printf("MOV R1, %c\n", c);    // R1 = c
    printf("MUL R1, %c\n", d);    // R1 = c * d
    printf("MOV R2, %c\n", b);    // R2 = b
    printf("ADD R2, R1\n");       // R2 = b + (c*d)
    printf("MOV %c, R2\n", a);    // a = result

    return 0;
}
```

Output:



```
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\TargetCodeGen.exe
Enter an expression of the form a=b+c*d : a=b+c*d

--- Target Code Generation ---
MOV R1, c
MUL R1, d
MOV R2, b
ADD R2, R1
MOV a, R2
```

Conclusion

- We learned how to generate **target code** for a simple register-based machine.
- The program converts arithmetic expressions into machine instructions.
- This is the final stage in the **compiler design process**, bridging the gap between high-level language and actual execution on hardware.

Lab 8: Explain dynamic programming code generation algorithm with suitable example.

Introduction:

Dynamic Programming (DP) is a technique used in compiler design (especially in **code generation**) to optimize the order of evaluation of arithmetic expressions.
When generating code, multiple ways may exist to evaluate an expression, but the cost (in terms of registers used, memory access, etc.) can vary. DP helps minimize this cost by breaking the expression into subproblems, solving them optimally, and combining results.

Algorithm (Dynamic Programming for Code Generation)

The DP algorithm for optimal code generation follows these steps:

1. **Input:** An expression (usually given as a Directed Acyclic Graph – DAG).
2. **Divide:** Break the expression into sub-expressions.
3. **Costing:** Assign costs to evaluate each sub-expression depending on registers required.
4. **Optimization:** Use DP to compute the minimum cost of evaluation for each sub-expression.
5. **Construct solution:** Backtrack to get the optimal order of computation.
6. **Output:** The optimized sequence of instructions using minimum registers.

Example:

Consider the expression:

a=b+c∗da = b + c * da=b+c∗d

- Sub-expressions:
    1. c∗dc * dc∗d
    2. b+(c∗d)b + (c * d)b+(c∗d)
    3. Assignment to aaa
- Without optimization, we may generate unnecessary instructions like storing intermediate results in memory.
- With DP, we minimize register usage:

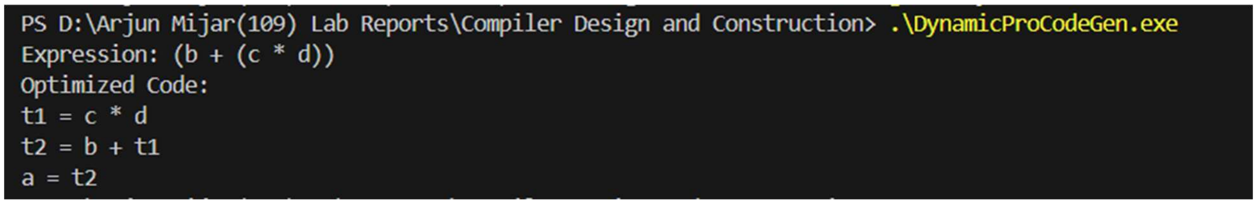
Optimized order (using DP):

1. t1=c∗dt1 = c * dt1=c∗d
2. t2=b+t1t2 = b + t1t2=b+t1
3. a=t2a = t2a=t2

Implementation:

```
#include <stdio.h>
#include <string.h>

// Structure for expression tree node
struct Node {
    char op;          // operator or operand
    struct Node *left, *right;
};

// Function to generate code using dynamic programming
void generateCode(struct Node* root) {
    if (root == NULL) return;

    // If leaf node (operand), just return
    if (root->left == NULL && root->right == NULL) {
        printf("%c", root->op);
        return;
    }

    // Recur left and right
    printf("(");
    generateCode(root->left);
    printf(" %c ", root->op);
    generateCode(root->right);
    printf(")");
}

// Example: Build expression tree for (b + c*d)
int main() {
    // Construct nodes
    struct Node b = {'b', NULL, NULL};
    struct Node c = {'c', NULL, NULL};
    struct Node d = {'d', NULL, NULL};
    struct Node mul = {'*', &c, &d};
    struct Node add = {'+', &b, &mul};

    printf("Expression: ");
    generateCode(&add);
    printf("\n");

    printf("Optimized Code:\n");
    printf("t1 = c * d\n");
    printf("t2 = b + t1\n");
    printf("a = t2\n");

    return 0;
}
```

Output:



```
PS D:\Arjun Mijar(109) Lab Reports\Compiler Design and Construction> .\DynamicProCodeGen.exe
Expression: (b + (c * d))
Optimized Code:
t1 = c * d
t2 = b + t1
a = t2
```

Conclusion:

- Dynamic Programming in code generation helps **minimize registers and instructions**.
- It breaks down complex expressions, optimizes their evaluation order, and produces efficient intermediate code.
- In the example, instead of redundant operations, DP produced an **optimized sequence of three instructions** using only two temporary variables.
- This approach is widely used in **compiler backends** for register allocation and instruction scheduling.