COMPILER DESIGN LAB
CS304

Project Phase1: Scanner for C- language

M Shree Harsha Bhat
211CS137
mshreeharshabhat.211cs137@nitk.edu.in

Shreekara Rajendra
211CS151
shreekararajendra.211cs151@nitk.edu.in

Shyam Balaji
211CS154
shyambalaji.211cs154@nitk.edu.in

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA

SURATHKAL, MANGALORE – 57025

Introduction

Compiler design is a complex field of computer science that focuses on creating software tools called compilers. Compilers are essential for translating high-level programming languages into low-level machine code or other intermediate representations that can be executed by a computer's processor.

Here are the different stages in building a compiler:

Lexical Analysis (Scanning): The first phase of compilation, where the source code is analyzed to recognize basic building blocks called tokens, such as keywords, identifiers, constants, and operators. Lexical analyzers use regular expressions and finite automata to perform this task.

Syntax Analysis (Parsing): In this phase, the compiler ensures that the sequence of tokens from the lexical analysis forms valid syntactic structures according to the language's grammar rules. Parsing is typically done using techniques like LL(k) or LR(k) parsing, and it produces a parse tree or abstract syntax tree (AST).

Semantic Analysis: This phase checks the meaning and consistency of the code. It enforces type-checking, and scope rules and detects semantic errors. The output is usually an annotated AST.

Intermediate Code Generation: The compiler generates an intermediate representation of the source code that is closer to machine code but still platform-independent. This representation simplifies code optimization and target code generation.

Code Optimization: Compiler optimization techniques aim to improve the efficiency of the generated code. This includes techniques like constant folding, dead code elimination, loop optimization, and more.

Phase 1: Lexical Analysis

Lexical analysis, also known as scanning or tokenization, is the process of breaking down a stream of characters from the source code into a sequence of tokens.

Tokens are the basic building blocks of a programming language, such as keywords, identifiers, constants, operators, and special symbols. Tokenization involves reading characters from the source code and grouping them into tokens based on specific rules defined by the programming language's syntax.

Regular Expressions and Finite Automata:

Lexical analyzers use regular expressions to describe the patterns of valid tokens in the source code.
Finite automata (DFA or NFA) are commonly employed to recognize these regular expressions efficiently

Error Handling:

Lexical analyzers should provide meaningful error messages when encountering invalid tokens or syntax errors.

Symbol Table:

In addition to recognizing tokens, the lexer may maintain a symbol table to keep track of identifiers, their names, and other information relevant to the parser and later phases of compilation.

Output:

The output of the lexical analysis phase is a sequence of tokens, often represented as a stream or list of records, each containing a token type and (optionally) associated data.

Lexical Code Format:

1.Definitions Section (%{ ... %}):

The Definitions Section is enclosed within %{ and %} delimiters.

Purpose:
This section is used to include C code and user-defined macros that will be copied verbatim into the generated lexer code. It allows you to define custom C code that can be used within your lexer.
Content:
C Code: You can include C code for various purposes, such as importing standard C libraries, declaring global variables, or defining functions that are used within the lexer actions.
Macros: You can define macros that can simplify your lexer rules or actions. For example, you might define a macro for error handling or frequently used regular expressions.

2. Rules Section (%%):

The Rules Section is demarcated by a double-percent symbol (%%).

Purpose:
This is the core of your lexer specification. It defines the regular expressions and the corresponding actions that are executed when these regular expressions match input tokens.
Rules: Each rule consists of a regular expression pattern followed by an associated action. The pattern describes the token's pattern, and the action is the code executed when that pattern is matched.

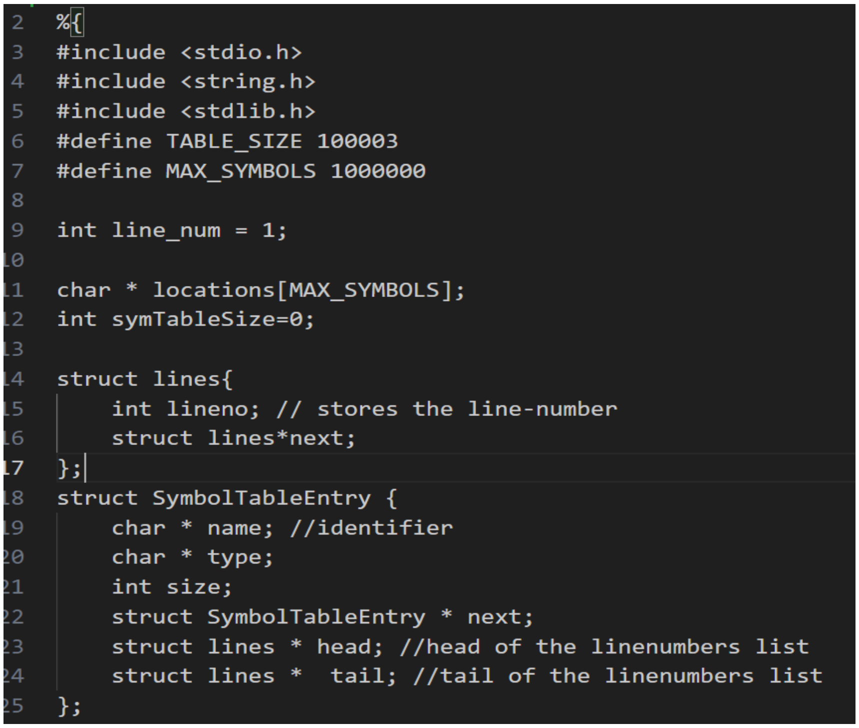
3.User Code Section (%{ ... %}):

The User Code Section is also enclosed within %{ and %} delimiters.

Purpose:
This section allows you to include additional C code that is copied directly into the generated lexer code. It's useful for adding custom functions, including external headers, or defining other global variables.
Content:
C Code: You can include any valid C code in this section. This code can be used to extend the functionality of your lexer or perform additional processing.

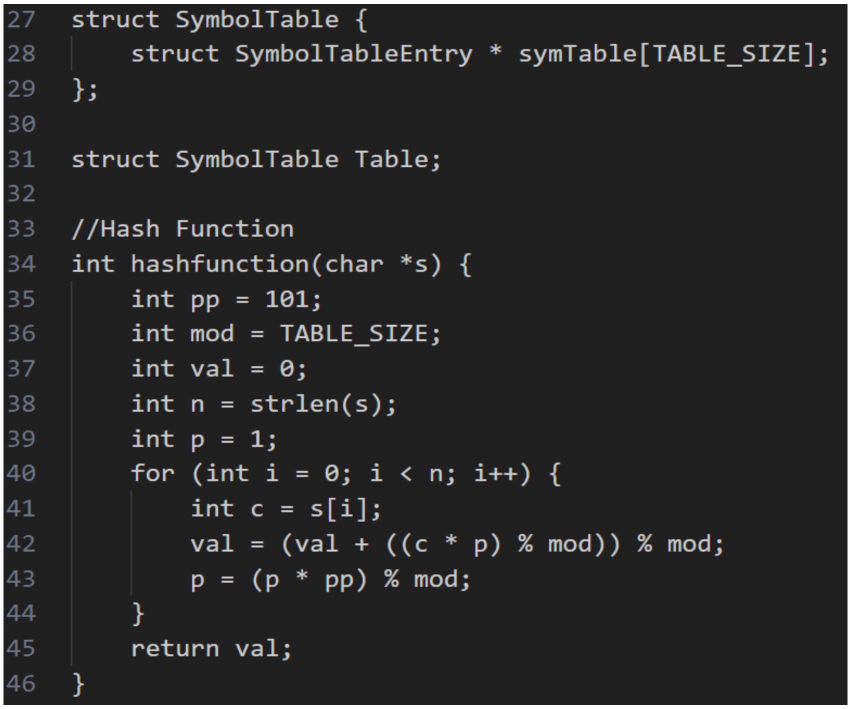
Code Explanation

1. Declaration Section



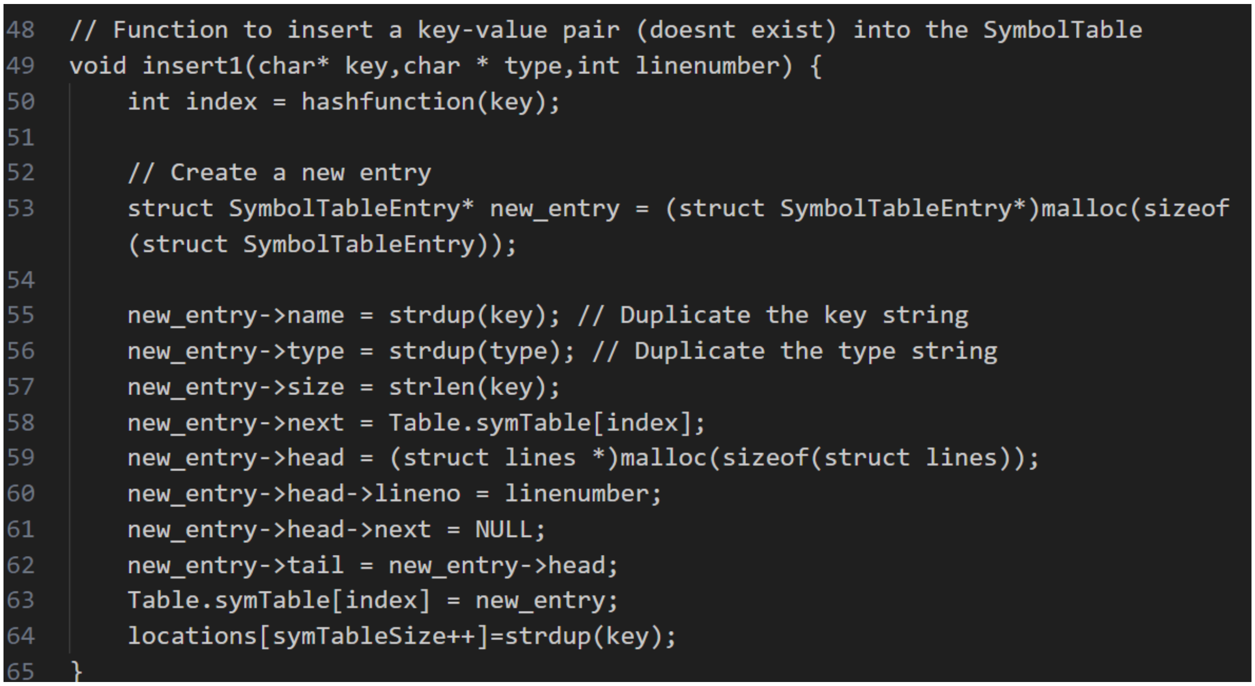
```
%{
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#define TABLE_SIZE 100003
#define MAX_SYMBOLS 1000000

int line_num = 1;

char * locations[MAX_SYMBOLS];
int symTableSize=0;

struct lines{
    int lineno; // stores the line-number
    struct lines*next;
};
struct SymbolTableEntry {
    char * name; //identifier
    char * type;
    int size;
    struct SymbolTableEntry * next;
    struct lines * head; //head of the linenumbers list
    struct lines *  tail; //tail of the linenumbers list
};
```

This code defines constants and data structures to manage a symbol table, including hash table sizing, tracking line numbers associated with symbols, and storing symbol entries with their names, types, and sizes.



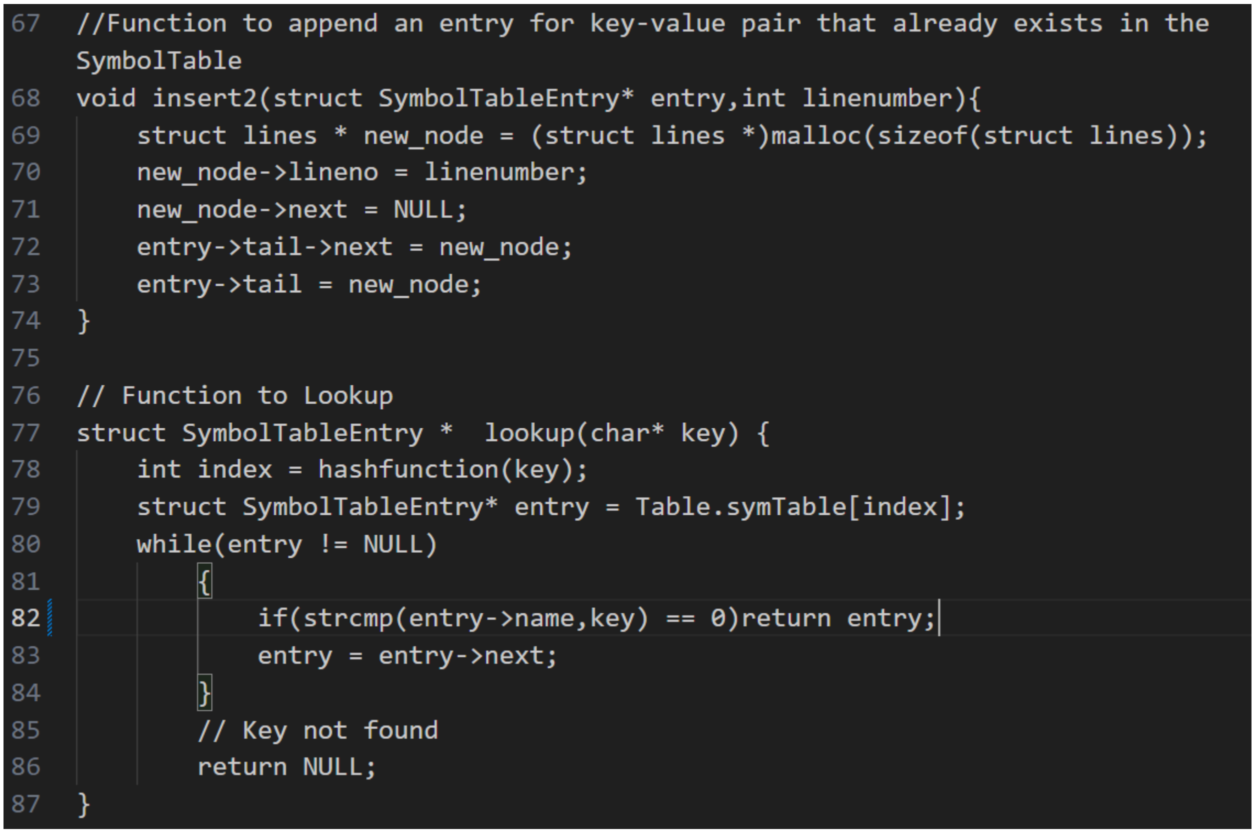
```
struct SymbolTable {
    struct SymbolTableEntry * symTable[TABLE_SIZE];
};

struct SymbolTable Table;

//Hash Function
int hashfunction(char *s) {
    int pp = 101;
    int mod = TABLE_SIZE;
    int val = 0;
    int n = strlen(s);
    int p = 1;
    for (int i = 0; i < n; i++) {
        int c = s[i];
        val = (val + ((c * p) % mod)) % mod;
        p = (p * pp) % mod;
    }
    return val;
}
```

This is used to calculate a hash value for a given string s using a custom hash function, ensuring that the hash value falls within the specified TABLE_SIZE for indexing into a symbol table.



```
// Function to insert a key-value pair (doesnt exist) into the SymbolTable
void insert1(char* key,char * type,int linenumber) {
    int index = hashfunction(key);

    // Create a new entry
    struct SymbolTableEntry* new_entry = (struct SymbolTableEntry*)malloc(sizeof
    (struct SymbolTableEntry));

    new_entry->name = strdup(key); // Duplicate the key string
    new_entry->type = strdup(type); // Duplicate the type string
    new_entry->size = strlen(key);
    new_entry->next = Table.symTable[index];
    new_entry->head = (struct lines *)malloc(sizeof(struct lines));
    new_entry->head->lineno = linenumber;
    new_entry->head->next = NULL;
    new_entry->tail = new_entry->head;
    Table.symTable[index] = new_entry;
    locations[symTableSize++]=strdup(key);
}
```

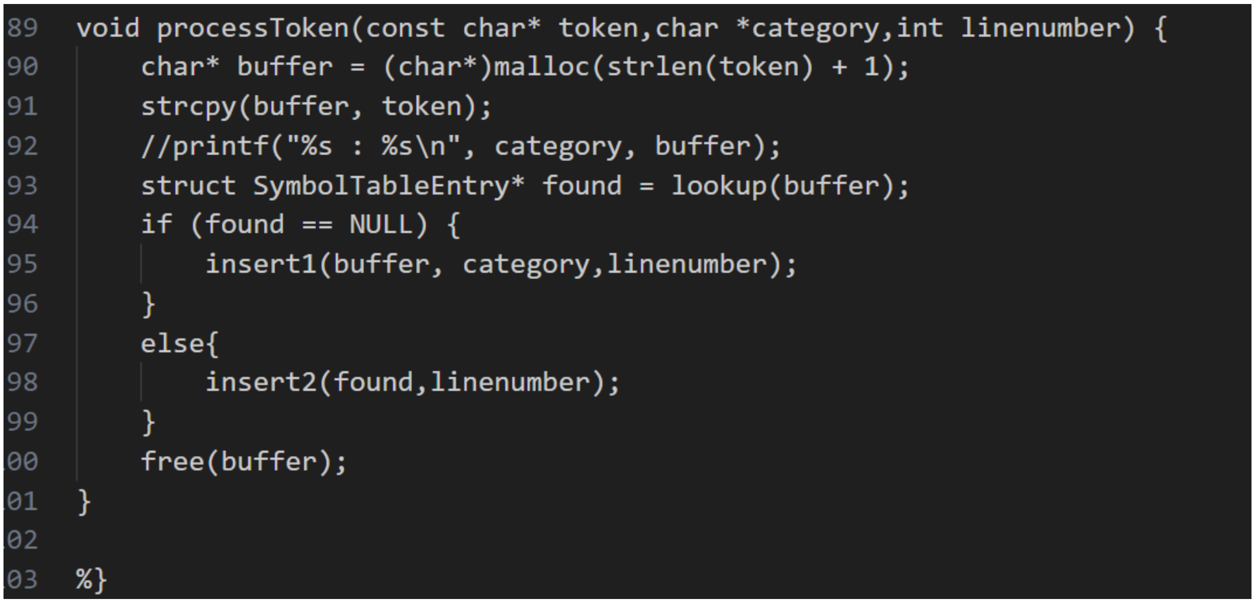
The insert () function inserts a new key-value pair (identifier and its associated type) into the symbol table, creating a new entry with memory allocation and linking it to the hash table, while also recording the line number of the first occurrence of the identifier and adding its name to the locations array for later reference.



```
//Function to append an entry for key-value pair that already exists in the
SymbolTable
void insert2(struct SymbolTableEntry* entry,int linenumber){
    struct lines * new_node = (struct lines *)malloc(sizeof(struct lines));
    new_node->lineno = linenumber;
    new_node->next = NULL;
    entry->tail->next = new_node;
    entry->tail = new_node;
}

// Function to Lookup
struct SymbolTableEntry *  lookup(char* key) {
    int index = hashfunction(key);
    struct SymbolTableEntry* entry = Table.symTable[index];
    while(entry != NULL)
        {
            if(strcmp(entry->name,key) == 0)return entry;
            entry = entry->next;
        }
        // Key not found
        return NULL;
}
```

In the insert2() function we append a new line number to the list of line numbers associated with an existing key-value pair (identifier) in the symbol table, creating a new node for the line number and updating the linked list accordingly.

The lookup () function looks up an identifier (specified by the key) in the symbol table by calculating its hash index, traversing the linked list at that index, and returning the corresponding symbol table entry if found; otherwise, it returns NULL to indicate that the identifier is not in the symbol table.



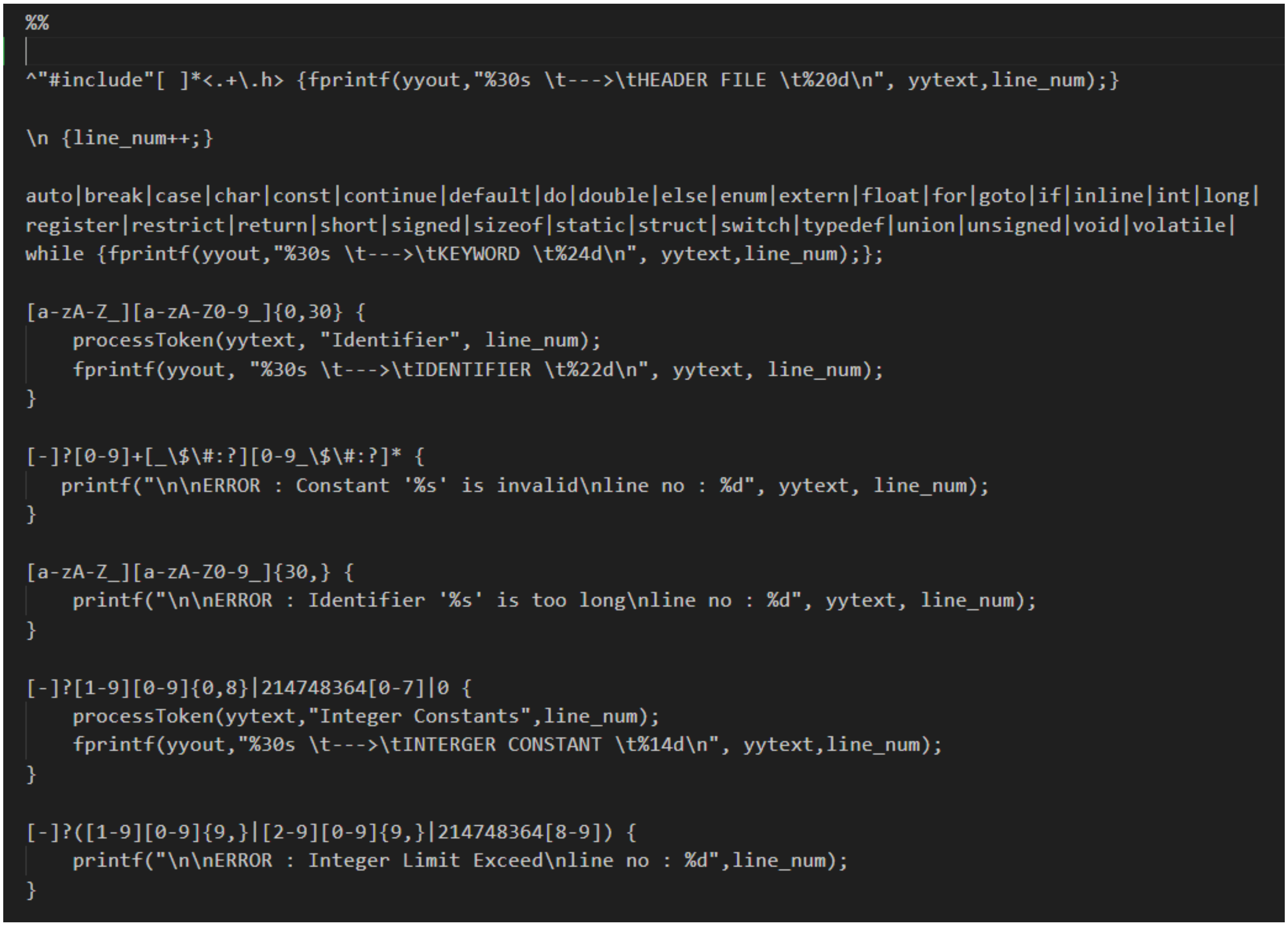
```
void processToken(const char* token,char *category,int linenumber) {
    char* buffer = (char*)malloc(strlen(token) + 1);
    strcpy(buffer, token);
    //printf("%s : %s\n", category, buffer);
    struct SymbolTableEntry* found = lookup(buffer);
    if (found == NULL) {
        insert1(buffer, category,linenumber);
    }
    else{
        insert2(found,linenumber);
    }
    free(buffer);
}

%}
```

The processToken() function processes a token by making a copy of it, checks if the token (identifier) is already in the symbol table using the lookup function, and either inserts it as a new entry with its category and line number or appends the line number to the existing entry's line numbers list based on whether it's found or not in the symbol table, and then frees the allocated memory for the token copy.

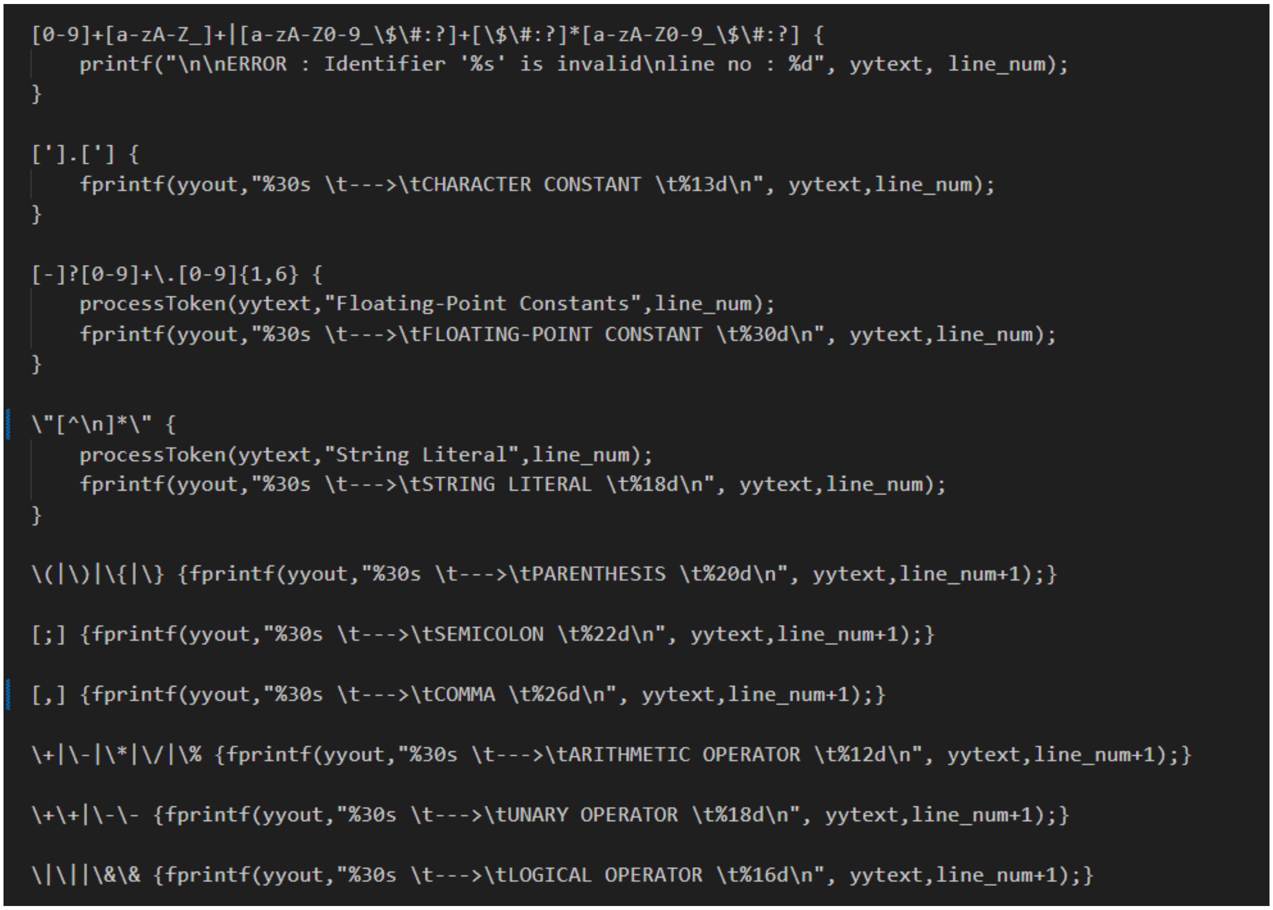
2. <u>Rules Section</u>

The rules for identifying identifiers, keywords, header files, numeric constants, string literal, single line comments, multiline comments, brackets, semicolons, commas, and operators (athematic, logical, relational, bit-wise, etc.) are written.

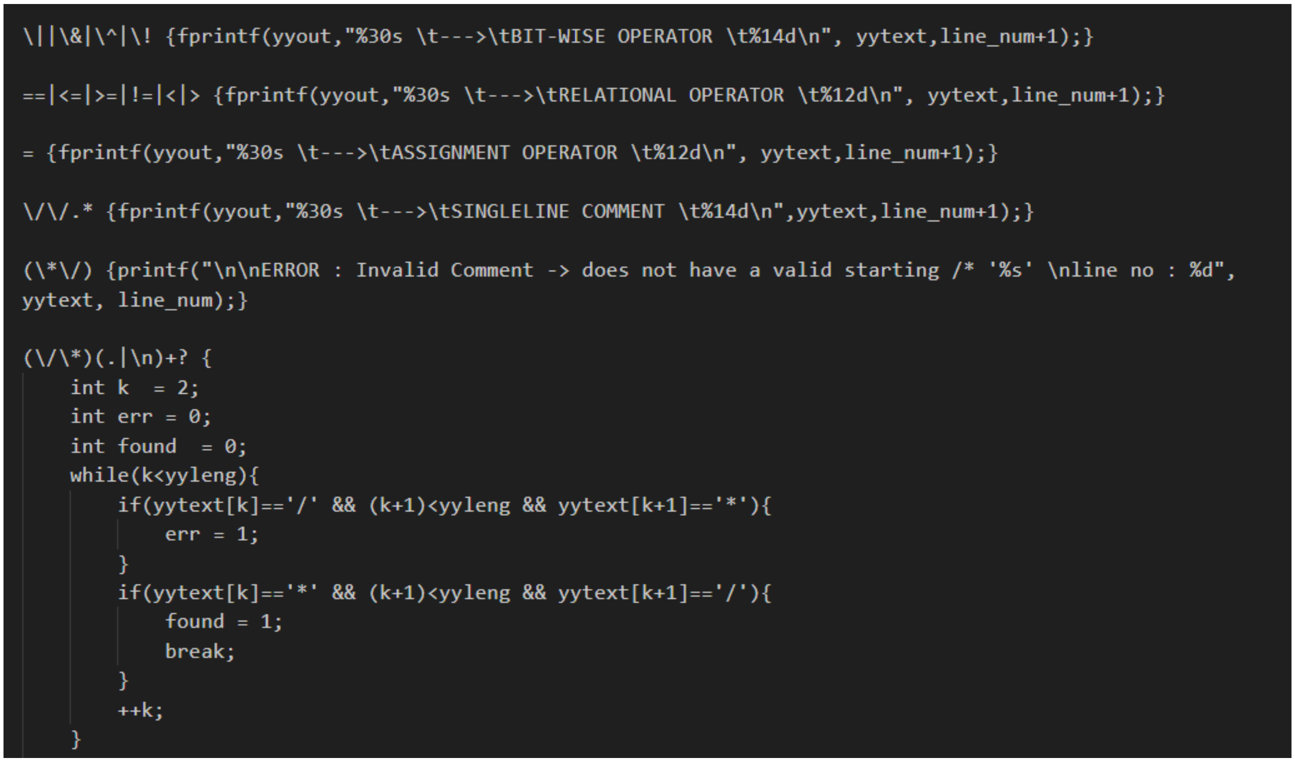
The rules for lexical error identification such as invalid identifier, invalid string literal, invalid numeric literal, invalid multiline comment and nested comments are specified.



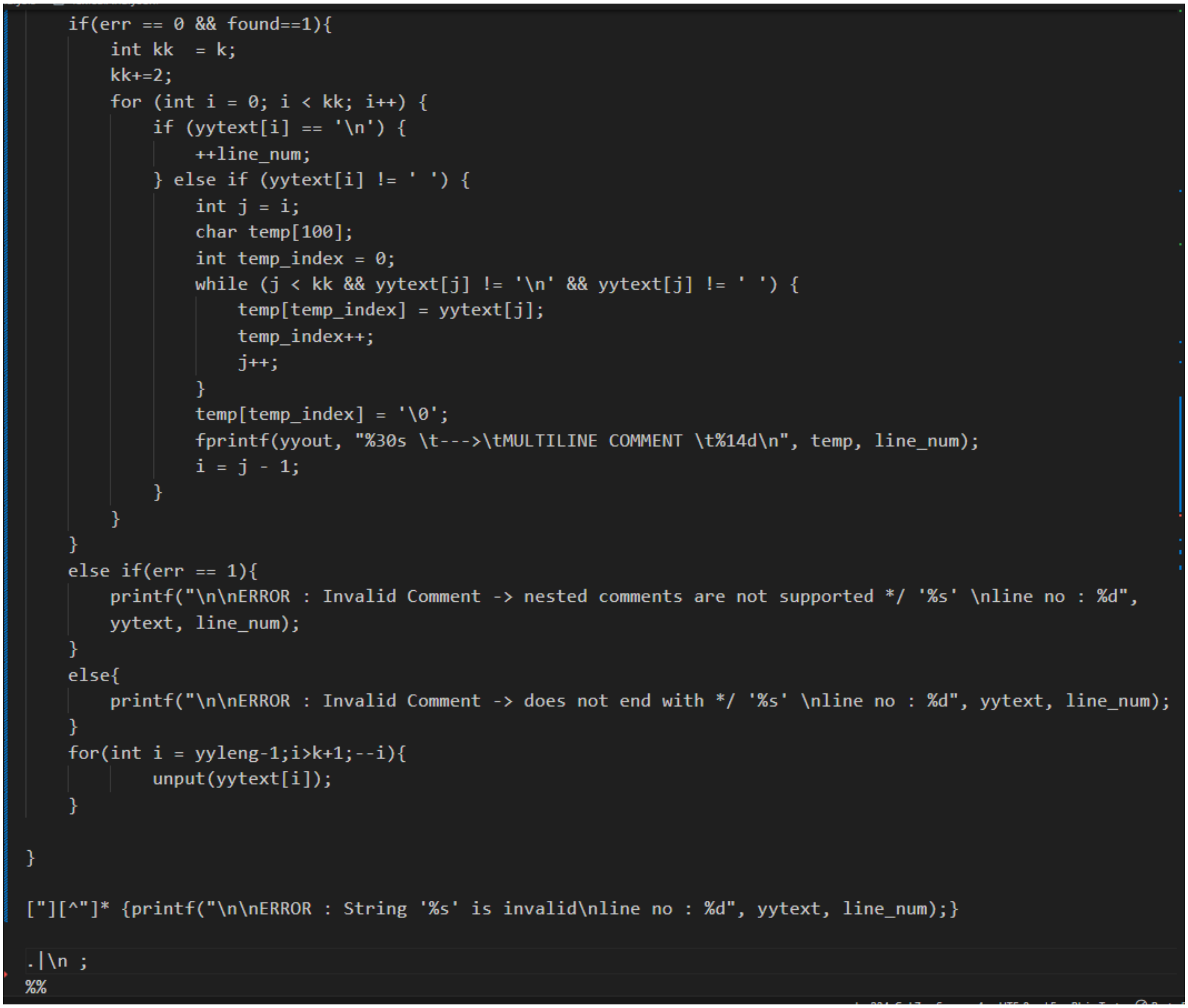
```
%%

^"#include"[ ]*<.+\.h> {fprintf(yyout,"%30s \t--->\tHEADER FILE \t%20d\n", yytext,line_num);}

\n {line_num++;}

auto|break|case|char|const|continue|default|do|double|else|enum|extern|float|for|goto|if|inline|int|long|
register|restrict|return|short|signed|sizeof|static|struct|switch|typedef|union|unsigned|void|volatile|
while {fprintf(yyout,"%30s \t--->\tKEYWORD \t%24d\n", yytext,line_num);};

[a-zA-Z_][a-zA-Z0-9_]{0,30} {
    processToken(yytext, "Identifier", line_num);
    fprintf(yyout, "%30s \t--->\tIDENTIFIER \t%22d\n", yytext, line_num);
}

[-]?[0-9]+[_\$\#:?][0-9_\$\#:?]* {
   printf("\n\nERROR : Constant '%s' is invalid\nline no : %d", yytext, line_num);
}

[a-zA-Z_][a-zA-Z0-9_]{30,} {
    printf("\n\nERROR : Identifier '%s' is too long\nline no : %d", yytext, line_num);
}

[-]?[1-9][0-9]{0,8}|214748364[0-7]|0 {
    processToken(yytext,"Integer Constants",line_num);
    fprintf(yyout,"%30s \t--->\tINTERGER CONSTANT \t%14d\n", yytext,line_num);
}

[-]?([1-9][0-9]{9,}|[2-9][0-9]{9,}|214748364[8-9]) {
    printf("\n\nERROR : Integer Limit Exceed\nline no : %d",line_num);
}
```



```
[0-9]+[a-zA-Z_]+|[a-zA-Z0-9_\$\#:?]+[\$\#:?]*[a-zA-Z0-9_\$\#:?] {
    printf("\n\nERROR : Identifier '%s' is invalid\nline no : %d", yytext, line_num);
}

['].['] {
    fprintf(yyout,"%30s \t--->\tCHARACTER CONSTANT \t%13d\n", yytext,line_num);
}

[-]?[0-9]+\.[0-9]{1,6} {
    processToken(yytext,"Floating-Point Constants",line_num);
    fprintf(yyout,"%30s \t--->\tFLOATING-POINT CONSTANT \t%30d\n", yytext,line_num);
}

\"[^\n]*\" {
    processToken(yytext,"String Literal",line_num);
    fprintf(yyout,"%30s \t--->\tSTRING LITERAL \t%18d\n", yytext,line_num);
}

\(|\)|\{|\} {fprintf(yyout,"%30s \t--->\tPARENTHESIS \t%20d\n", yytext,line_num+1);}

[;] {fprintf(yyout,"%30s \t--->\tSEMICOLON \t%22d\n", yytext,line_num+1);}

[,] {fprintf(yyout,"%30s \t--->\tCOMMA \t%26d\n", yytext,line_num+1);}

\+|\-|\*|\/|\% {fprintf(yyout,"%30s \t--->\tARITHMETIC OPERATOR \t%12d\n", yytext,line_num+1);}

\+\+|\-\- {fprintf(yyout,"%30s \t--->\tUNARY OPERATOR \t%18d\n", yytext,line_num+1);}

\|\||\&\& {fprintf(yyout,"%30s \t--->\tLOGICAL OPERATOR \t%16d\n", yytext,line_num+1);}
```

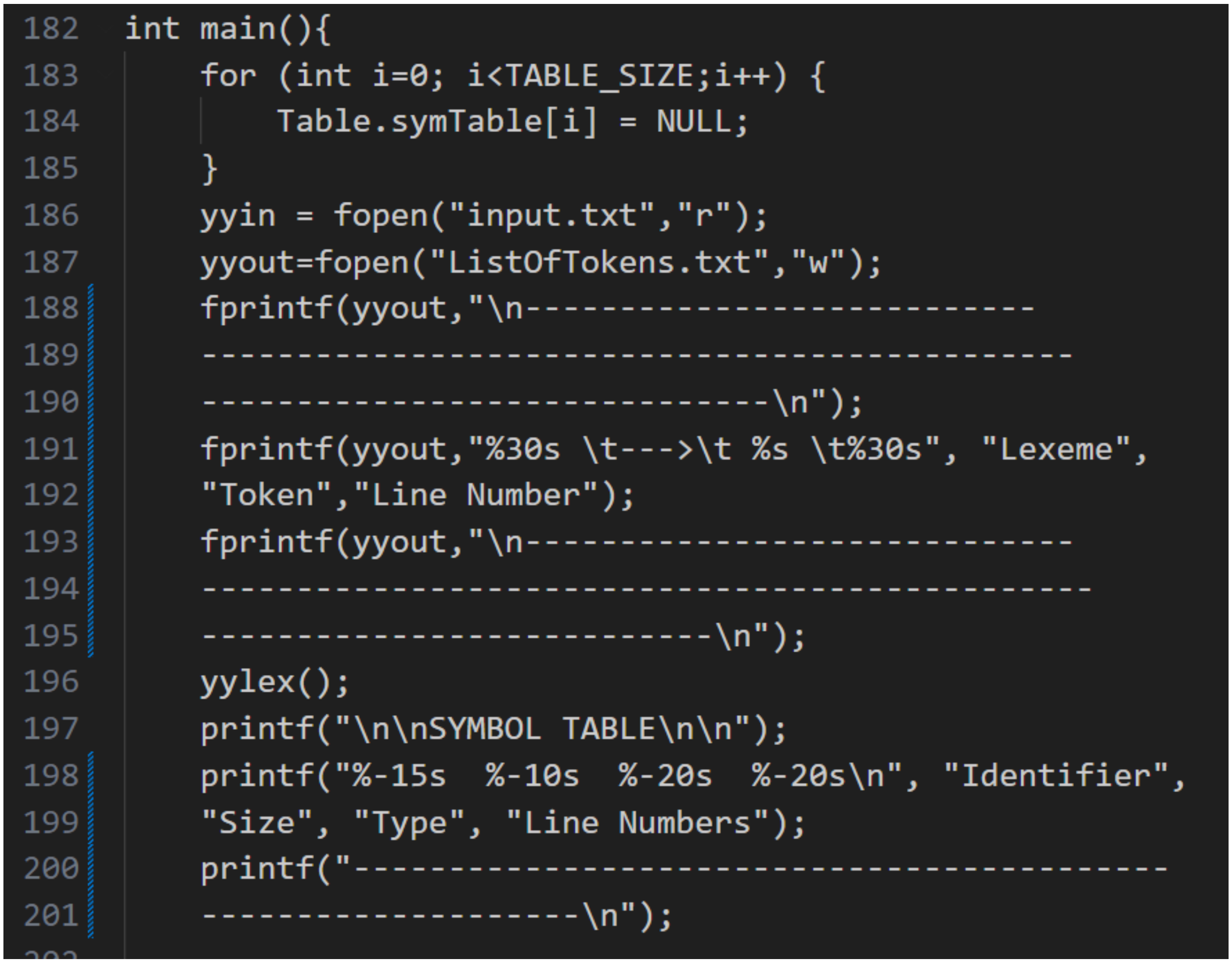


```
\||\&|\^|\! {fprintf(yyout,"%30s \t--->\tBIT-WISE OPERATOR \t%14d\n", yytext,line_num+1);}

==|<=|>=|!=|<|> {fprintf(yyout,"%30s \t--->\tRELATIONAL OPERATOR \t%12d\n", yytext,line_num+1);}

= {fprintf(yyout,"%30s \t--->\tASSIGNMENT OPERATOR \t%12d\n", yytext,line_num+1);}

\/\/.* {fprintf(yyout,"%30s \t--->\tSINGLELINE COMMENT \t%14d\n",yytext,line_num+1);}

(\*\/) {printf("\n\nERROR : Invalid Comment -> does not have a valid starting /* '%s' \nline no : %d",
yytext, line_num);}

(\/\*)(.|\n)+? {
    int k  = 2;
    int err = 0;
    int found  = 0;
    while(k<yyleng){
        if(yytext[k]=='/' && (k+1)<yyleng && yytext[k+1]=='*'){
            err = 1;
        }
        if(yytext[k]=='*' && (k+1)<yyleng && yytext[k+1]=='/'){
            found = 1;
            break;
        }
        ++k;
    }
```



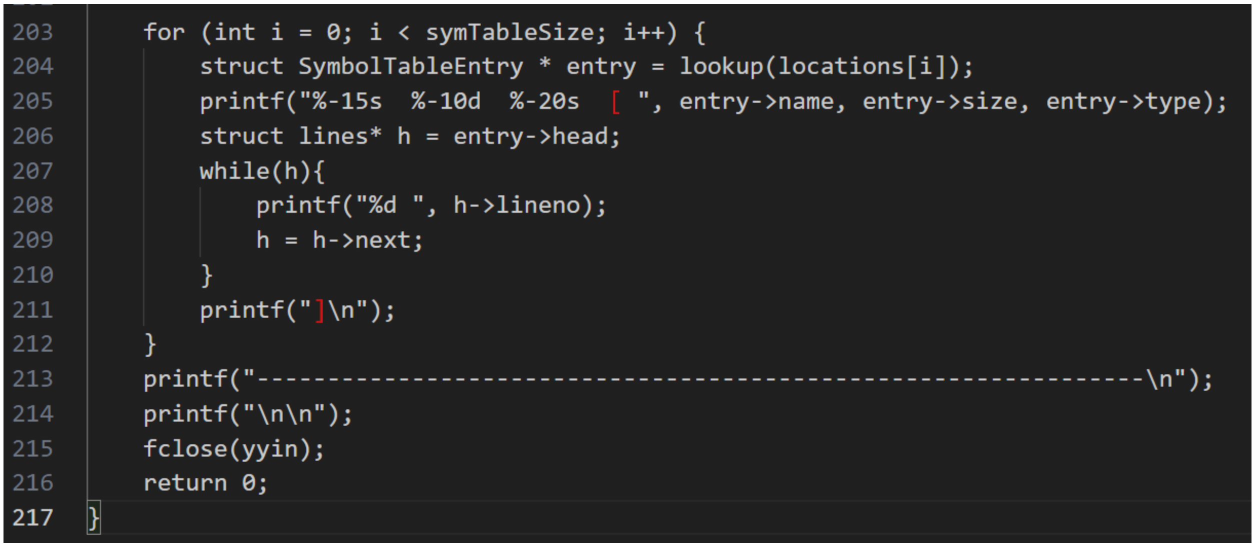
```
    if(err == 0 && found==1){
        int kk  = k;
        kk+=2;
        for (int i = 0; i < kk; i++) {
            if (yytext[i] == '\n') {
                ++line_num;
            } else if (yytext[i] != ' ') {
                int j = i;
                char temp[100];
                int temp_index = 0;
                while (j < kk && yytext[j] != '\n' && yytext[j] != ' ') {
                    temp[temp_index] = yytext[j];
                    temp_index++;
                    j++;
                }
                temp[temp_index] = '\0';
                fprintf(yyout, "%30s \t--->\tMULTILINE COMMENT \t%14d\n", temp, line_num);
                i = j - 1;
            }
        }
    }
    else if(err == 1){
        printf("\n\nERROR : Invalid Comment -> nested comments are not supported */ '%s' \nline no : %d",
        yytext, line_num);
    }
    else{
        printf("\n\nERROR : Invalid Comment -> does not end with */ '%s' \nline no : %d", yytext, line_num);
    }
    for(int i = yyleng-1;i>k+1;--i){
            unput(yytext[i]);
    }

}

["][^"]* {printf("\n\nERROR : String '%s' is invalid\nline no : %d", yytext, line_num);}

.|\n ;
%%
```

3. Main Function



```
int main(){
    for (int i=0; i<TABLE_SIZE;i++) {
        Table.symTable[i] = NULL;
    }
    yyin = fopen("input.txt","r");
    yyout=fopen("ListOfTokens.txt","w");
    fprintf(yyout,"\n-------------------------
    -------------------------------------------
    ----------------------------\n");
    fprintf(yyout,"%30s \t--->\t %s \t%30s", "Lexeme",
    "Token","Line Number");
    fprintf(yyout,"\n---------------------------
    --------------------------------------------
    -------------------------\n");
    yylex();
    printf("\n\nSYMBOL TABLE\n\n");
    printf("%-15s  %-10s  %-20s  %-20s\n", "Identifier",
    "Size", "Type", "Line Numbers");
    printf("----------------------------------------
    -------------------\n");
```

We are initializing the table to NULL values. Here we are just outputting all our tokens into a “List of Tokens “file.



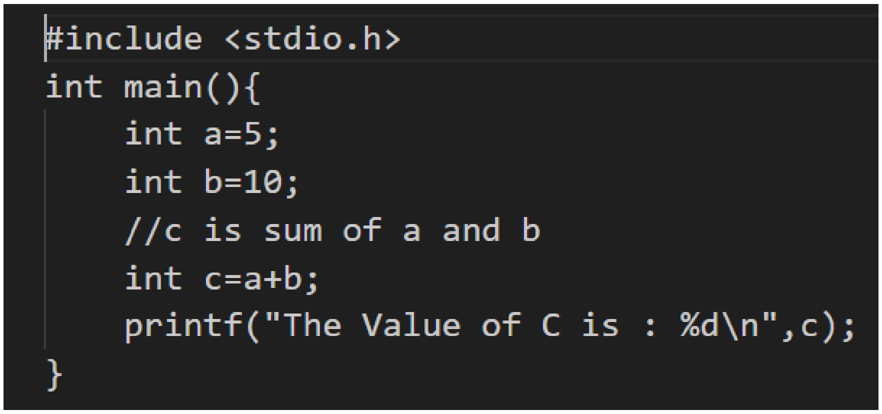
```
    for (int i = 0; i < symTableSize; i++) {
        struct SymbolTableEntry * entry = lookup(locations[i]);
        printf("%-15s  %-10d  %-20s  [ ", entry->name, entry->size, entry->type);
        struct lines* h = entry->head;
        while(h){
            printf("%d ", h->lineno);
            h = h->next;
        }
        printf("]\n");
    }
    printf("---------------------------------------------------------------\n");
    printf("\n\n");
    fclose(yyin);
    return 0;
}
```

Here for each symbol in our Symbol table, we are printing its name, size, type, and line numbers.

TEST CASES And their OUTPUTS

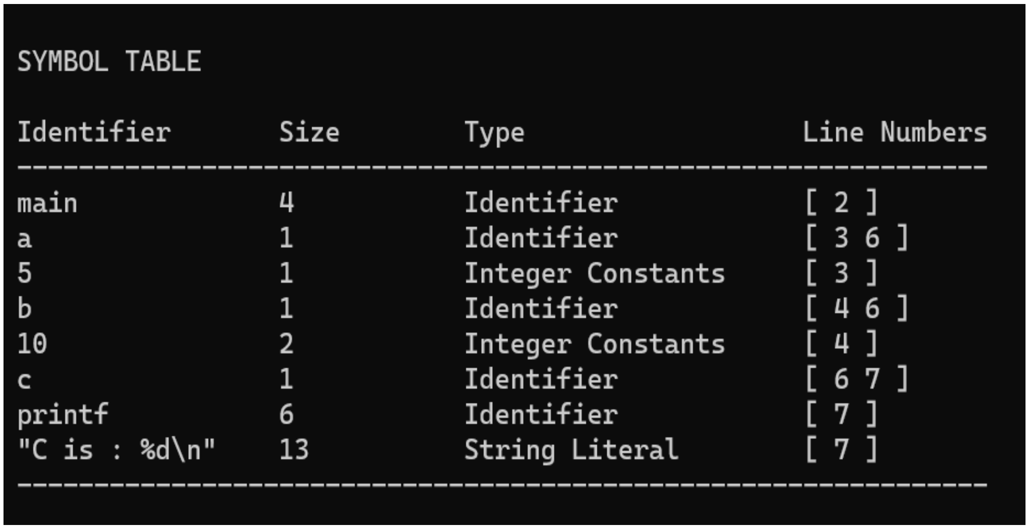
1. input.txt - test input file 1

- Input File code



```
#include <stdio.h>
int main(){
    int a=5;
    int b=10;
    //c is sum of a and b
    int c=a+b;
    printf("The Value of C is : %d\n",c);
}
```

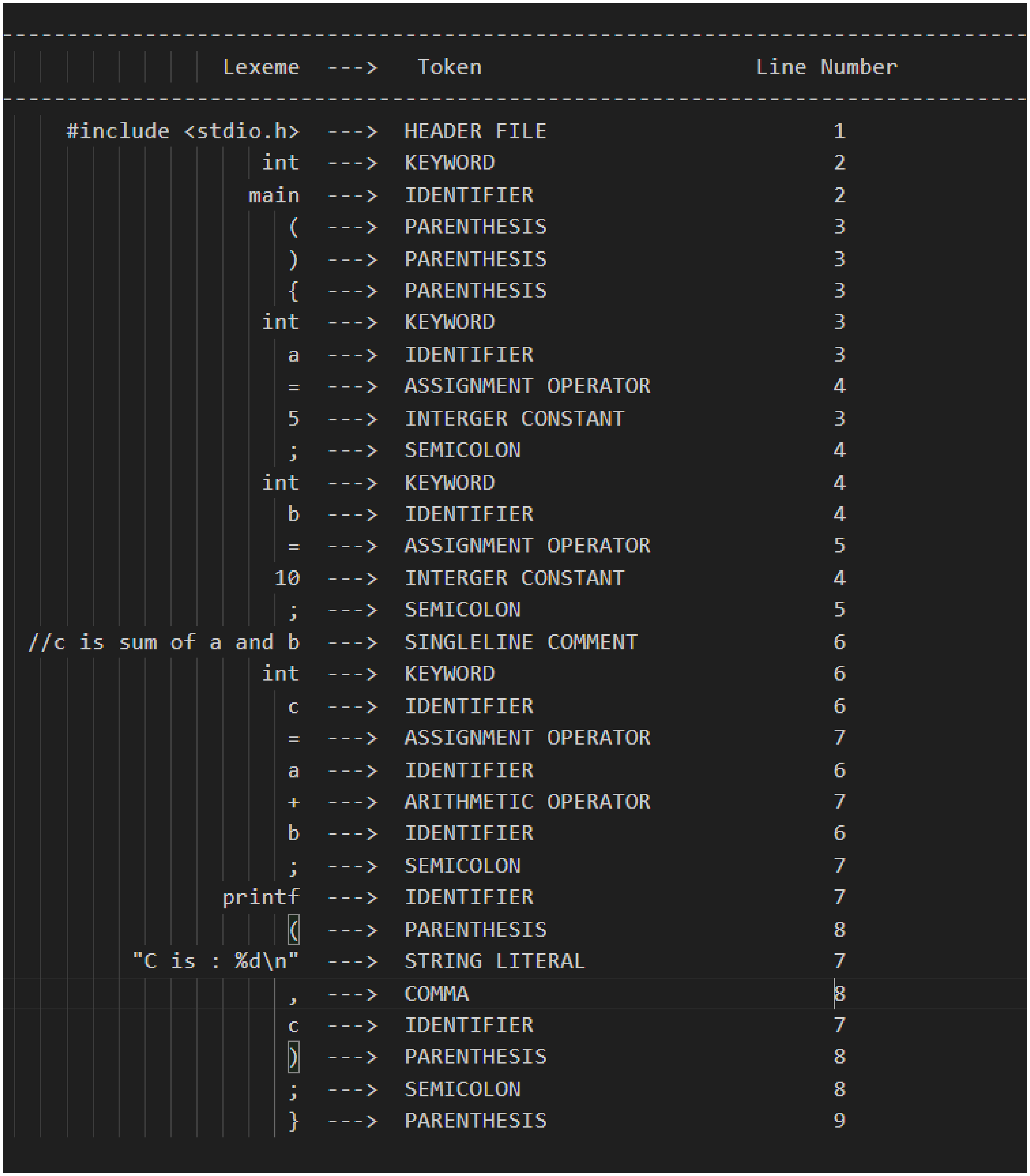
- Symbol Table



```
SYMBOL TABLE

Identifier       Size        Type                  Line Numbers
----------------------------------------------------------------
main             4           Identifier            [ 2 ]
a                1           Identifier            [ 3 6 ]
5                1           Integer Constants     [ 3 ]
b                1           Identifier            [ 4 6 ]
10               2           Integer Constants     [ 4 ]
c                1           Identifier            [ 6 7 ]
printf           6           Identifier            [ 7 ]
"C is : %d\n"    13          String Literal        [ 7 ]
----------------------------------------------------------------
```

The Symbol Table fo the above input c file. The code does not have any lexical errors and the tokens are identified and are outputted into a file.

- ListOfToken.txt

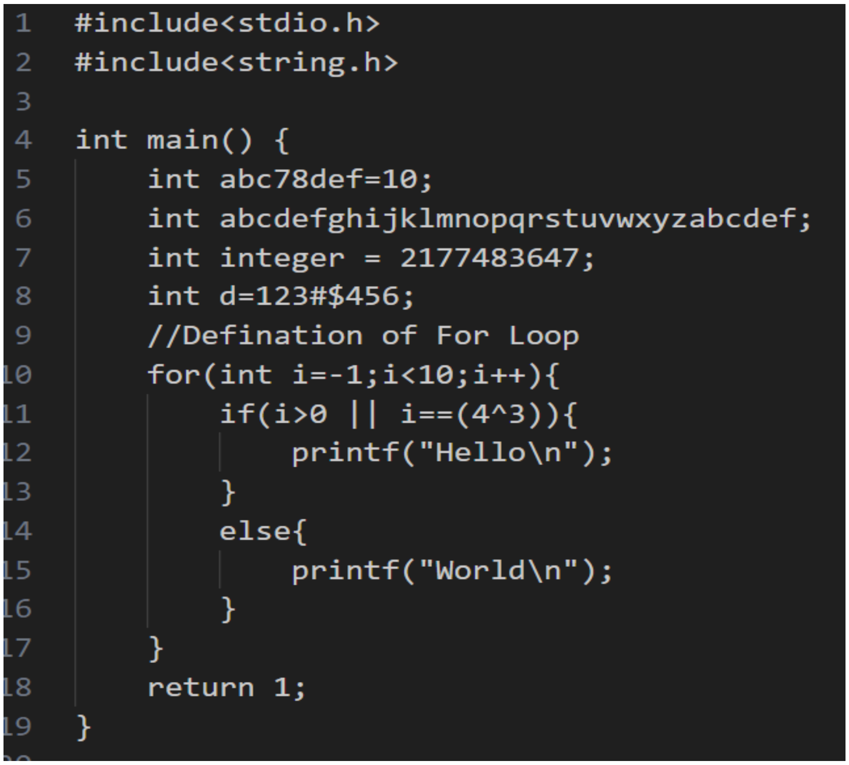


```
-------------------------------------------------------------------------------
                 Lexeme  --->   Token                     Line Number
-------------------------------------------------------------------------------
     #include <stdio.h>  --->  HEADER FILE                      1
                    int  --->  KEYWORD                          2
                   main  --->  IDENTIFIER                       2
                      (  --->  PARENTHESIS                      3
                      )  --->  PARENTHESIS                      3
                      {  --->  PARENTHESIS                      3
                    int  --->  KEYWORD                          3
                      a  --->  IDENTIFIER                       3
                      =  --->  ASSIGNMENT OPERATOR              4
                      5  --->  INTERGER CONSTANT                3
                      ;  --->  SEMICOLON                        4
                    int  --->  KEYWORD                          4
                      b  --->  IDENTIFIER                       4
                      =  --->  ASSIGNMENT OPERATOR              5
                     10  --->  INTERGER CONSTANT                4
                      ;  --->  SEMICOLON                        5
  //c is sum of a and b  --->  SINGLELINE COMMENT               6
                    int  --->  KEYWORD                          6
                      c  --->  IDENTIFIER                       6
                      =  --->  ASSIGNMENT OPERATOR              7
                      a  --->  IDENTIFIER                       6
                      +  --->  ARITHMETIC OPERATOR              7
                      b  --->  IDENTIFIER                       6
                      ;  --->  SEMICOLON                        7
                 printf  --->  IDENTIFIER                       7
                      (  --->  PARENTHESIS                      8
          "C is : %d\n"  --->  STRING LITERAL                   7
                      ,  --->  COMMA                            8
                      c  --->  IDENTIFIER                       7
                      )  --->  PARENTHESIS                      8
                      ;  --->  SEMICOLON                        8
                      }  --->  PARENTHESIS                      9
```

This is the output file generated after the lexical analysis phase. All tokens identified are sent to this file and displayed. Every token has the lexeme, its type, and line number of appearance displayed in the output file.

2. inputTwo.txt - test input file 2

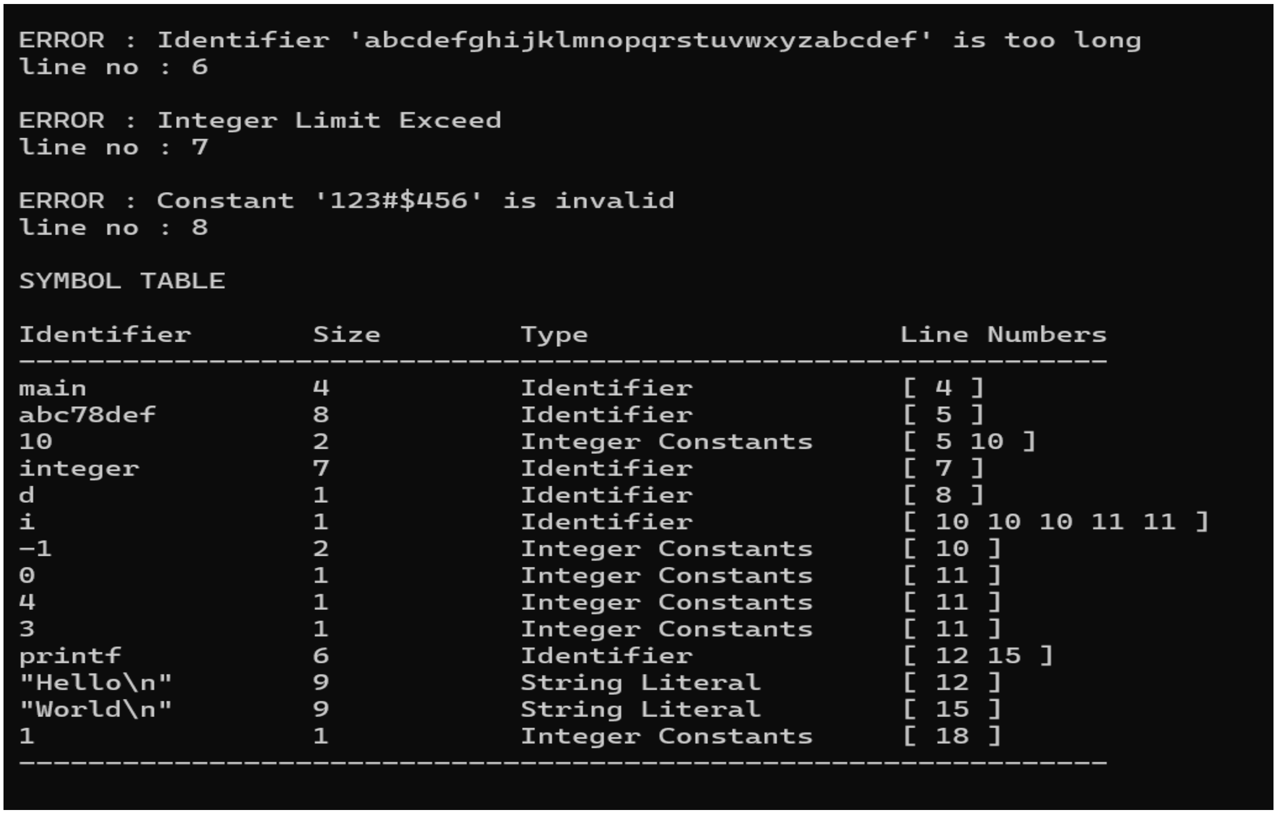
- Input File code



```
1   #include<stdio.h>
2   #include<string.h>
3
4   int main() {
5       int abc78def=10;
6       int abcdefghijklmnopqrstuvwxyzabcdef;
7       int integer = 2177483647;
8       int d=123#$456;
9       //Defination of For Loop
10      for(int i=-1;i<10;i++){
11          if(i>0 || i==(4^3)){
12              printf("Hello\n");
13          }
14          else{
15              printf("World\n");
16          }
17      }
18      return 1;
19  }
```

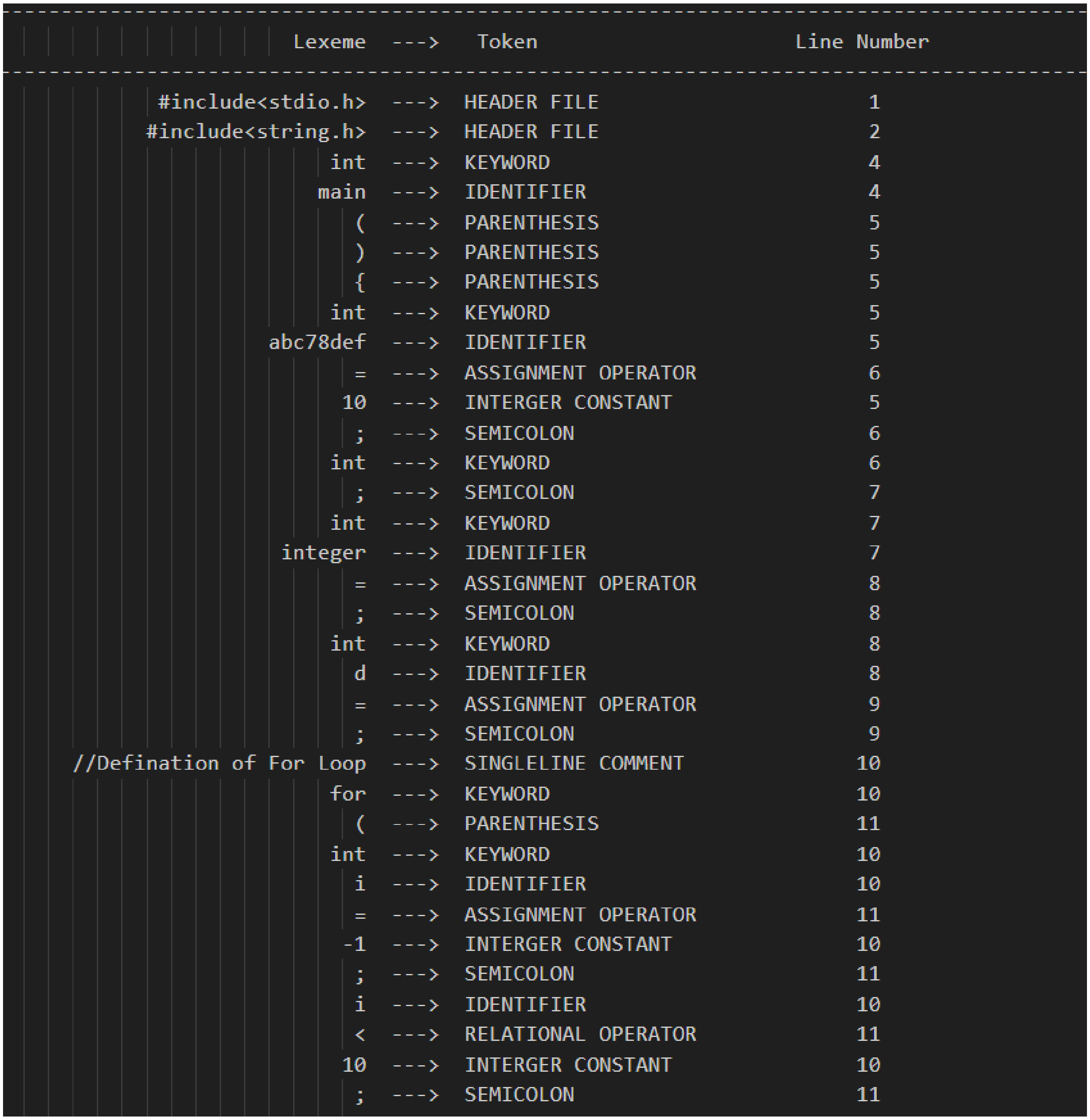
In this input test case, the variable **‘abcdefghijklmnopqrstuvwxyzabcdef’** has exceeded the Identifier name size limit. This error is a lexica error and has to be detected in the lexical analysis phase. Thus Our scanner identifies the error and displays it along with the line no. Similarly, the variable **‘integer’** has exceeded the integer limit so it is also detected by a scanner. The variable **‘d’** is assigned with a constant value that is an invalid numeric constant. So, our scanner identifies these lexical errors and displays them.

- Symbol Table

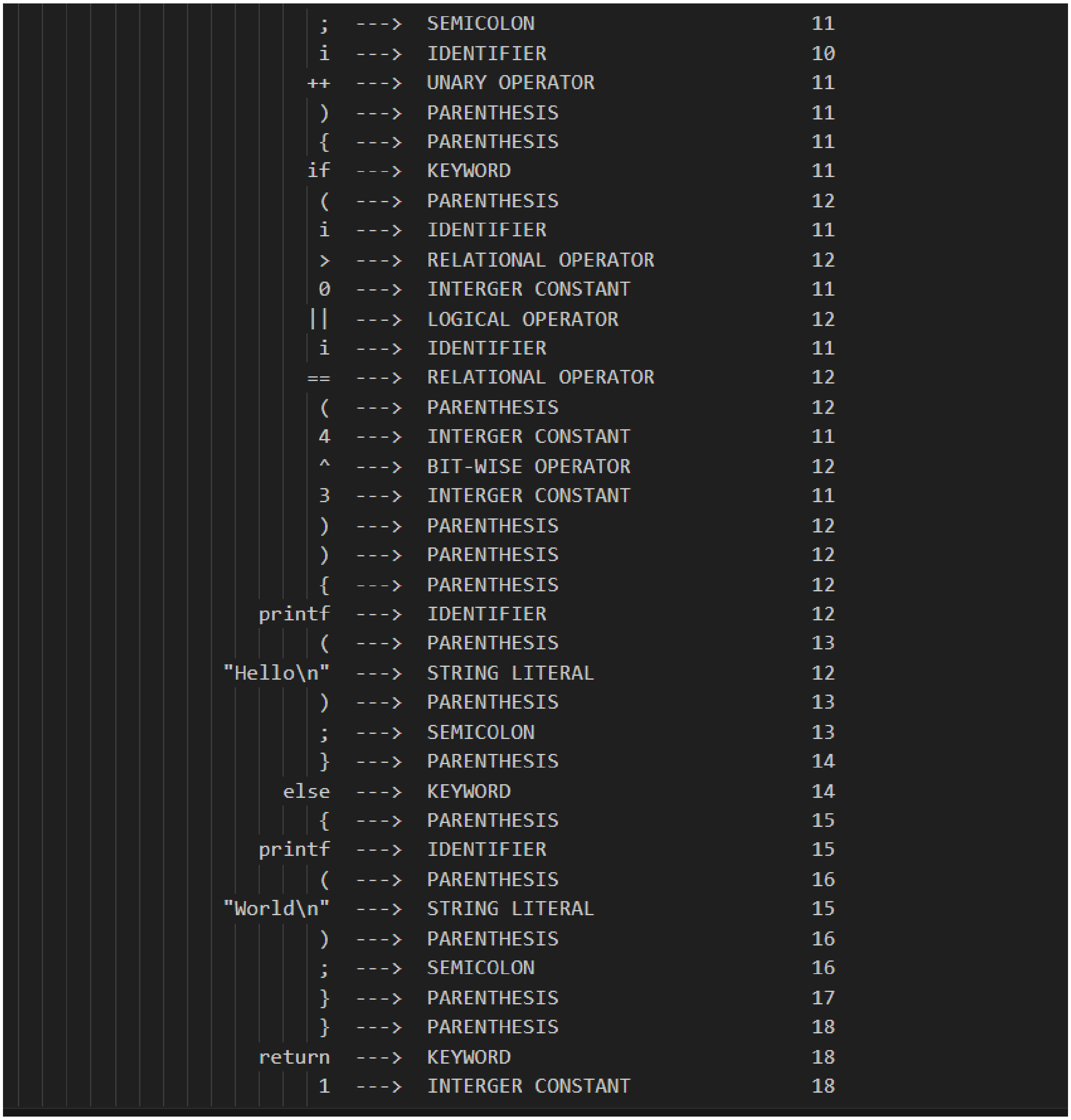


```
ERROR : Identifier 'abcdefghijklmnopqrstuvwxyzabcdef' is too long
line no : 6

ERROR : Integer Limit Exceed
line no : 7

ERROR : Constant '123#$456' is invalid
line no : 8

SYMBOL TABLE

Identifier       Size        Type                   Line Numbers
--------------------------------------------------------------
main             4           Identifier             [ 4 ]
abc78def         8           Identifier             [ 5 ]
10               2           Integer Constants      [ 5 10 ]
integer          7           Identifier             [ 7 ]
d                1           Identifier             [ 8 ]
i                1           Identifier             [ 10 10 10 11 11 ]
-1               2           Integer Constants      [ 10 ]
0                1           Integer Constants      [ 11 ]
4                1           Integer Constants      [ 11 ]
3                1           Integer Constants      [ 11 ]
printf           6           Identifier             [ 12 15 ]
"Hello\n"        9           String Literal         [ 12 ]
"World\n"        9           String Literal         [ 15 ]
1                1           Integer Constants      [ 18 ]
--------------------------------------------------------------
```

- ListOfSymbol.txt



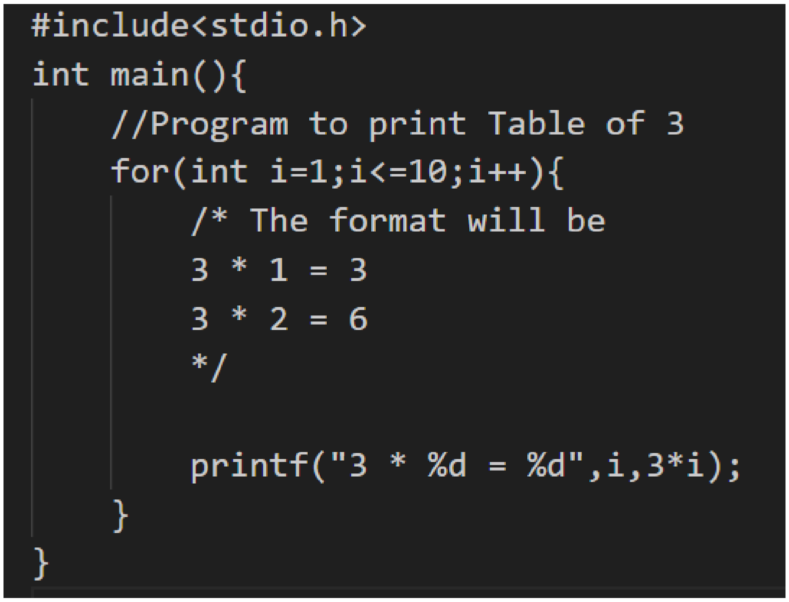
```
---------------------------------------------------------------------------------------
                       Lexeme  --->   Token                    Line Number
---------------------------------------------------------------------------------------
            #include<stdio.h>  --->  HEADER FILE                    1
           #include<string.h>  --->  HEADER FILE                    2
                          int  --->  KEYWORD                        4
                         main  --->  IDENTIFIER                     4
                            (  --->  PARENTHESIS                    5
                            )  --->  PARENTHESIS                    5
                            {  --->  PARENTHESIS                    5
                          int  --->  KEYWORD                        5
                     abc78def  --->  IDENTIFIER                     5
                            =  --->  ASSIGNMENT OPERATOR            6
                           10  --->  INTERGER CONSTANT              5
                            ;  --->  SEMICOLON                      6
                          int  --->  KEYWORD                        6
                            ;  --->  SEMICOLON                      7
                          int  --->  KEYWORD                        7
                      integer  --->  IDENTIFIER                     7
                            =  --->  ASSIGNMENT OPERATOR            8
                            ;  --->  SEMICOLON                      8
                          int  --->  KEYWORD                        8
                            d  --->  IDENTIFIER                     8
                            =  --->  ASSIGNMENT OPERATOR            9
                            ;  --->  SEMICOLON                      9
     //Defination of For Loop  --->  SINGLELINE COMMENT            10
                          for  --->  KEYWORD                       10
                            (  --->  PARENTHESIS                   11
                          int  --->  KEYWORD                       10
                            i  --->  IDENTIFIER                    10
                            =  --->  ASSIGNMENT OPERATOR           11
                           -1  --->  INTERGER CONSTANT             10
                            ;  --->  SEMICOLON                     11
                            i  --->  IDENTIFIER                    10
                            <  --->  RELATIONAL OPERATOR           11
                           10  --->  INTERGER CONSTANT             10
                            ;  --->  SEMICOLON                     11
```



```
        ;  --->  SEMICOLON                        11
        i  --->  IDENTIFIER                       10
       ++  --->  UNARY OPERATOR                   11
        )  --->  PARENTHESIS                      11
        {  --->  PARENTHESIS                      11
       if  --->  KEYWORD                          11
        (  --->  PARENTHESIS                      12
        i  --->  IDENTIFIER                       11
        >  --->  RELATIONAL OPERATOR              12
        0  --->  INTERGER CONSTANT                11
       ||  --->  LOGICAL OPERATOR                 12
        i  --->  IDENTIFIER                       11
       ==  --->  RELATIONAL OPERATOR              12
        (  --->  PARENTHESIS                      12
        4  --->  INTERGER CONSTANT                11
        ^  --->  BIT-WISE OPERATOR                12
        3  --->  INTERGER CONSTANT                11
        )  --->  PARENTHESIS                      12
        )  --->  PARENTHESIS                      12
        {  --->  PARENTHESIS                      12
   printf  --->  IDENTIFIER                       12
        (  --->  PARENTHESIS                      13
"Hello\n"  --->  STRING LITERAL                   12
        )  --->  PARENTHESIS                      13
        ;  --->  SEMICOLON                        13
        }  --->  PARENTHESIS                      14
     else  --->  KEYWORD                          14
        {  --->  PARENTHESIS                      15
   printf  --->  IDENTIFIER                       15
        (  --->  PARENTHESIS                      16
"World\n"  --->  STRING LITERAL                   15
        )  --->  PARENTHESIS                      16
        ;  --->  SEMICOLON                        16
        }  --->  PARENTHESIS                      17
        }  --->  PARENTHESIS                      18
   return  --->  KEYWORD                          18
        1  --->  INTERGER CONSTANT                18
```

3. inputThree.txt - test input file 3

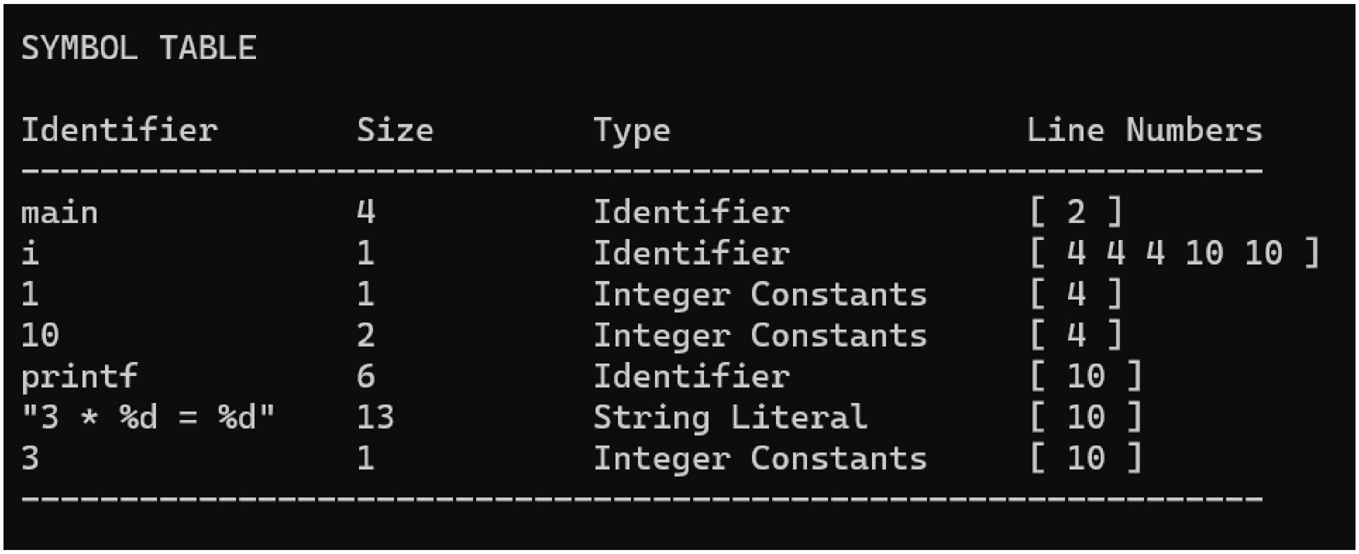
- Input File code



```
#include<stdio.h>
int main(){
    //Program to print Table of 3
    for(int i=1;i<=10;i++){
        /* The format will be
        3 * 1 = 3
        3 * 2 = 6
        */

        printf("3 * %d = %d",i,3*i);
    }
}
```

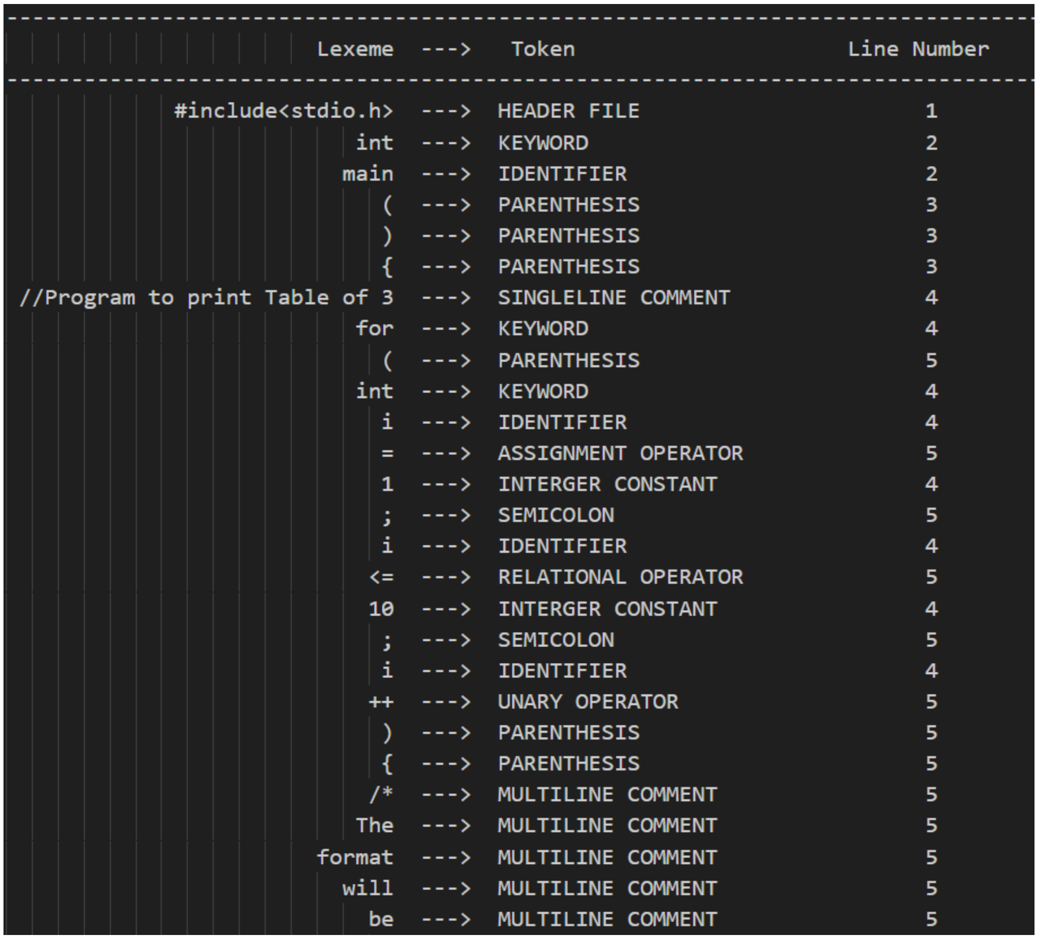
This test case is to show that our scanner is capable of identifying the single line and, multiline comments in C. After the identification of comments, they are sent to the ListOfTokens.txt file which maintains a list of all the tokens.

- Symbol Table

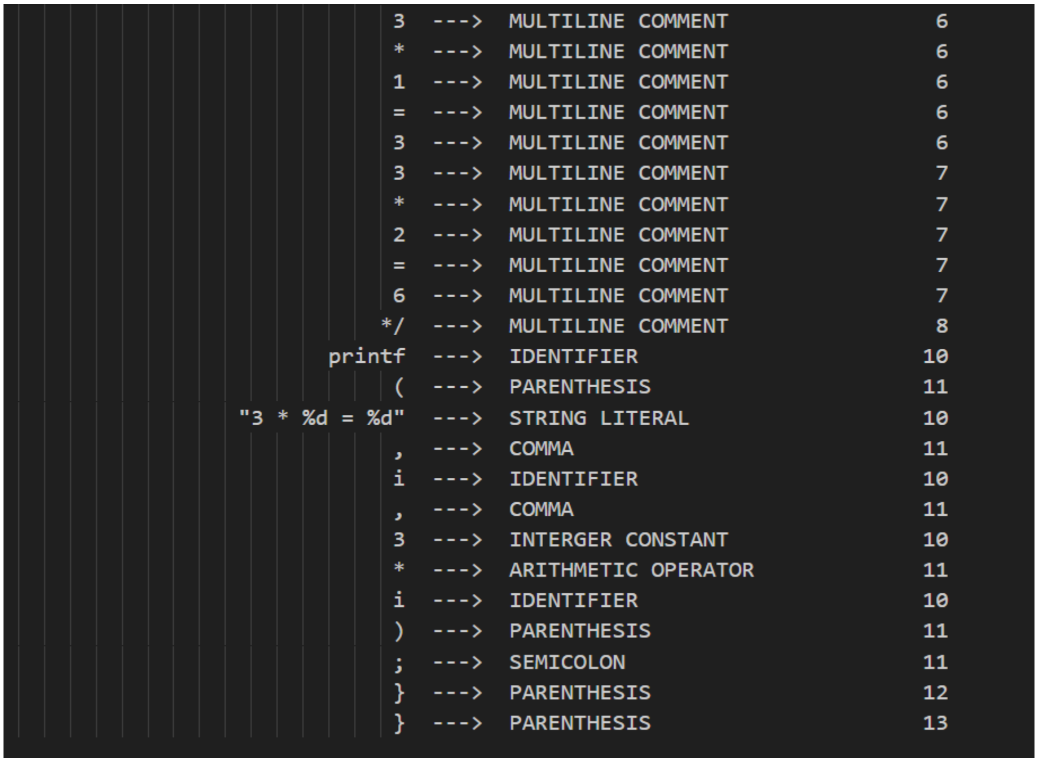


```
SYMBOL TABLE

Identifier       Size         Type                   Line Numbers
---------------------------------------------------------------
main             4            Identifier             [ 2 ]
i                1            Identifier             [ 4 4 4 10 10 ]
1                1            Integer Constants      [ 4 ]
10               2            Integer Constants      [ 4 ]
printf           6            Identifier             [ 10 ]
"3 * %d = %d"    13           String Literal         [ 10 ]
3                1            Integer Constants      [ 10 ]
---------------------------------------------------------------
```

- ListOfTokens.txt



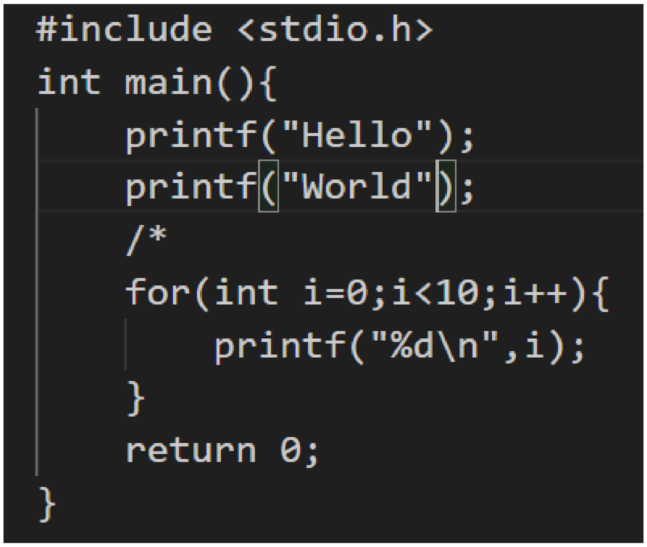
```
--------------------------------------------------------------------------------
                      Lexeme  --->   Token                         Line Number
--------------------------------------------------------------------------------
           #include<stdio.h>  --->  HEADER FILE                          1
                         int  --->  KEYWORD                              2
                        main  --->  IDENTIFIER                           2
                           (  --->  PARENTHESIS                          3
                           )  --->  PARENTHESIS                          3
                           {  --->  PARENTHESIS                          3
//Program to print Table of 3  --->  SINGLELINE COMMENT                   4
                         for  --->  KEYWORD                              4
                           (  --->  PARENTHESIS                          5
                         int  --->  KEYWORD                              4
                           i  --->  IDENTIFIER                           4
                           =  --->  ASSIGNMENT OPERATOR                  5
                           1  --->  INTERGER CONSTANT                    4
                           ;  --->  SEMICOLON                            5
                           i  --->  IDENTIFIER                           4
                          <=  --->  RELATIONAL OPERATOR                  5
                          10  --->  INTERGER CONSTANT                    4
                           ;  --->  SEMICOLON                            5
                           i  --->  IDENTIFIER                           4
                          ++  --->  UNARY OPERATOR                       5
                           )  --->  PARENTHESIS                          5
                           {  --->  PARENTHESIS                          5
                          /*  --->  MULTILINE COMMENT                    5
                         The  --->  MULTILINE COMMENT                    5
                      format  --->  MULTILINE COMMENT                    5
                        will  --->  MULTILINE COMMENT                    5
                          be  --->  MULTILINE COMMENT                    5
```



```
                           3  --->  MULTILINE COMMENT                    6
                           *  --->  MULTILINE COMMENT                    6
                           1  --->  MULTILINE COMMENT                    6
                           =  --->  MULTILINE COMMENT                    6
                           3  --->  MULTILINE COMMENT                    6
                           3  --->  MULTILINE COMMENT                    7
                           *  --->  MULTILINE COMMENT                    7
                           2  --->  MULTILINE COMMENT                    7
                           =  --->  MULTILINE COMMENT                    7
                           6  --->  MULTILINE COMMENT                    7
                          */  --->  MULTILINE COMMENT                    8
                      printf  --->  IDENTIFIER                          10
                           (  --->  PARENTHESIS                         11
               "3 * %d = %d"  --->  STRING LITERAL                      10
                           ,  --->  COMMA                               11
                           i  --->  IDENTIFIER                          10
                           ,  --->  COMMA                               11
                           3  --->  INTERGER CONSTANT                   10
                           *  --->  ARITHMETIC OPERATOR                 11
                           i  --->  IDENTIFIER                          10
                           )  --->  PARENTHESIS                         11
                           ;  --->  SEMICOLON                           11
                           }  --->  PARENTHESIS                         12
                           }  --->  PARENTHESIS                         13
```

4. inputFour.txt - test input file 4

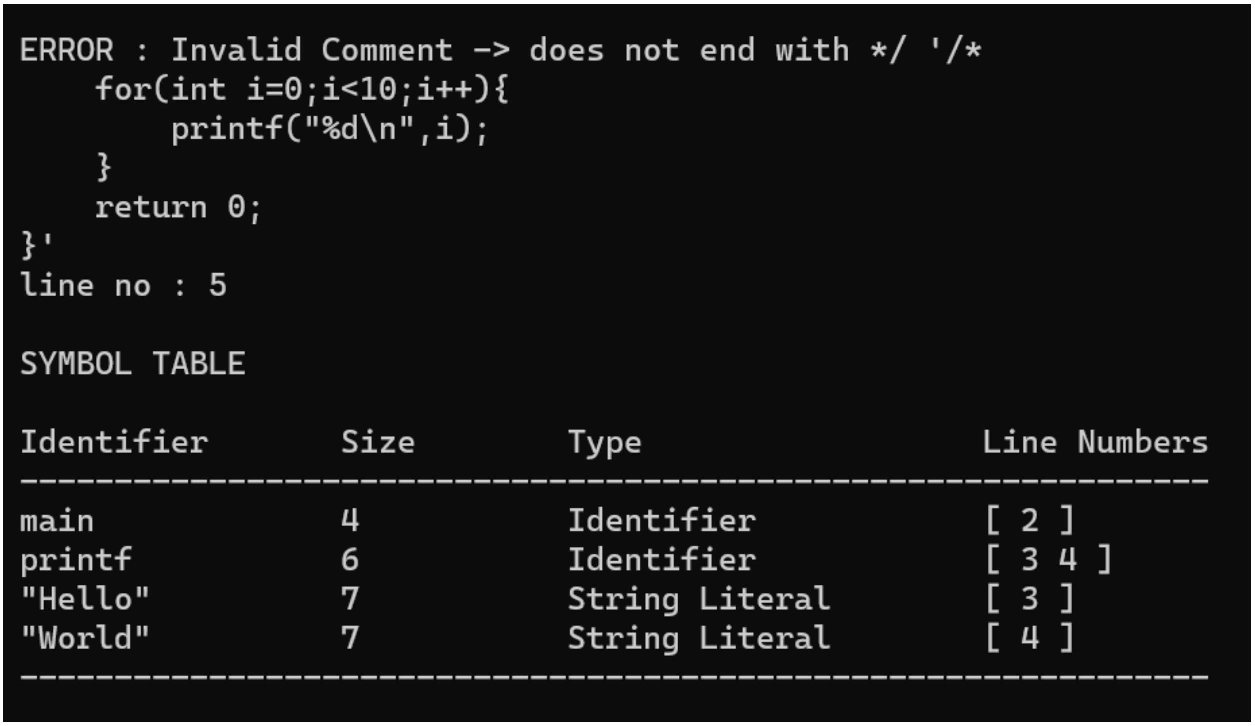
- Input File code



```
#include <stdio.h>
int main(){
    printf("Hello");
    printf("World");
    /*
    for(int i=0;i<10;i++){
        printf("%d\n",i);
    }
    return 0;
}
```

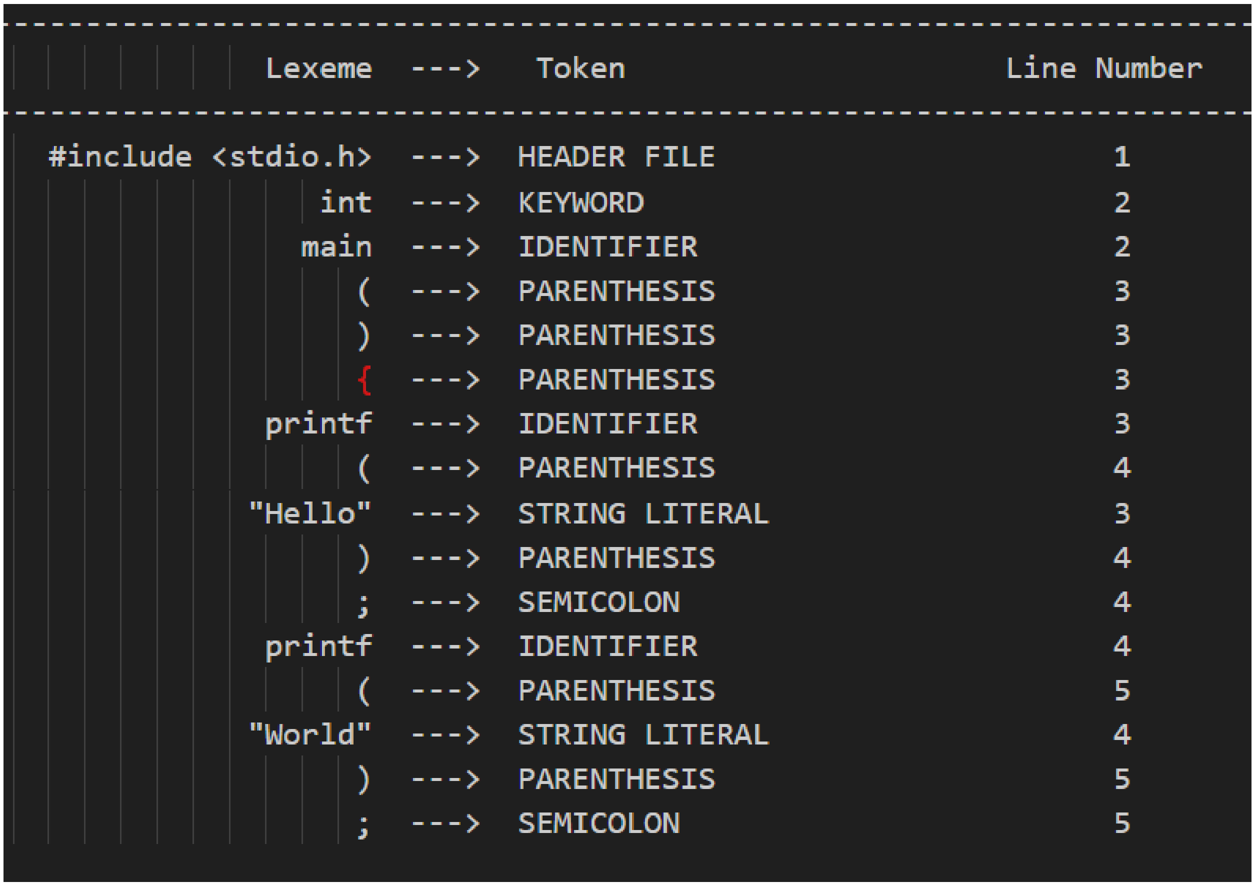
This test case has an error related to multiline comments. The ‘/*’ indicates the beginning of a multiline comment but there is no ‘*/’ to end it. This Lexical error is detected by our scanner and the Error is displayed along with the line number. All the other tokens that are inside the multiline comments are not added to the ListOftoken.txt file.

- Symbol Table



```
ERROR : Invalid Comment -> does not end with */ '/*
    for(int i=0;i<10;i++){
        printf("%d\n",i);
    }
    return 0;
}'
line no : 5

SYMBOL TABLE

Identifier       Size        Type                  Line Numbers
---------------------------------------------------------------
main             4           Identifier            [ 2 ]
printf           6           Identifier            [ 3 4 ]
"Hello"          7           String Literal        [ 3 ]
"World"          7           String Literal        [ 4 ]
---------------------------------------------------------------
```

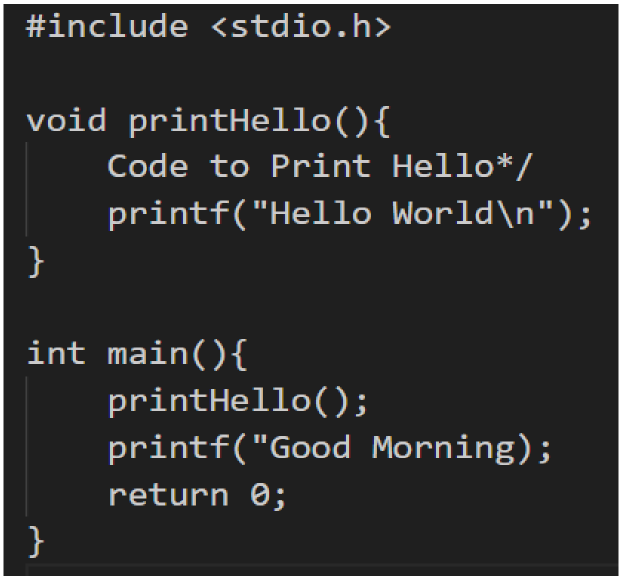
- ListOfToken.txt



```
---------------------------------------------------------------------------
            Lexeme  --->   Token                         Line Number
---------------------------------------------------------------------------
  #include <stdio.h>  --->  HEADER FILE                         1
                 int  --->  KEYWORD                             2
                main  --->  IDENTIFIER                          2
                   (  --->  PARENTHESIS                         3
                   )  --->  PARENTHESIS                         3
                   {  --->  PARENTHESIS                         3
              printf  --->  IDENTIFIER                          3
                   (  --->  PARENTHESIS                         4
             "Hello"  --->  STRING LITERAL                      3
                   )  --->  PARENTHESIS                         4
                   ;  --->  SEMICOLON                           4
              printf  --->  IDENTIFIER                          4
                   (  --->  PARENTHESIS                         5
             "World"  --->  STRING LITERAL                      4
                   )  --->  PARENTHESIS                         5
                   ;  --->  SEMICOLON                           5
```

5. inputFive.txt - test input file 5

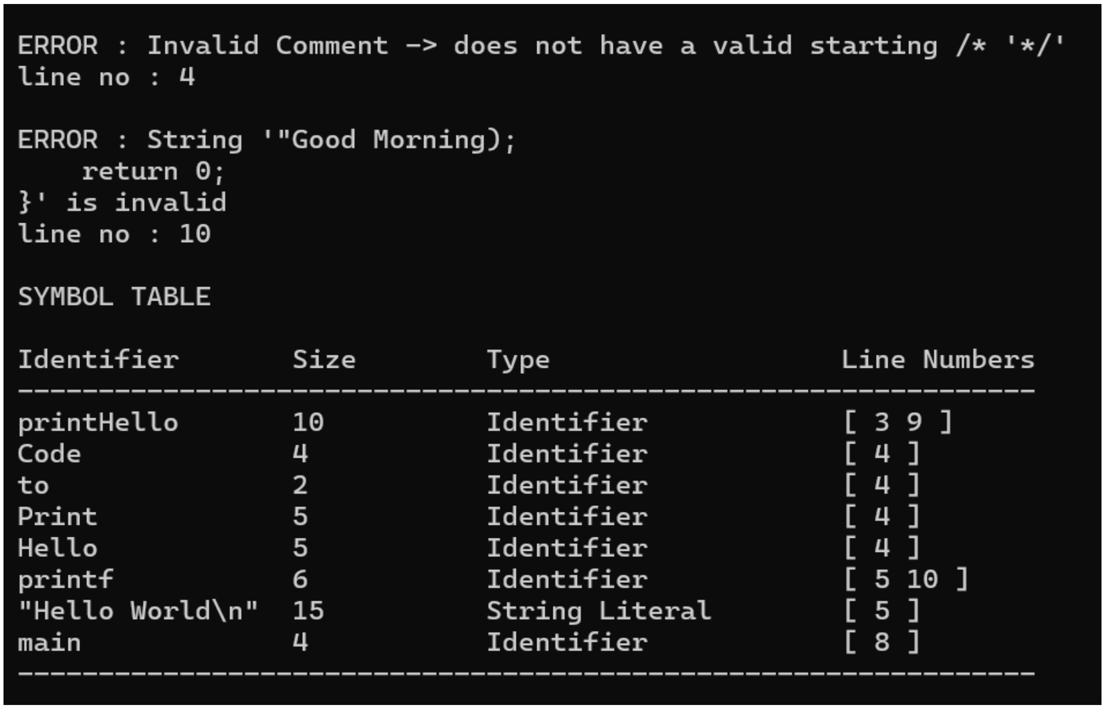
- Input file code



```
#include <stdio.h>

void printHello(){
    Code to Print Hello*/
    printf("Hello World\n");
}

int main(){
    printHello();
    printf("Good Morning);
    return 0;
}
```

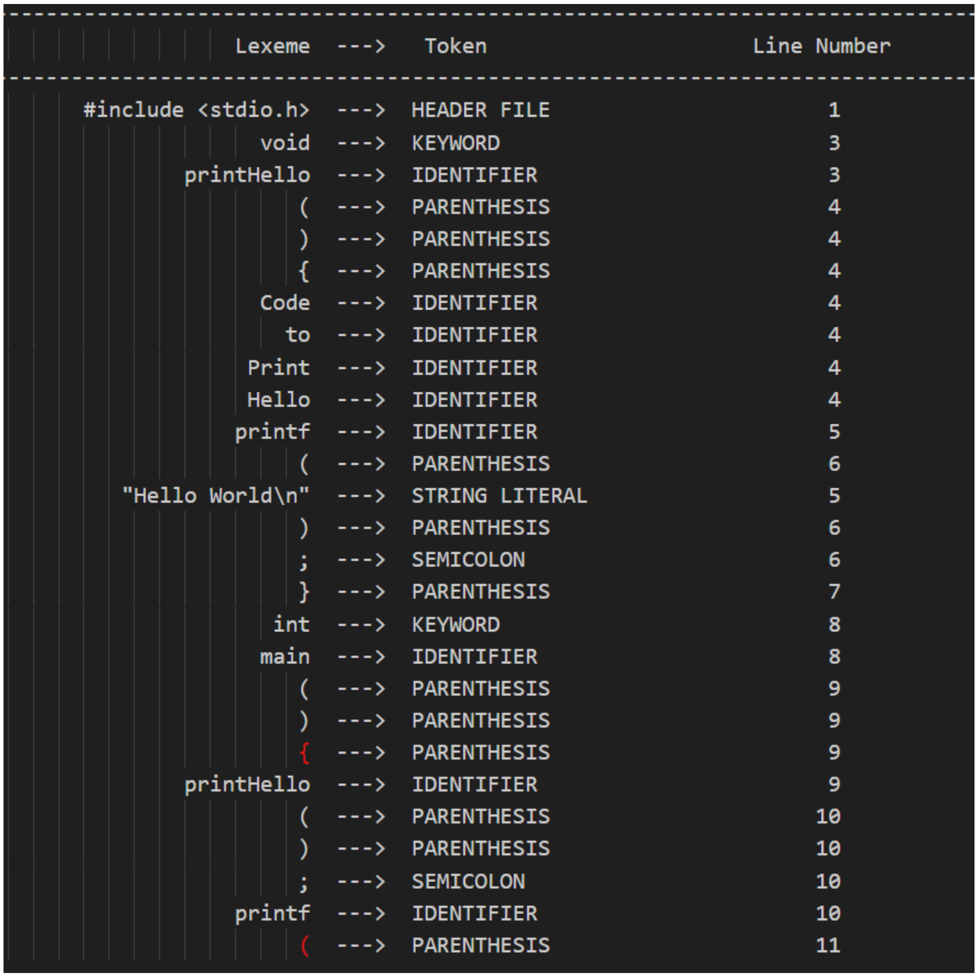
This test case has 2 lexical errors - an invalid string as it doesn’t have a closing quote and an invalid comment as there is no ‘/*’ to indicate the beginning of the multiline comment. This is identified by our scanner. And displayed as an error along with the line no of error.

- <u>Symbol Table</u>



```
ERROR : Invalid Comment -> does not have a valid starting /* '*/'
line no : 4

ERROR : String '"Good Morning);
    return 0;
}' is invalid
line no : 10

SYMBOL TABLE

Identifier       Size        Type                  Line Numbers
---------------------------------------------------------------
printHello       10          Identifier            [ 3 9 ]
Code             4           Identifier            [ 4 ]
to               2           Identifier            [ 4 ]
Print            5           Identifier            [ 4 ]
Hello            5           Identifier            [ 4 ]
printf           6           Identifier            [ 5 10 ]
"Hello World\n"  15          String Literal        [ 5 ]
main             4           Identifier            [ 8 ]
---------------------------------------------------------------
```

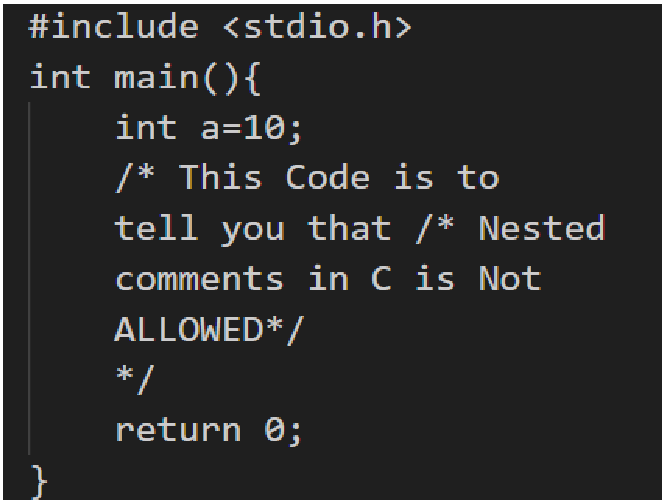
- <u>ListOfTokens.txt</u>



```
-----------------------------------------------------------------------------
                  Lexeme  --->   Token                          Line Number
-----------------------------------------------------------------------------
      #include <stdio.h>  --->  HEADER FILE                          1
                    void  --->  KEYWORD                              3
              printHello  --->  IDENTIFIER                           3
                       (  --->  PARENTHESIS                          4
                       )  --->  PARENTHESIS                          4
                       {  --->  PARENTHESIS                          4
                    Code  --->  IDENTIFIER                           4
                      to  --->  IDENTIFIER                           4
                   Print  --->  IDENTIFIER                           4
                   Hello  --->  IDENTIFIER                           4
                  printf  --->  IDENTIFIER                           5
                       (  --->  PARENTHESIS                          6
         "Hello World\n"  --->  STRING LITERAL                       5
                       )  --->  PARENTHESIS                          6
                       ;  --->  SEMICOLON                            6
                       }  --->  PARENTHESIS                          7
                     int  --->  KEYWORD                              8
                    main  --->  IDENTIFIER                           8
                       (  --->  PARENTHESIS                          9
                       )  --->  PARENTHESIS                          9
                       {  --->  PARENTHESIS                          9
              printHello  --->  IDENTIFIER                           9
                       (  --->  PARENTHESIS                         10
                       )  --->  PARENTHESIS                         10
                       ;  --->  SEMICOLON                           10
                  printf  --->  IDENTIFIER                          10
                       (  --->  PARENTHESIS                         11
```

6. inputSix.txt - test input file 6

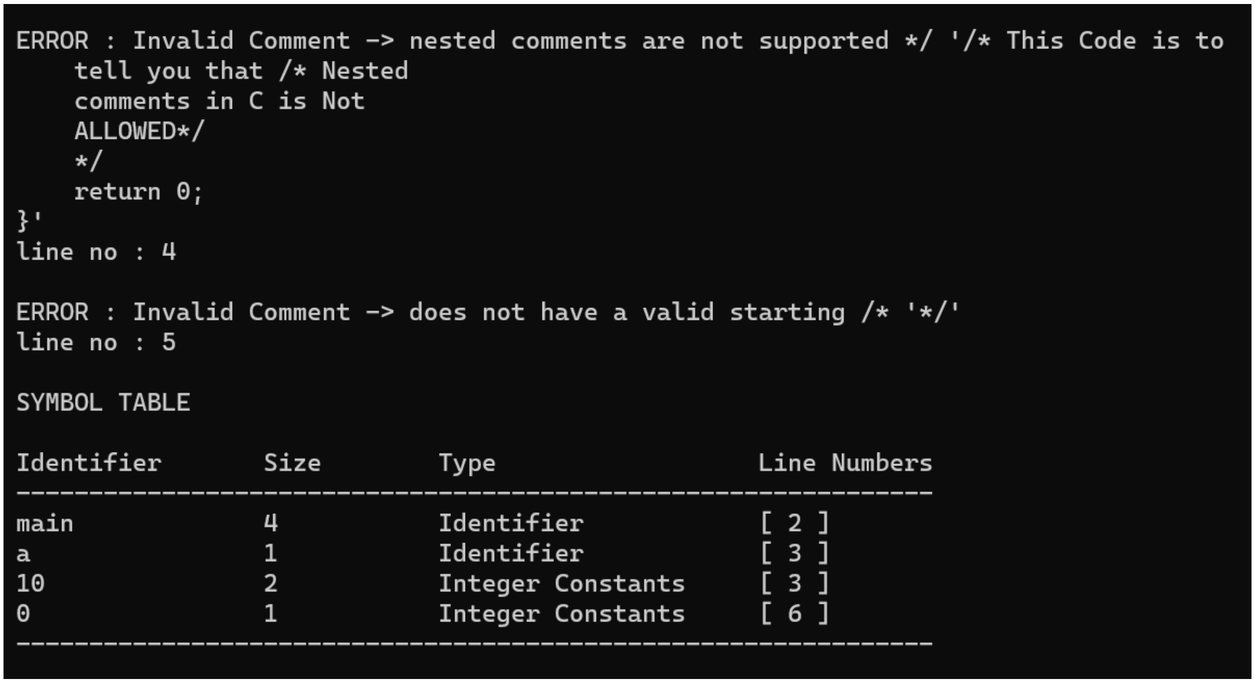
- input file code



```
#include <stdio.h>
int main(){
    int a=10;
    /* This Code is to
    tell you that /* Nested
    comments in C is Not
    ALLOWED*/
    */
    return 0;
}
```

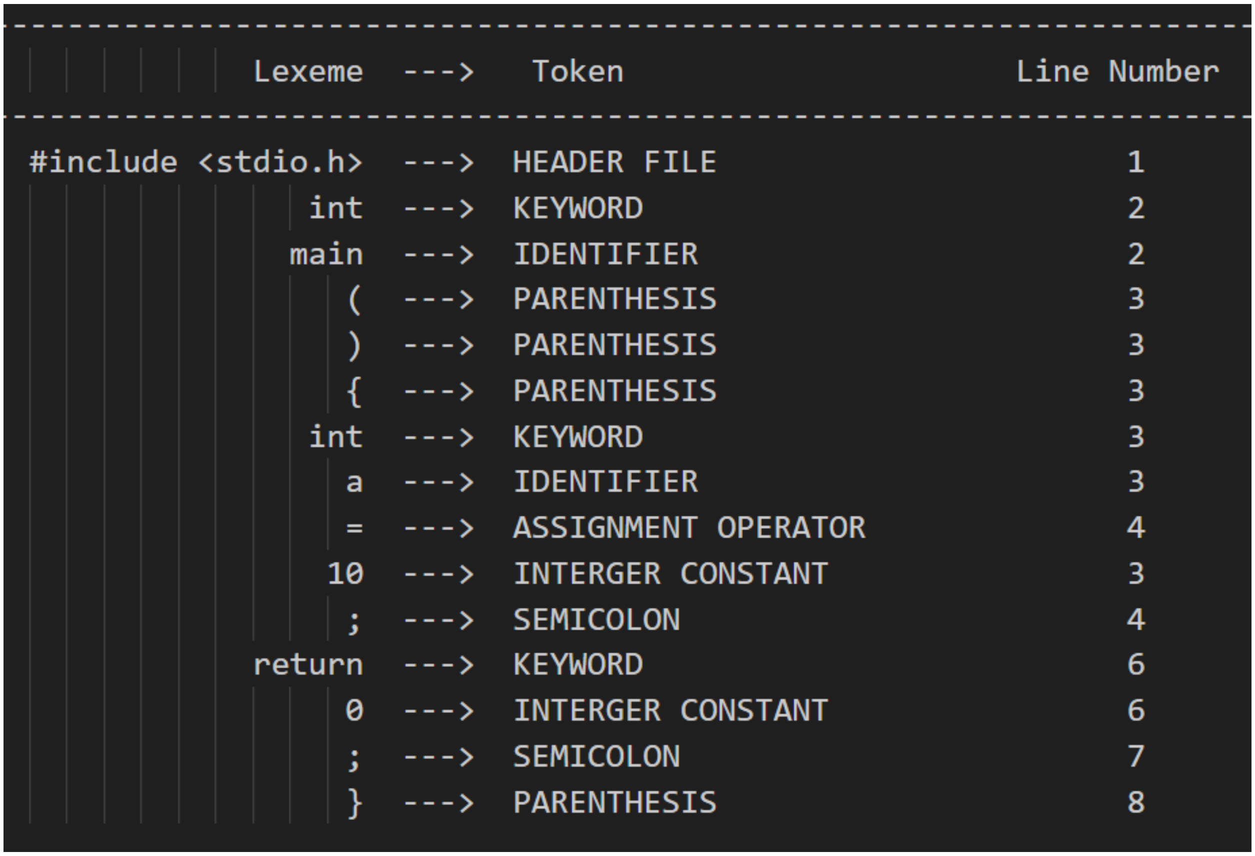
This test case has a nested multiline comment. In C multiline comment can’t be nested and it comes under the category of Lexical errors. This error is identified and displayed by scanner.

- Symbol Table



```
ERROR : Invalid Comment -> nested comments are not supported */ '/* This Code is to
    tell you that /* Nested
    comments in C is Not
    ALLOWED*/
    */
    return 0;
}'
line no : 4

ERROR : Invalid Comment -> does not have a valid starting /* '*/'
line no : 5

SYMBOL TABLE

Identifier       Size        Type                 Line Numbers
---------------------------------------------------------------
main             4           Identifier           [ 2 ]
a                1           Identifier           [ 3 ]
10               2           Integer Constants    [ 3 ]
0                1           Integer Constants    [ 6 ]
---------------------------------------------------------------
```

- ListOfTokens.txt

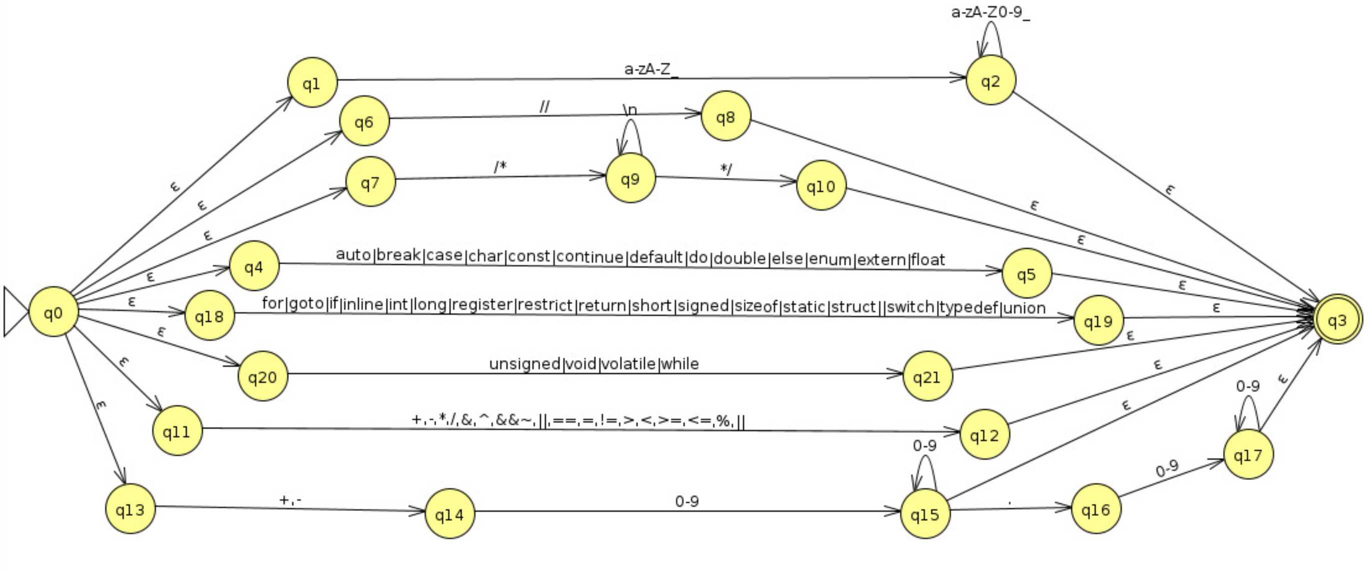


```
-------------------------------------------------------------------
            Lexeme  --->   Token                     Line Number
-------------------------------------------------------------------
#include <stdio.h>  --->  HEADER FILE                     1
               int  --->  KEYWORD                         2
              main  --->  IDENTIFIER                      2
                 (  --->  PARENTHESIS                     3
                 )  --->  PARENTHESIS                     3
                 {  --->  PARENTHESIS                     3
               int  --->  KEYWORD                         3
                 a  --->  IDENTIFIER                      3
                 =  --->  ASSIGNMENT OPERATOR             4
                10  --->  INTERGER CONSTANT               3
                 ;  --->  SEMICOLON                       4
            return  --->  KEYWORD                         6
                 0  --->  INTERGER CONSTANT               6
                 ;  --->  SEMICOLON                       7
                 }  --->  PARENTHESIS                     8
```

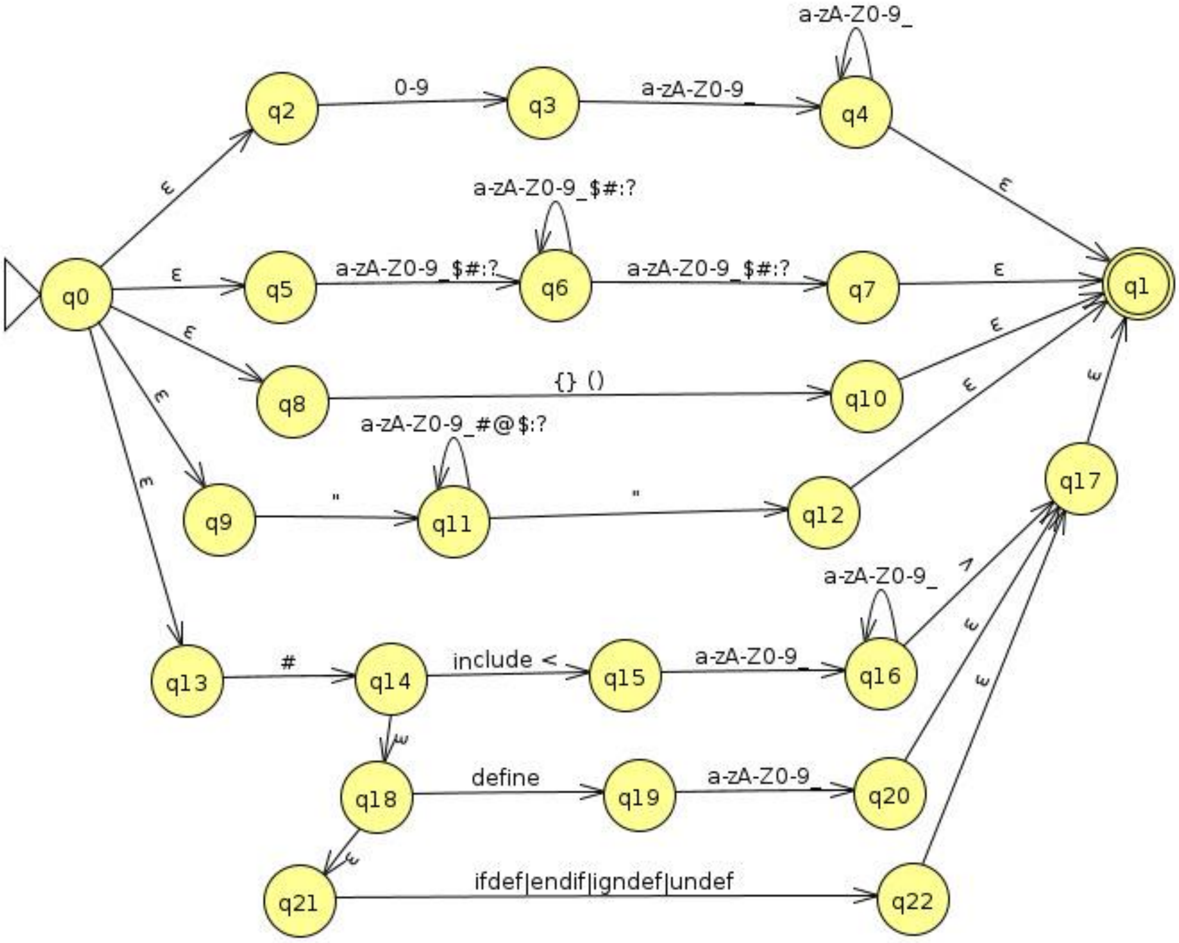
List of rules not implemented

- Lexical error regarding the number and correctness of opening and closing flower braces.
- Error handling for floating-point numbers and characters.

Pictures of DFA underlying the scanner



a-zA-Z0-9_
q1
a-zA-Z_
q2
q6
//
\n
q8
q7
/*
q9
*/
q10
ε
q4
auto|break|case|char|const|continue|default|do|double|else|enum|extern|float
q5
q0
q18
for|goto|if|inline|int|long|register|restrict|return|short|signed|sizeof|static|struct||switch|typedef|union
q19
q3
q20
unsigned|void|volatile|while
q21
0-9
q11
+,-,*,/,&,^,&&~,||,==,=,!=,>,<,>=,<=,%,||
q12
q17
q13
+,-
q14
q15
.
q16



CODE

```
%{
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#define TABLE_SIZE 100003
#define MAX_SYMBOLS 1000000

int line_num = 1;

char * locations[MAX_SYMBOLS];
int symTableSize=0;

struct lines{
    int lineno; // stores the line-number
    struct lines*next;
};
struct SymbolTableEntry {
    char * name; //identifier
    char * type;
    int size;
    struct SymbolTableEntry * next;
    struct lines * head; //head of the linenumbers list
    struct lines *  tail; //tail of the linenumbers list
};

struct SymbolTable {
    struct SymbolTableEntry * symTable[TABLE_SIZE];
};

struct SymbolTable Table;

//Hash Function
int hashfunction(char *s) {
    int pp = 101;
    int mod = TABLE_SIZE;
    int val = 0;
    int n = strlen(s);
    int p = 1;
    for (int i = 0; i < n; i++) {
        int c = s[i];
        val = (val + ((c * p) % mod)) % mod;
        p = (p * pp) % mod;
    }
    return val;
}

// Function to insert a key-value pair (doesnt exist) into the SymbolTable
void insert1(char* key,char * type,int linenumber) {
    int index = hashfunction(key);

    // Create a new entry
    struct SymbolTableEntry* new_entry = (struct
SymbolTableEntry*)malloc(sizeof(struct SymbolTableEntry));

    new_entry->name = strdup(key); // Duplicate the key string
    new_entry->type = strdup(type); // Duplicate the type string
    new_entry->size = strlen(key);
    new_entry->next = Table.symTable[index];
    new_entry->head = (struct lines *)malloc(sizeof(struct lines));
    new_entry->head->lineno = linenumber;
    new_entry->head->next = NULL;
    new_entry->tail = new_entry->head;
    Table.symTable[index] = new_entry;
    locations[symTableSize++]=strdup(key);
}

//Function to append an entry for key-value pair that already exists in the SymbolTable
void insert2(struct SymbolTableEntry* entry,int linenumber){
    struct lines * new_node = (struct lines *)malloc(sizeof(struct lines));
    new_node->lineno = linenumber;
    new_node->next = NULL;
    entry->tail->next = new_node;
    entry->tail = new_node;
}
```

```
// Function to Lookup
struct SymbolTableEntry *  lookup(char* key) {
    int index = hashfunction(key);
    struct SymbolTableEntry* entry = Table.symTable[index];
    while(entry != NULL)
        {
            if(strcmp(entry->name,key) == 0)return entry;
            entry = entry->next;
        }
        // Key not found
        return NULL;
}

void processToken(const char* token,char *category,int linenumber) {
    char* buffer = (char*)malloc(strlen(token) + 1);
    strcpy(buffer, token);
    //printf("%s : %s\n", category, buffer);
    struct SymbolTableEntry* found = lookup(buffer);
    if (found == NULL) {
        insert1(buffer, category,linenumber);
    }
    else{
        insert2(found,linenumber);
    }
    free(buffer);
}

%}

%%

^"#include"[ ]*<.+\.h> {fprintf(yyout,"%30s \t--->\tHEADER FILE \t%20d\n",
yytext,line_num);}

\n {line_num++;}

auto|break|case|char|const|continue|default|do|double|else|enum|extern|float|for|goto|if|i
nline|int|long|register|restrict|return|short|signed|sizeof|static|struct|switch|typedef|union|
unsigned|void|volatile|while {fprintf(yyout,"%30s \t--->\tKEYWORD \t%24d\n",
yytext,line_num);};

[a-zA-Z_][a-zA-Z0-9_]{0,30} {
    processToken(yytext, "Identifier", line_num);
    fprintf(yyout, "%30s \t--->\tIDENTIFIER \t%22d\n", yytext, line_num);
}

[-]?[0-9]+[_\$\#:?][0-9_\$\#:?]* {
   printf("\n\nERROR : Constant '%s' is invalid\nline no : %d", yytext, line_num);
}

[a-zA-Z_][a-zA-Z0-9_]{30,} {
    printf("\n\nERROR : Identifier '%s' is too long\nline no : %d", yytext, line_num);
}

[-]?[1-9][0-9]{0,8}|214748364[0-7]|0 {
    processToken(yytext,"Integer Constants",line_num);
    fprintf(yyout,"%30s \t--->\tINTERGER CONSTANT \t%14d\n", yytext,line_num);
}

[-]?([1-9][0-9]{9,}|[2-9][0-9]{9,}|214748364[8-9]) {
    printf("\n\nERROR : Integer Limit Exceed\nline no : %d",line_num);
}

[0-9]+[a-zA-Z_]+|[a-zA-Z0-9_\$\#:?]+[\$\#:?]*[a-zA-Z0-9_\$\#:?] {
    printf("\n\nERROR : Identifier '%s' is invalid\nline no : %d", yytext, line_num);
}

['].['] {
    fprintf(yyout,"%30s \t--->\tCHARACTER CONSTANT \t%13d\n", yytext,line_num);
}

[-]?[0-9]+\.[0-9]{1,6} {
    processToken(yytext,"Floating-Point Constants",line_num);
    fprintf(yyout,"%30s \t--->\tFLOATING-POINT CONSTANT \t%30d\n",
yytext,line_num);
}
```

```
\"[^\n]*\" {
    processToken(yytext,"String Literal",line_num);
    fprintf(yyout,"%30s \t--->\tSTRING LITERAL \t%18d\n", yytext,line_num);
}

\(|\)|\{|\} {fprintf(yyout,"%30s \t--->\tPARENTHESIS \t%20d\n", yytext,line_num+1);}

[;] {fprintf(yyout,"%30s \t--->\tSEMICOLON \t%22d\n", yytext,line_num+1);}

[,] {fprintf(yyout,"%30s \t--->\tCOMMA \t%26d\n", yytext,line_num+1);}

\+|\-|\*|\/|\% {fprintf(yyout,"%30s \t--->\tARITHMETIC OPERATOR \t%12d\n",
yytext,line_num+1);}

\+\+|\-\- {fprintf(yyout,"%30s \t--->\tUNARY OPERATOR \t%18d\n", yytext,line_num+1);}

\|\||\&\& {fprintf(yyout,"%30s \t--->\tLOGICAL OPERATOR \t%16d\n",
yytext,line_num+1);}

\||\&|\^|\! {fprintf(yyout,"%30s \t--->\tBIT-WISE OPERATOR \t%14d\n",
yytext,line_num+1);}

==|<=|>=|!=|<|> {fprintf(yyout,"%30s \t--->\tRELATIONAL OPERATOR \t%12d\n",
yytext,line_num+1);}

= {fprintf(yyout,"%30s \t--->\tASSIGNMENT OPERATOR \t%12d\n",
yytext,line_num+1);}

\/\/.* {fprintf(yyout,"%30s \t--->\tSINGLELINE COMMENT \t%14d\n",yytext,line_num+1);}

(\*\/) {printf("\n\nERROR : Invalid Comment -> does not have a valid starting /* '%s'
\nline no : %d", yytext, line_num);}

(\/\*)(.|\n)+? {
    int k  = 2;
    int err = 0;
    int found  = 0;
    while(k<yyleng){
        if(yytext[k]=='/' && (k+1)<yyleng && yytext[k+1]=='*'){
            err = 1;
        }
        if(yytext[k]=='*' && (k+1)<yyleng && yytext[k+1]=='/'){
            found = 1;
            break;
        }
        ++k;
    }
    if(err == 0 && found==1){
        int kk  = k;
        kk+=2;
        for (int i = 0; i < kk; i++) {
            if (yytext[i] == '\n') {
                ++line_num;
            } else if (yytext[i] != ' ') {
                int j = i;
                char temp[100];
                int temp_index = 0;
                while (j < kk && yytext[j] != '\n' && yytext[j] != ' ') {
                    temp[temp_index] = yytext[j];
                    temp_index++;
                    j++;
                }
                temp[temp_index] = '\0';
                fprintf(yyout, "%30s \t--->\tMULTILINE COMMENT \t%14d\n", temp,
line_num);
                i = j - 1;
            }
        }
    }
    else if(err == 1){
        printf("\n\nERROR : Invalid Comment -> nested comments are not supported */
'%s' \nline no : %d", yytext, line_num);
    }
    else{
        printf("\n\nERROR : Invalid Comment -> does not end with */ '%s' \nline no : %d",
yytext, line_num);
    }
    for(int i = yyleng-1;i>k+1;--i){
            unput(yytext[i]);
    }

}

["][^"]* {printf("\n\nERROR : String '%s' is invalid\nline no : %d", yytext, line_num);}

.|\n ;
%%

int yywrap(){
    return 1;
}

int main(){
    for (int i=0; i<TABLE_SIZE;i++) {
        Table.symTable[i] = NULL;
    }
    yyin = fopen("inputSix.txt","r");
    yyout=fopen("ListOfTokens.txt","w");
    fprintf(yyout,"\n-----------------------------------------------------------------------------------------
----------\n");
    fprintf(yyout,"%30s \t--->\t %s \t%30s", "Lexeme",
    "Token","Line Number");
    fprintf(yyout,"\n-----------------------------------------------------------------------------------------
----------\n");
    yylex();
    printf("\n\nSYMBOL TABLE\n\n");
    printf("%-15s  %-10s  %-20s  %-20s\n", "Identifier",
    "Size", "Type", "Line Numbers");
    printf("--------------------------------------------------------------\n");

    for (int i = 0; i < symTableSize; i++) {
        struct SymbolTableEntry * entry = lookup(locations[i]);
        printf("%-15s  %-10d  %-20s  [ ", entry->name, entry->size, entry->type);
        struct lines* h = entry->head;
        while(h){
            printf("%d ", h->lineno);
            h = h->next;
        }
        printf("]\n");
    }
    printf("----------------------------------------------------------------\n");
    printf("\n\n");
    fclose(yyin);
    return 0;
}
```

Conclusion

In conclusion, the development of a comprehensive lexical analyzer for the C language using LEX/Flex has been a substantial undertaking that has yielded a powerful tool for parsing and understanding C code. Through meticulous study of the language's grammar and specifications, we successfully identified and categorized the essential lexical components, including keywords, identifiers, constants, string literals, and comments. Our implementation goes beyond mere token recognition by addressing more complex language features, such as nested comments, and ensuring that the generated error messages are as informative as possible, aiding developers in pinpointing and rectifying issues within their code. Additionally, the incorporation of a hash-based symbol table enhances the analyzer's potential for broader use in compiler construction. This project underscores the significance of precise language analysis, effective tool usage, and robust error handling in the development of a sophisticated C compiler or similar software systems, marking a significant milestone in the realm of programming language processing.

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