CS305 – Compiler Design Lab

Project – 1
Scanner for C Language

Report

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Project-1
Scanner for the C language

Objective:
Build a lexical analyzer for the C language using LEX.

Summary:
The lexical analyzer can achieve the following:

- Identify and differentiate between keywords, identifiers, constants, operators (arithmetic, comparison and bitwise), strings, comments and other symbols (like brackets - square, round and curly).
- Detect looping constructs like for loops and while loops and conditional statements (if - else if - else).
- Detect single line and multiline comments.
- Detect extended data types like signed, unsigned, long, short for integers and characters.
- Detect arrays with specified data types.
- Detect errors like unclosed comments, brackets and strings.
- Build a symbol table by implementing hashing.

The above-mentioned have been implemented in two files:

- `code.c:` Has code related to the implementation of the hashing operations used to build the symbol table.
- `scanner.l :` Parse through the C program to identify the tokens.

The object files of these are to be run together. This has been implemented in `runfile.sh`. To run the files, use `./runfile.sh` (after giving execution privileges using chmod).

Requirements:

- GCC, the GNU Compiler Collection
- Flex (Fast Lexical Analyzer Generator)

Table of Contents

1. Introduction

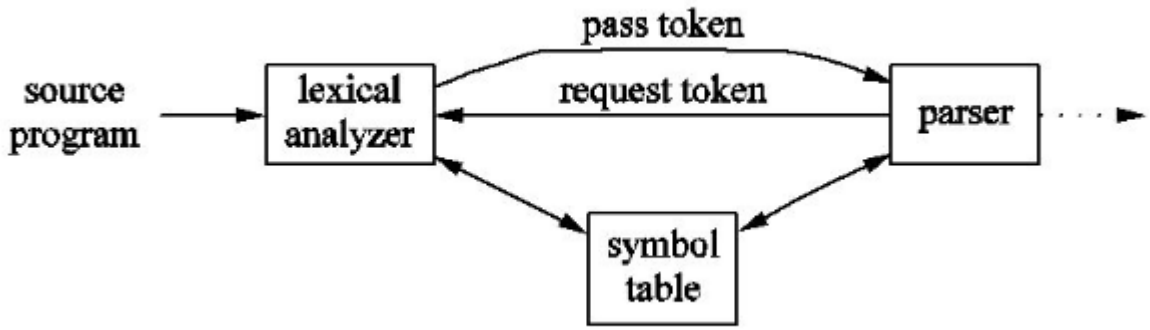
Lexical analysis is the first phase of a compiler which takes a high-level input program as input and converts it into a sequence of tokens. A lexical analyzer has the following functions:

- Tokenization
- Removing whitespace
- Removing comments
- Detecting errors and the line number in which the error occurred.

Lexemes are said to be a sequence of characters (alphanumeric) in a token. There are some predefined rules for every lexeme to be identified as a valid token. These rules are defined by grammar rules, by means of a pattern. A pattern explains what can be a token, and these patterns are defined by means of regular expressions. A lexical token is a sequence of characters that can be treated as a unit in the grammar of the programming languages. Some examples include keywords (like `int, if, for`), symbols (like `+, -, *, %, /, &, etc`)

If the lexical analyzer finds a token invalid, it generates an error. The lexical analyzer works closely with the syntax analyzer. It reads character streams from the source code, checks for legal tokens, and passes the data to the syntax analyzer when on demand.

A diagrammatic representation of the lexical analyzer working in tandem with the parser is shown below:



2. Implementation

2.1. Code

The lexical analyzer is implemented in two parts:

- `code.c` : A C program to read the input C program and implement the symbol table. The code for it is given below:

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

struct Table{
    char name[100];
    char type[100];
    int len;
} symbolTable[1001];

int hashFunction(char *s){
    int mod = 1001;
    int l = strlen(s), val = 0, i;
    for(i = 0; i < l; i++){
        val = val * 10 + (s[i]-'A');
        val = val % mod;
        while(val < 0){
            val += mod;
        }
    }
    return val;
}

void insertToken(char *token, char *tokenType){

    int l1 = strlen(token);
    int l2 = strlen(tokenType);
    int v = hashFunction(token);
    if(symbolTable[v].len == 0){
        strcpy(symbolTable[v].name, token);
        strcpy(symbolTable[v].type, tokenType);

        symbolTable[v].len = strlen(token);
        return;
    }

    if (strcmp(symbolTable[v].name,token) == 0)
        return;

    int i, pos = 0;

    for (i = 1; i < 1001; i++){
        int x = (i+v)%1001;
        if (strcmp(symbolTable[x].name,token) == 0)
            return;
```

```
        if(symbolTable[x].len == 0){

            pos = x;
            break;
        }
    }

    strcpy(symbolTable[pos].name, token);
    strcpy(symbolTable[pos].type, tokenType);
    symbolTable[pos].len = strlen(token);

}

void print(){
    int i;
    for(i = 0;i < 1001; i++){
        if(symbolTable[i].len == 0){
            continue;
        }
        printf("%15s \t
%40s\n",symbolTable[i].name,symbolTable[i].type);
    }
}


extern FILE* yyin;
int main(){

    int i;
    for (i = 0; i < 1001; i++){
        strcpy(symbolTable[i].name, "");
        strcpy(symbolTable[i].type, "");
        symbolTable[i].len = 0;
    }
    yyin = fopen("test.c","r");

    yylex();
    printf("\n\n-----------------------------------------------------
-------------------------\n\t\t\t\tSYMBOL TABLE\n----------------
-------------------------------------------------------------\n");
      printf("\tToken \t\t\t\t\t\tToken Type\n");
      printf("-----------------------------------------------------
-----------------------\n");
    print();
}
```

Symbol Table

Implemented as a hash-table, it is maintained throughout all the phases of a compiler. All the identifier's names along with their types are stored here. The symbol table makes it easier for the compiler to quickly search for the identifier record and retrieve it. The `insertToken` function inserts the new token into the symbol table at the location given by the hash function

implemented in `hashFunction`. Linear probing is used to resolve collisions in the hash function.
The input C file is stored in `yyin` which is an `extern` variable. It is used in the scanner as shown below.

- `scanner.l :` Has the lex code to detect the various parts of the grammar of the C programming language.

```
%{
    #include<stdio.h>
    #include<string.h>
      #include <stdlib.h>

    int stackTop = 0;
      int nestedCommentStack = 0;
      int line = 0;
      char parenthesisStack[100];


%}
%x comment

Preprocessor
#(include<.*>|define.*|ifdef|endif|if|else|ifndef|undef|pragma)
ArithmeticOperator \+\+|\-\-|\+|\-|\*|\/|=
ComparisionOperator <=|>=|<|>
BitwiseOperator \^|\%|\&|\||\~
Identifier [a-zA-Z_]([a-zA-Z0-9_])*
NumericConstant [1-9][0-9]*(\.[0-9]+)?|0(\.[0-9]+)?
String \".*\"|\'.*\'
InvalidString \"[^"\n]*|\'[^'\n]*
SingleLineComment \/\/.*
MultiLineComment "/*"([^*]|\*+[^*/])*\*+"/"
Keyword
auto|const|default|enum|extern|register|return|sizeof|static|stru
ct|typedef|union|volatile|break|continue|goto|else|switch|if|case
|default|for|do|while|char|double|float|int|long|short|signed|uns
igned|void
InvalidID [^\n\t ]
InvalidIdentifier ([0-9\*\-\+\%\/]+[a-zA-Z][a-zA-Z0-9\*\-
\+\%\/]*)


%%
\n line++;
[\t ] ;
; {printf("%s \t---- Semicolon Delimiter\n", yytext);}
, {printf("%s \t---- Comma Delimiter\n", yytext);}

\{ {
```

```
    printf("%s \t---- Parenthesis\n", yytext);
    parenthesisStack[stackTop]='{';
      stackTop++;

}
\} {
    printf("%s \t---- Parenthesis\n", yytext);
      if(stackTop == 0 || parenthesisStack[stackTop-1] != '{')
            printf("ERROR: Unbalanced parenthesis at line number:
%d\n",line);
      stackTop--;
}
\( {
    printf("%s \t---- Parenthesis\n", yytext);
      parenthesisStack[stackTop]='(';
    stackTop++;
}
\) {
    printf("%s \t---- Parenthesis\n", yytext);
      if(stackTop == 0 || parenthesisStack[stackTop-1] != '(')
            printf("ERROR: UNBALANCED PARENTHESIS AT LINE NUMBER:
%d\n",line);
      stackTop--;
}

\[ {
    printf("%s \t---- Parenthesis\n", yytext);
      parenthesisStack[stackTop]='[';
    stackTop++;
}

\] {
    printf("%s \t---- Parenthesis\n", yytext);
      if (stackTop == 0 || parenthesisStack[stackTop-1] != '[')
            printf("ERROR: UNBALANCED PARENTHESIS AT LINE NUMBER:
%d\n",line);
      stackTop--;
}
\\ {
    printf("%s \t- Backward Slash\n", yytext);
}
\. {
    printf("%s \t- Dot Delimiter\n", yytext);
}


"/*" {
    BEGIN(comment);
    nestedCommentStack=1;
    yymore();
}
<comment><<EOF>> {
    printf("\nERROR: Multiline Comment: \"");
```

```
    yyless(yyleng-2);
    ECHO;
    printf("\", Doesn't terminate at line: %d",line);
    yyterminate();
}
<comment>"/*" {
    nestedCommentStack++;
    yymore();
}
<comment>. {
    yymore();
}
<comment>\n {
    yymore();
    line++;
}
<comment>"*/" {
    nestedCommentStack--;
    if(nestedCommentStack<0)
    {
        printf("\n \"%s\"\t---- ERROR: Unbalanced comment at
line: %d.", yytext, line);
        yyterminate();
    }
    else if(nestedCommentStack==0)
    {
        BEGIN(INITIAL);
    }
    else
        yymore();
}

"*/"    {
    printf("%s \t---- ERROR: Unintialized comment at line: %d\n",
yytext,line);
    yyterminate();
}

"//".*  {
    printf("%s \t---- Single line comment\n", yytext);
}

{Preprocessor} {
    printf("%s \t---- Preprocessor Directive\n", yytext);
}
{String} {
    printf("%s \t---- String \n", yytext);
    insertToken(yytext,"String Constant");
}
{MultiLineComment} {
    printf("%s \t---- Multi-Line Comment\n", yytext);
}
{Keyword} {
```

```
    printf("%s \t---- Keyword\n", yytext);
    insertToken(yytext, "Keyword");
}
{Identifier} {
    printf("%s \t---- Identifier\n", yytext);
    insertToken(yytext, "Identifier");
}
{InvalidIdentifier} {
    printf("%s \t---- ERROR: Invalid Identifier\n", yytext);
}
{NumericConstant} {
    printf("%s \t---- Numeric Constant\n", yytext);
    insertToken(yytext, "Numeric Constant");
}
{ArithmeticOperator} {
    printf("%s \t---- Arithmetic\n", yytext);
}
{BitwiseOperator} {
    printf("%s \t---- Bitwise Operator\n", yytext);
}
{ComparisionOperator} {
    printf("%s \t---- Comparision Operator\n", yytext);
}
{InvalidString} {
    printf("%s \t---- ERROR: Unterminated string at line number:
%d\n", yytext,line);
}
{InvalidID} {
    printf("%s \t---- ERROR: Invalid identifier at line number:
%d\n", yytext,line);
}
%%

int yywrap(){
    return 1;
}
```

The following class of tokens can be detected:

- **Preprocessor directives:**

Statements processed : `#include, #define var1 var2`,
Token generated : Preprocessor Directive

- **Operators**

Statements processed : `+, -, *, /, %`
Tokens generated : Operators

- **Keywords**

Statements processed : `auto, const, default, enum, extern , register, return, sizeof, static, struct, typedef, union, volatile, break, continue, goto, else, switch, if, case, for, do, while, char, double, float, int, long, short, signed, unsigned, void`.
Tokens generated: Keyword

● **Identifiers**
Statements processed : `printf, i, varName` etc.
Tokens generated : Identifier
● **Single-line comments**:
Statements processed : `//..........`
● **Multi-line comments:**
Statements processed : `/*..........*/, /*.../*...*/*...*/`
● **Brackets:**
Statements processed : `(..), {..}, [..]` (without errors)
`(..)..), {..}..}, [..]..], (..., [...` (with errors)
Tokens generated : Parenthesis (without error) / Error with line number (with error)
● **Errors for incomplete strings**
Statements processed : `char a[]= ”abcd`
Error generated: `Error Incomplete string and line number`
● **Errors for nested comments**
Statements processed : `/*....../*....*/....`
Error generated: `Error with line number`
● **Errors for unmatched comments**
Statements processed : /*.....
Error generated: `Error with line number`

2.2 Some details

Regular expressions to identify the different tokens are given below:

- Preprocessor Directives:
  `#(include<.*>|define.*|ifdef|endif|if|else|ifndef|undef|pragma)`
- Arithmetic operators:
  `\+\+|\-\-|\+|\-|\*|\/|=`
- Comparison Operators:
  `<=|>=|<|>`
- Bitwise Operator
  `\^|\%|\&|\||\~`
- Identifier
  `[a-zA-Z_]([a-zA-Z0-9_])*`
- Numeric Constant
  `[1-9][0-9]*(\.[0-9]+)?|0(\.[0-9]+)?`
- String
  `\".*\"|\'.*\'`
- Invalid String
  `\"[^"\n]*|\'[^'\n]*`
- Single Line Comment
  `\/\/.*`
- Multi line Comment
  `"/*"([^*]|\*+[^*/])*\*+"/"`
- InvalidID
  `[^\n\t ]`
- Invalid Identifier

```
([0-9\*\-\+\%\/]+[a-zA-Z][a-zA-Z0-9\*\-\+\%\/]*)
```

- Error Handling for Incomplete String: Opening quote or closing quote missing, both kinds of errors have been handled in the rules written in the script.
- Error Handling for Nested Comments: This use-case has been handled by checking for occurrence of multiple successive '/*' or '*/' in the C code, and by omitting the text in between them.

After all tokens have been detected, they are printed to the terminal. As successive tokens are encountered, their values are updated in the symbol table and the symbol table is displayed at the end.

3. Testing the lexical analyzer:

Given below are a few test programs and their outputs:

Test 1

```
#include<stdio.h>
int main()
{
    int a,b,c;
    a = b + c;
    printf("Sum is %d",a);
    return 0;
}
shruthan@DESKTOP-QMQLGCS:/mnt/c/Users/shrut/Compiler-Design/Lexical Analyzer$ ./runfile.sh
#include<stdio.h>       ---- Preprocessor Directive
int     ---- Keyword
main    ---- Identifier
(       ---- Parenthesis
)       ---- Parenthesis
{       ---- Parenthesis
int     ---- Keyword
a       ---- Identifier
,       ---- Comma Delimiter
b       ---- Identifier
,       ---- Comma Delimiter
c       ---- Identifier
;       ---- Semicolon Delimiter
a       ---- Identifier
=       ---- Arithmetic
b       ---- Identifier
+       ---- Arithmetic
c       ---- Identifier
;       ---- Semicolon Delimiter
printf  ---- Identifier
(       ---- Parenthesis
"Sum is %d"     ---- String
,       ---- Comma Delimiter
a       ---- Identifier
)       ---- Parenthesis
;       ---- Semicolon Delimiter
return  ---- Keyword
0       ---- Numeric Constant
;       ---- Semicolon Delimiter
```

```
}       ---- Parenthesis


--------------------------------------------------------------------------
------
                                SYMBOL TABLE
--------------------------------------------------------------------------
------
          Token                                          Token Type
--------------------------------------------------------------------------
------
              a                                          Identifier
              b                                          Identifier
              c                                          Identifier
         return                                             Keyword
            int                                             Keyword
           main                                         Identifier
         printf                                         Identifier
    "Sum is %d"                                   String Constant
              0                                  Numeric Constant
```

Test 2

```c
#include<stdio.h>
int main()
{
    int a[5], b[5], c[5];
    int i;
    for (i = 0; i < 5; i++)

        a[i] = 1;
        b[i] = i;
    }
    i=0;
    while(i < 5)
    {
        c[i] = a[i] + b[i];
        i++;
    }
     /*
    This File Contains Test cases about Comments and Parenthesis imbala
nce
}
```

```
shruthan@DESKTOP-QMQLGCS:/mnt/c/Users/shrut/Compiler-Design/Lexical
Analyzer$ ./runfile.sh
#include<stdio.h>       ---- Preprocessor Directive
int     ---- Keyword
main    ---- Identifier
(       ---- Parenthesis
)       ---- Parenthesis
{       ---- Parenthesis
int     ---- Keyword
a       ---- Identifier
```

```
[       ---- Parenthesis
5       ---- Numeric Constant
]       ---- Parenthesis
,       ---- Comma Delimiter
b       ---- Identifier
[       ---- Parenthesis
5       ---- Numeric Constant
]       ---- Parenthesis
,       ---- Comma Delimiter
c       ---- Identifier
[       ---- Parenthesis
5       ---- Numeric Constant
]       ---- Parenthesis
;       ---- Semicolon Delimiter
int     ---- Keyword
i       ---- Identifier
;       ---- Semicolon Delimiter
for     ---- Keyword
(       ---- Parenthesis
i       ---- Identifier
=       ---- Arithmetic
0       ---- Numeric Constant
;       ---- Semicolon Delimiter
i       ---- Identifier
<       ---- Comparision Operator
5       ---- Numeric Constant
;       ---- Semicolon Delimiter
i       ---- Identifier
++      ---- Arithmetic
)       ---- Parenthesis
a       ---- Identifier
[       ---- Parenthesis
i       ---- Identifier
]       ---- Parenthesis
=       ---- Arithmetic
1       ---- Numeric Constant
;       ---- Semicolon Delimiter
b       ---- Identifier
[       ---- Parenthesis
i       ---- Identifier
]       ---- Parenthesis
=       ---- Arithmetic
i       ---- Identifier
;       ---- Semicolon Delimiter
}       ---- Parenthesis
i       ---- Identifier
=       ---- Arithmetic
0       ---- Numeric Constant
;       ---- Semicolon Delimiter
while   ---- Keyword
(       ---- Parenthesis
i       ---- Identifier
<       ---- Comparision Operator
5       ---- Numeric Constant
)       ---- Parenthesis
{       ---- Parenthesis
c       ---- Identifier
[       ---- Parenthesis
i       ---- Identifier
]       ---- Parenthesis
```

```
=       ---- Arithmetic
a       ---- Identifier
[       ---- Parenthesis
i       ---- Identifier
]       ---- Parenthesis
+       ---- Arithmetic
b       ---- Identifier
[       ---- Parenthesis
i       ---- Identifier
]       ---- Parenthesis
;       ---- Semicolon Delimiter
i       ---- Identifier
++      ---- Arithmetic
;       ---- Semicolon Delimiter
}       ---- Parenthesis

ERROR: Multiline Comment: "
    This File Contains Test cases about Comments and Parenthesis
imbalance
", Doesn't terminate at line: 18

------------------------------------------------------------------------
------
                                SYMBOL TABLE
------------------------------------------------------------------------
------
         Token                                          Token Type
------------------------------------------------------------------------
------
             a                                         Identifier
             b                                         Identifier
             c                                         Identifier
             i                                         Identifier
           for                                            Keyword
           int                                            Keyword
          main                                       Identifier
         while                                            Keyword
             0                                  Numeric Constant
             1                                  Numeric Constant
             5                                  Numeric Constant
```

Test 3

```c
#include<stdio.h>

int main()
{
    char string[10];
    string = "Hello World!;
}
```

```
shruthan@DESKTOP-QMQLGCS:/mnt/c/Users/shrut/Compiler-Design/Lexical
Analyzer$ ./runfile.sh
#include<stdio.h>       ---- Preprocessor Directive
int     ---- Keyword
main    ---- Identifier
(       ---- Parenthesis
)       ---- Parenthesis
{       ---- Parenthesis
char    ---- Keyword
string  ---- Identifier
[       ---- Parenthesis
10      ---- Numeric Constant
]       ---- Parenthesis
;       ---- Semicolon Delimiter
string  ---- Identifier
=       ---- Arithmetic
"Hello World!;  ---- ERROR: Unterminated string at line number: 5
}       ---- Parenthesis


------------------------------------------------------------------------
------
                                SYMBOL TABLE
------------------------------------------------------------------------
------
          Token                                          Token type
------------------------------------------------------------------------
------
           char                                             Keyword
            int                                             Keyword
           main                                          Identifier
             10                                  Numeric Constant
         string                                          Identifier
```

Test 4

```c
/* Program to multiply by 10
*/
// Header Files
#include <stdio.h>

#define ten 10

int main(void) {
    // Prompt input
    printf("Enter the number to be multiplied by 10\n");
    int n;
    // Take input
    scanf("%d", &n);
    return ten*n;
}
```

```
shruthan@DESKTOP-QMQLGCS:/mnt/c/Users/shrut/Compiler-Design/Lexical
Analyzer$ ./runfile.sh
/* Program to multiply by 10
*/      ---- Multi-Line Comment
// Header Files         ---- Single line comment
#       ---- ERROR: Invalid identifier at line number: 2
include         ---- Identifier
<       ---- Comparision Operator
stdio   ---- Identifier
.       - Dot Delimiter
h       ---- Identifier
>       ---- Comparision Operator
#define ten 10  ---- Preprocessor Directive
int     ---- Keyword
main    ---- Identifier
(       ---- Parenthesis
void    ---- Keyword
)       ---- Parenthesis
{       ---- Parenthesis
// Prompt input         ---- Single line comment
printf  ---- Identifier
(       ---- Parenthesis
"Enter the number to be multiplied by 10\n"     ---- String
)       ---- Parenthesis
;       ---- Semicolon Delimiter
int     ---- Keyword
n       ---- Identifier
;       ---- Semicolon Delimiter
// Take input   ---- Single line comment
scanf   ---- Identifier
(       ---- Parenthesis
"%d"    ---- String
,       ---- Comma Delimiter
&       ---- Bitwise Operator
n       ---- Identifier
)       ---- Parenthesis
;       ---- Semicolon Delimiter
return  ---- Keyword
ten     ---- Identifier
*n      ---- ERROR: Invalid Identifier
;       ---- Semicolon Delimiter
}       ---- Parenthesis


------------------------------------------------------------------------
------
                              SYMBOL TABLE
------------------------------------------------------------------------
------
        Token                                           Token Type
------------------------------------------------------------------------
------
              h                                        Identifier
              n                                        Identifier
          scanf                                        Identifier
          stdio                                        Identifier
         return                                           Keyword
            int                                           Keyword
            ten                                      Identifier
           "%d"                                  String Constant
```

```
              main                                              Identifier
            include                                             Identifier
   "Enter the number to be multiplied by 10\n"
   String Constant
             printf                                             Identifier
               void                                                Keyword
```

Test 5

```c
/* Program to multiply by 10 */

// Header Files
#include <stdio.h>

int main(void) {
    // Prompt input
    printf("Enter the number to be multiplied by 10\n");
    int n;
    int ten = 1xabc;
    // Take input
    scanf("%d", &n);
    return ten * n;
}
```

```
shruthan@DESKTOP-QMQLGCS:/mnt/c/Users/shrut/Compiler-Design/Lexical Analyzer$
./runfile.sh
/* Program to multiply by 10 */         ---- Multi-Line Comment
// Header Files          ---- Single line comment
#       ---- ERROR: Invalid identifier at line number: 3
include         ---- Identifier
<       ---- Comparision Operator
stdio   ---- Identifier
.       - Dot Delimiter
h       ---- Identifier
>       ---- Comparision Operator
int     ---- Keyword
main    ---- Identifier
(       ---- Parenthesis
void    ---- Keyword
)       ---- Parenthesis
{       ---- Parenthesis
// Prompt input         ---- Single line comment
printf  ---- Identifier
(       ---- Parenthesis
"Enter the number to be multiplied by 10\n"     ---- String
)       ---- Parenthesis
;       ---- Semicolon Delimiter
int     ---- Keyword
n       ---- Identifier
;       ---- Semicolon Delimiter
int     ---- Keyword
ten     ---- Identifier
=       ---- Arithmetic
1xabc   ---- ERROR: Invalid Identifier
;       ---- Semicolon Delimiter
// Take input   ---- Single line comment
scanf   ---- Identifier
(       ---- Parenthesis
```

```
"%d"    ---- String
,       ---- Comma Delimiter
&       ---- Bitwise Operator
n       ---- Identifier
)       ---- Parenthesis
;       ---- Semicolon Delimiter
return  ---- Keyword
ten     ---- Identifier
*       ---- Arithmetic
n       ---- Identifier
;       ---- Semicolon Delimiter
}       ---- Parenthesis


--------------------------------------------------------------------------
                              SYMBOL TABLE
--------------------------------------------------------------------------
            Token                                        Token Type
--------------------------------------------------------------------------
              h                                          Identifier
              n                                          Identifier
          scanf                                          Identifier
          stdio                                          Identifier
         return                                             Keyword
            int                                             Keyword
            ten                                        Identifier
           "%d"                                   String Constant
           main                                        Identifier
        include                                        Identifier
"Enter the number to be multiplied by 10\n"
String Constant
         printf                                        Identifier
           void                                             Keyword
```

4. References

- https://cs.nyu.edu/courses/spring11/G22.2130-001/lecture4.pdf
- https://en.wikipedia.org/wiki/Lexical_analysis
- https://silcnitc.github.io/lex.html
- https://www.d.umn.edu/~rmaclin/cs5641/Notes/L15_SymbolTable.pdf