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Compiler Principles Course Lab Report

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Contents

XL-Scanner

1 Motivation/Aim

The aim is to deepen the understanding of the lexical analysis process by writing a lexical analysis program.

2 Content description

2.1 Non - programming implementation part (Constructing DFA of self - defined language)

- Define regular expressions.
- Convert the regular expressions into multiple NFAs.
- Merge these NFAs to form an overall NFA.
- Transform the NFA into the minimum DFA.

2.2 Programming implementation part (Programming based on DFA)

The lexical analysis program scans the test program character by character from left to right, generates triples of words (recognized string, word category, word category number), and outputs them to the result file.

3 Ideas/Methods

3.1 Idea

The overall idea is to build a lexical analyzer to parse the content in the input text file (test.txt) according to lexical rules, split the text into different types of lexical units, and process and record relevant information for each type of lexical unit, thus providing processed basic data for subsequent compilation stages. By identifying different character combinations and symbol features, keywords, identifiers, numbers, strings, operators, etc. are distinguished, and comment content is properly handled to eliminate its interference with lexical analysis.

3.2 Method

3.2.1 Classification and identification of lexical units

Define the rules corresponding to various lexical units such as keywords and operators in advance. For example, keywords are listed through the predefined KEY_WORDS array, and operators are listed through the OPERATORS array. When reading characters later, match and compare the character composition with these predefined contents to determine the type of lexical unit. In the judge_str function, the type of lexical unit is preliminarily screened by judging the characteristics of the first character or the first few characters read. For example, those starting with letters may be keywords or identifiers, those starting with numbers are likely to be of the number type, those starting with " are likely to be strings, and those starting with // or /* correspond to different types of comments. According to these starting characteristics, different functions are called for further precise judgment and processing.

3.2.2 Data storage and management

Create data structures of type map<string, mpair> such as flag_table (identifier table), num_table (number table), and str_table (string table) to store identifiers, numbers, strings, and their related information (the category number and number value in the table are saved in the form of mpair). Each time a lexical unit of the corresponding type is encountered, first check whether it already exists in the corresponding table. If it exists, obtain the existing number value. If it does not exist, add a new record and assign a new number value to manage the lexical unit information, facilitating subsequent query and repeated judgment operations.

3.2.3 Comment processing

The handle_single_comment function is used to directly ignore characters as comment content until a newline character or the end of the file is encountered after encountering content starting with //. In the handle_multi_comment function, once content starting with /* is identified, characters are read cyclically, and after encountering *, the next character is checked to see if it is / to determine whether the multi - line comment ends. All characters between /* and */ are ignored as comment parts to ensure that multi - line comments can be correctly processed without affecting the analysis of other lexical units.

The main function guides the entire lexical analysis process. First, try to open the input file. If it is successfully opened, read the file content character by character, filter out blank characters (spaces, tabs, newline characters), and call the judge_str function for non - blank characters to further distinguish lexical units and perform corresponding processing until the file is read completely. Finally, close the file to complete the comprehensive lexical analysis task of the input text.

4 Assumptions

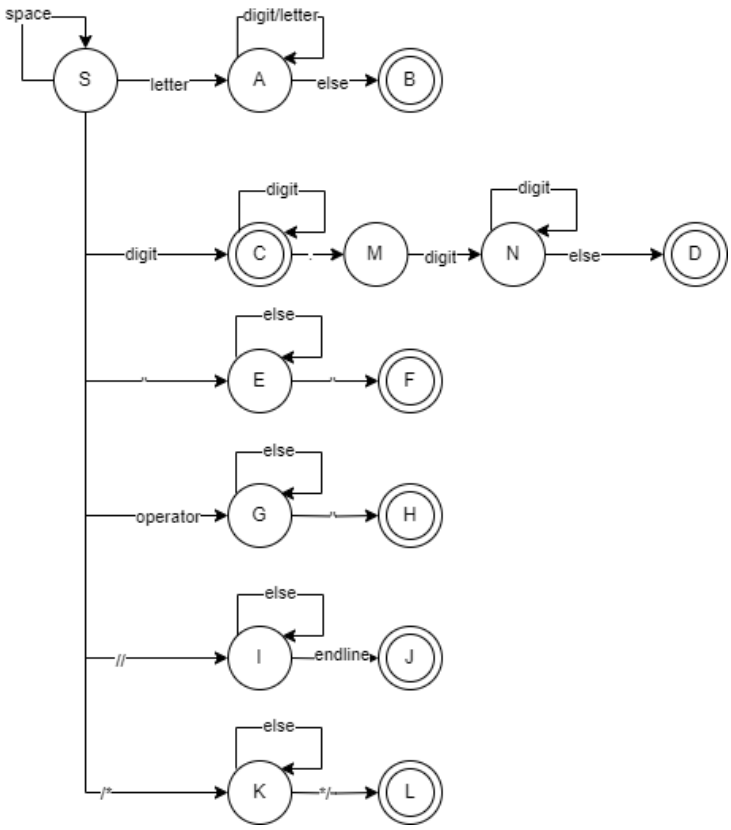
Token Type	Example	Regular Expression
keyword	main	main/if/while/else/return/for/break/continue/do/switch/void/int/float/char/const
id	Custom Identifier	[a-zA-Z_][a-zA-Z0-9_]*
num	Integer Constant	[0-9]+
float	Floating Constant	[0-9]+\.[0-9]+
string	String Constant	"[^"]*"
operator	=	=
error	Unknown Symbol	. (Matches any single symbol not conforming to the above rules)

Lexical Unit Type	Lexical Unit Example	Number
keyword	main	1
keyword	int	2
keyword	char	3
keyword	if	4
keyword	else	5
keyword	for	6
keyword	while	7
keyword	return	8
keyword	void	9
keyword	float	10
keyword	then	11
keyword	switch	12
keyword	break	13
keyword	continue	14
keyword	do	15
keyword	const	16
id	Custom identifier	Numbered starting from 1 according to the insertion order in flag_table (determined by flag_table.size() + 1 in the code)
num	Integer constant	Numbered starting from 1 according to the insertion order in num_table (determined by num_table.size() + 1 in the code, and the category number is assumed to be 20)

Lexical Unit Type	Lexical Unit Example	Number
`float`	Floating-point constant	Numbered starting from 1 according to the insertion order in `num_table` (determined by `num_table.size() + 1` in the code, and the category number is assumed to be 30)
`string`	String constant	Numbered starting from 1 according to the insertion order in `str_table` (determined by `str_table.size() + 1` in the code, and the category number is 50)
`operator`	`=`	21
`operator`	`+`	22
`operator`	`-`	23
`operator`	`*`	24
`operator`	`/`	25
`operator`	`(`	26
`operator`	`)`	27
`operator`	`[`	28
`operator`	`]`	29
`operator`	`{`	30
`operator`	`}`	31
`operator`	`,`	32
`operator`	`:`	33
`operator`	`;`	34
`operator`	`>`	35
`operator`	`<`	36
`operator`	`>=`	37
`operator`	`<=`	38
`operator`	`==`	39
`operator`	`"`	40
`error`	(Various unknown symbols that do not conform to the above rules)	No fixed number

5 Related FA descriptions

The state transition diagram



6 Description of important Data Structures

- mpair (typedef pair<int, int> mpair;) It is a custom type alias used to combine two integer values. The first integer is used to represent the word category, and the second integer is used to represent the value of the word itself.
- map<string, mpair> (flag_table, num_table, str_table) flag_table (identifier table) is used to store the identifiers in the program. When an identifier is encountered, if the identifier is not in this table, the program will add it to the table and record the category information and position of the identifier in the table. If the identifier already exists in the table, relevant information can be quickly obtained through lookup operations. num_table (number table) is used to store the numbers appearing in the program. When encountering a number, this table can distinguish different types of numbers such as integers and floating - point numbers, and record the position of each number in the table and its corresponding category information. str_table (string table) is used to store the strings in the program. When encountering a string, the program will look up or add the string and its related category and position information in this table.
- Character arrays KEY_WORDS stores a list of keywords in the program, including "main", "int", "char", "if", "else", "for", "while", "return", "void", "float", "then",

"switch", "break", "continue", "do", "const". The input string is compared with the elements in this array one by one to determine whether the input string is a keyword. OPERATORS stores a list of operators, including "=", "+", "-", "*", "/", "(", ")", "[", "]", "", "", ",", ":", ";", ">", "<", ">=", "<=", "==", "". It is used to determine whether the input character is an operator.

7 Description of core Algorithms

7.1 Lexical unit judgment functions

7.1.1 iskey function

```
int iskey(char* str)
{
    int len = sizeof(KEY_WORDS) / sizeof(char*);
    for (int i = 0; i < len; i++) {
        if (!strcmp(KEY_WORDS[i], str)) {
            return i;
        }
    }
    return -1;
}
```

Function: Determine whether the input string is a keyword. Implementation: Traverse the KEY_WORDS array and use the strcmp function to compare the input string with the elements in the keyword array one by one. If a match is found, return the index of the keyword in the array, otherwise return - 1.

7.1.2 isope function

```
int isope(char* str)
{
    int len = sizeof(OPERATORS) / sizeof(char*);
    for (int i = 0; i < len; i++) {
        if (!strcmp(OPERATORS[i], str)) {
            return i;
        }
    }
    return -1;
}
```

Function: Determine whether the input string is an operator. Implementation: Traverse the OPERATORS array and use the strcmp function to compare the input string with the elements in the operator array one by one. If a match is found, return the index of the operator in the array, otherwise return - 1.

7.1.3 isFloatPart function

```
bool isFloatPart(char ch)
{
    int asciiCode = static_cast<int>(ch);
    return (asciiCode == 46 || asciiCode == 101 || asciiCode == 69 ||
       isdigit(static_cast<int>(ch)));
```

```
}
```

Function: Assist in determining whether a character may be part of a floating - point number. Implementation: Determine whether the character is., e, E, or a digit by judging the ASCII code value of the character.

7.2 Lexical unit acquisition functions

7.2.1 get_keyorid function

```
void get_keyorid(char* token, char* ptr, FILE* fp)
{
    while (isalnum(*ptr)) {
        *++ptr = fgetc(fp);// Read letters or numbers
    }
    ungetc(*ptr, fp);// If no letters or numbers are read, return a
       string ending with \0, that is, a token
    *ptr = '\0';
    int flag = iskey(token);
    if (flag!= -1) { // It is a keyword
        if (!mark_key[flag])
            mark_key[flag] = 1;
        cout << "(" << token << ",keyword," << flag + 1 << ")" << endl;
    }
    else { // It is an identifier
        string s = "";
        map<string, mpair>::iterator it;
        s.append(token);
        it = flag_table.find(s);
        mpair mp;
        if (it == flag_table.end()) { // The identifier is not in the
           symbol table
            mp = make_pair(10, flag_table.size() + 1);// Create an
               mpair object
            flag_table[s] = mp;
            cout << "(" << s << ",id," << flag_table.size() << ")" <<
               endl;
        }
        else {
            it = flag_table.find(s);
            mp = it->second;
            cout << "(" << s << ",id," << mp.second << ")" << endl;
        }
    }
}
```

Function: Get keywords or identifiers. Implementation: When the input character is a letter, continuously read subsequent characters until they are not letters or numbers, and form a string token from the read characters. Then call the iskey function to determine whether it is a keyword. If it is a keyword, record relevant information and output it. If it is not a keyword, treat it as an identifier. According to the identifier table flag_table, determine whether the identifier already exists. If it does not exist, add it to the table, record relevant information, and output it. If it exists, directly output the existing relevant information in the table.

7.2.2 get_number function

```
void get_number(char* token, char* ptr, FILE* fp)
{
    bool isFloat = false;  // Mark whether it is a floating - point
       number
    while (isdigit(*ptr) || (isFloatPart(*ptr) &&!isFloat)) {
        if (*ptr == '.' || *ptr == 'e' || *ptr == 'E') {
            isFloat = true;
        }
        *++ptr = fgetc(fp);
    }
    ungetc(*ptr, fp);
    *ptr = '\0';

    map<string, mpair>::iterator it;
    string num;
    num.append(token);
    it = num_table.find(num);
    mpair mp;
    if (it == num_table.end()) {
        if (isFloat) {
            mp = make_pair(30, num_table.size() + 1);  // Assume the
               category number of floating - point numbers is 30, which
                can be adjusted according to the actual situation
        }
        else {
            mp = make_pair(20, num_table.size() + 1);
        }
        num_table[num] = mp;
    }
    else {
        it = num_table.find(num);
        mp = it->second;
    }
    string sub;
    if (num.length() > width1 - 1) {
        sub = num.substr(0, width1 - 4);
        sub.append("...");
    }
    else
        sub = num;
    if (isFloat) {
        cout << "(" << num << ",float," << mp.second << ")" << endl;
    }
    else {
        cout << "(" << num << ",num," << mp.second << ")" << endl;
    }
}
```

Function: Get numbers (including integers and floating - point numbers). Implementation: When the input character is a number, continuously read subsequent characters, determine whether it is a floating - point number according to the isFloatPart function, until the read character does not conform to the rules of numbers or floating - point numbers. Form a string num from the read characters, then determine whether the number already exists according to num_table. If it does not exist, add it to the number table according to whether it is a floating - point number, record relevant information, and

output it. If it exists, directly output the existing relevant information in the table.

7.2.3 try_string function

```
1
2  void try_string(char* token, char* ptr, FILE* fp)
3  {
4      ***ptr = fgetc(fp);
5      while (!feof(fp) && *ptr!= '"') {
6          ***ptr = fgetc(fp);
7      }
8      if (!feof(fp)) // Haven't reached the end of the file
9          ***ptr = '\0';
10     else // Have reached the end of the file
11         *ptr = '\0';
12     string s = "", sub;
13     s.append(token);
14     if (s.size() > 0) {
15         if (*(ptr - 1) == '"') { // Found the matching "
16             map<string, mpair>::iterator it;
17             it = str_table.find(s);
18             mpair mp;
19             if (it == str_table.end()) {
20                 mp = make_pair(50, str_table.size() + 1);
21                 str_table[s] = mp;
22                 cout << "(" << s << ",string," << str_table.size() << "
                       )" << endl;
23             }
24             else {
25                 it = str_table.find(s);
26                 mp = it->second;
27                 cout << "(" << s << ",string," << mp.second << ")" <<
                       endl;
28             }
29         }
30         else { // Didn't find the matching "
31             int i;
32             int len = strlen(token);
33             for (i = 0; i < len - 1; i++)
34                 ungetc(*--ptr, fp);
35             cout << "(" << s << ",error,miss terminal '\"')" << endl;
36         }
37     }
38 }
```

Function: Determine whether it is a string. Implementation: When the input character is a double quotation mark ("), continuously read subsequent characters until the next double quotation mark is encountered or the end of the file is reached. If a matching double quotation mark is encountered, then determine whether the string already exists in the `str_table`. If it does not exist, add it to the table and record relevant information and then output it. If it exists, directly output the existing relevant information in the table. If a matching double quotation mark is not encountered, then perform error handling and output an error message.

7.2.4 try_double_ope Function

```
void try_double_ope(char* token, char* ptr, FILE* fp)
{
    ***++ptr = fgetc(fp);
    ***++ptr = '\0';
    int sub = isope(token);
    if (sub!= -1)
        mark_ope[sub] = 1;
    else {
        ungetc(*--ptr, fp);
        *ptr = '\0';
        sub = isope(token);
        mark_ope[sub] = 1;
    }
    cout << "(" << token << ",operator," << sub + 21 << ")" << endl;
}
```

Function: Process possible double - operand operators. Implementation: When the input character is one of the possible starting characters of double - operand operators such as >, <, or =, read the next character to form a string `token`, and call the `isope` function to determine whether it is an operator. If it is, record relevant information and output it. If it is not, return the second character to the input stream and re - judge the first character as a single - operand operator.

7.2.5 try_single_ope Function

```
void try_single_ope(char* token, char* ptr, FILE* fp)
{
    ***++ptr = '\0';
    int sub = isope(token);
    if (sub!= -1) {
        mark_ope[sub] = 1;
        cout << "(" << token << ",operator," << sub + 21 << ")" << endl
            ;
    }
    else {
        if (token[0] < 0 || token[0] > 127) // Non - ASCII code
            token[0] = '?';
        cout << "(" << token << ",error,unknown symbol)" << endl;
    }
}
```

Function: Process single - operand operators. Implementation: When the input character is an operator and not the starting character of a double - operand operator, call the `isope` function to determine whether it is an operator. If it is, record relevant information and output it. If it is not and the character is a non - ASCII code, then perform error handling and output an error message.

7.3 Comment Processing Functions

7.3.1 handle_single_comment Function

```
void handle_single_comment(FILE* fp)
{
    char ch;
```

```
    while ((ch = fgetc(fp))!= '\n' && ch!= EOF) {
        // Continuously read characters until a newline character or
           the end of the file is encountered
    }
}
```

Function: Process single - line comments. Implementation: When the input character is //, continuously read subsequent characters until a newline character or the end of the file is encountered.

7.3.2 handle_multi_comment Function

```
void handle_multi_comment(FILE* fp)
{
    char ch;
    int comment_end_found = 0;
    while ((ch = fgetc(fp))!= EOF &&!comment_end_found) {
        if (ch == '*') {
            char next_ch = fgetc(fp);
            if (next_ch == '/') {
                comment_end_found = 1;
            }
            else {
                ungetc(next_ch, fp);
            }
        }
    }
}
```

Function: Process multi - line comments. Implementation: When the input character is /*, continuously read subsequent characters until */ is encountered or the end of the file is reached.

7.4 Lexical Analysis Loop in the main Function

```
void judge_str(char ch, FILE* fp)
{
    char token[TOKEN_SIZE];
    char* ptr = token;
    *ptr = ch;
    char next_char = fgetc(fp);// Read the next character for auxiliary
        judgment
    ungetc(next_char, fp);// Immediately return to prevent affecting
       the reading

    if (isalpha(*ptr)) { // The token starts with a letter
        get_keyorid(token, ptr, fp); // Determine whether it is a
           keyword or an identifier
    }
    else if (isdigit(*ptr)) { // The token starts with a number
        get_number(token, ptr, fp); // Determine whether it is a number
    }
    else if (*ptr == '"') { // The token starts with "
        try_string(token, ptr, fp); // It may be a string
    }
```

```
18      else if (*ptr == '>' || *ptr == '<' || *ptr == '=') { // It may be
            a double - operand operator
19          try_double_ope(token, ptr, fp);
20      }
21      else if (*ptr == '/' && next_char == '/') { // Starts with "//",
            process single - line comments
22          handle_single_comment(fp);
23      }
24      else if (strncmp(COMMENT_START_MULTI, ptr, 2) == 0) { // Starts
            with "/*", process multi - line comments
25          handle_multi_comment(fp);
26      }
27      else {
28          try_single_ope(token, ptr, fp); // It may be a single - operand
                operator
29      }
30  }
31  int main()
32  {
33      FILE* fp = fopen("test.txt", "r");
34      if (fp == NULL) {
35          perror("file open failed\n");
36          return 1;
37      }
38      char ch = fgetc(fp);
39      while (!feof(fp)) {
40          if (ch!= ' ' && ch!= '\t' && ch!= '\n') {
41              judge_str(ch, fp);
42          }
43          ch = fgetc(fp);
44      }
45      fclose(fp);
46      cout << "----------------------------------------" << endl;
47      // Output the identifier table
48      cout << "identifier table:" << endl;
49      for (auto& it : flag_table) {
50          cout << it.second.second << "    " << it.first << endl;
51      }
52
53      // Output the integer table
54      cout << "num table:" << endl;
55      for (auto& it : num_table) {
56          if (it.second.first == 20) {
57              cout << it.second.second << "    " << it.first << endl;
58          }
59      }
60
61      // Output the floating - point table
62      cout << "float table:" << endl;
63      for (auto& it : num_table) {
64          if (it.second.first == 30) {
65              cout << it.second.second << "    " << it.first << endl;
66          }
67      }
68
69      return 0;
70  }
```

In the `main` function, the file `test.txt` is opened and its content is read character by character. When the read character is not a space, tab, or newline character, the `judge_str` function is called for lexical analysis. The `judge_str` function calls the corresponding lexical unit acquisition functions or comment processing functions according to the type of the input character. When the file reading is completed (judged by the `feof` function), the file is closed and the program ends.

8 Use Cases on Running

The following `test.cpp` file is used for code testing, and the results are output in the form of triples:

```
int num1 = 123;
float num2 = 3.14;
char str1 = "Hello, World!";
if (num1 > 100) {
    int num3 = 456;
    return num3;
} else {
    continue;
}
&
// This is a single-line comment
/* This is a
multi-line
comment */
```

The output is:

```
identifier table:
5    This
7    a
10    comment
6    is
9    line
8    multi
1    num1
2    num2
4    num3
3    str1
num table:
3    100
1    123
4    456
float table:
2    3.14
```

The output file test.txt:

```
(int,keyword,2)
(num1,id,1)
(=,operator,21)
(123,num,1)
(;,operator,34)
(float,keyword,10)
(num2,id,2)
(=,operator,21)
(3.14,float,2)
(;,operator,34)
(char,keyword,3)
(str1,id,3)
(=,operator,21)
("Hello, World!",string,1)
(;,operator,34)
(if,keyword,4)
((,operator,26)
(num1,id,1)
(>,operator,35)
(100,num,3)
(),operator,27)
({,operator,30)
(int,keyword,2)
(num3,id,4)
(=,operator,21)
(456,num,4)
(;,operator,34)
(return,keyword,8)
(num3,id,4)
(;,operator,34)
(},operator,31)
(else,keyword,5)
({,operator,30)
(continue,keyword,14)
(;,operator,34)
(},operator,31)
(&,error,unknown symbol)
(/,operator,25)
(*,operator,24)
(This,id,5)
(is,id,6)
(a,id,7)
(multi,id,8)
(-,operator,23)
(line,id,9)
(comment,id,10)
(*,operator,24)
(/,operator,25)
```

9 Problems Occurred and Related Solutions

At first, the judgment of / was not very clear. Later, a method was found. When // was recognized as the start of a single - line comment, a special state flag was set to enter the single - line comment processing state. In this state, no matter what characters were encountered subsequently (except for the newline character as the end mark), they were directly ignored until the newline character was encountered and then exited this state to return to the normal lexical analysis state. For the multi - line comment /* */, a corresponding state was also set. After entering the multi - line comment state, characters were continuously read, and only when */ was read in sequence would the state be exited to return to the normal analysis state. And some error handling mechanisms could be added. For example, if the end of the file was reached without encountering */, an appropriate error message could be output to inform the user that the comment was

not correctly closed. In addition, for the case where the string originally contained escape characters, the initial program might prematurely consider the double quotation mark as the end, resulting in the truncation of the string. The loop logic in the `try_string` function was modified. When the backslash character was read, it was necessary to additionally determine whether the next character was a specific character used for escape (such as the case where was followed by "). If it was an escape character combination, it was normally read as part of the string content instead of being treated as the end double quotation mark, so that the string content containing escape characters could be correctly parsed.

10 Feelings and Comments

(1) By writing a lexical analyzer, I have a deeper understanding of the compilation process. Lexical analysis is the first stage of compilation, which needs to convert the source code text into a series of tokens, maintain a symbol table to record the encountered self - defined identifiers and some constants, and also needs to complete the error detection function to identify lexical errors in the source code, such as spelling errors and illegal characters.

(2) Before writing a lexical analyzer, it is necessary to draw a state transition diagram first and write processing functions for different situations according to the state transition diagram. The basis for drawing the state transition diagram is to divide the read characters into different categories and determine which category they belong to according to the first character, and then specifically analyze the possible read characters for different categories.