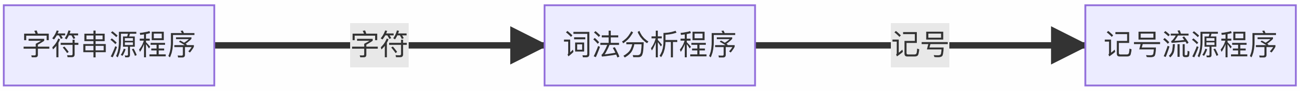
chapter-03 词法分析

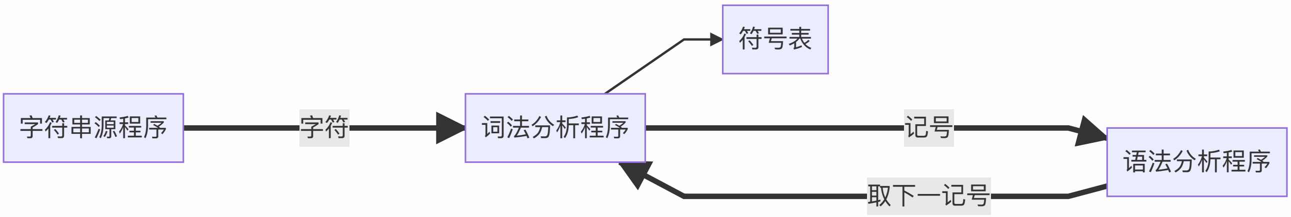
1. 词法分析在编译过程中的定位

   - 词法分析作为独立的一遍：



     将词法分析程序分离，便于语法分析程序专注于语法处理，简化设计；不用考虑上层分析程序，可构造更有效的词法分析程序，提高效率；同时也加强了编译程序的的可移植性。

   - 词法分析作为语法分析的子程序：

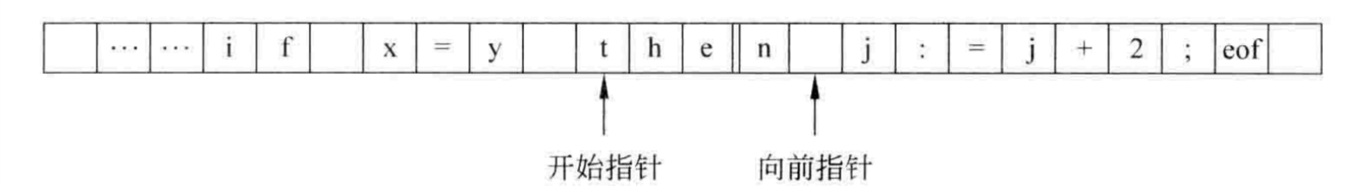


     避免了中间文件的产生；省去了取送符号的操作；提高编译程序的效率。

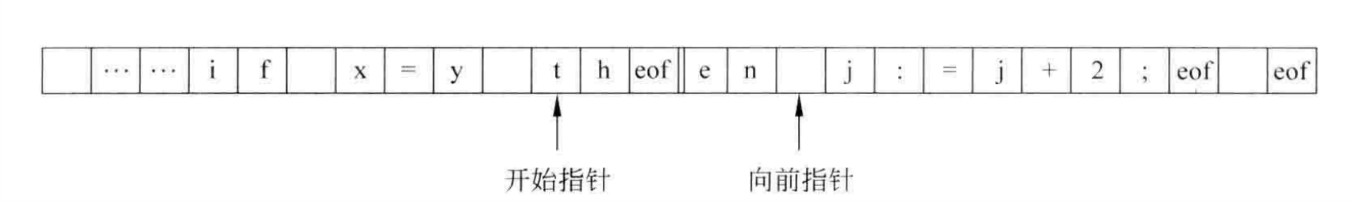
   - 词法分析与语法分析作为协同程序，两者处于同一遍中，交叉进行，以生产者和消费者的关系同时进行。

2. 词法分析程序的输入

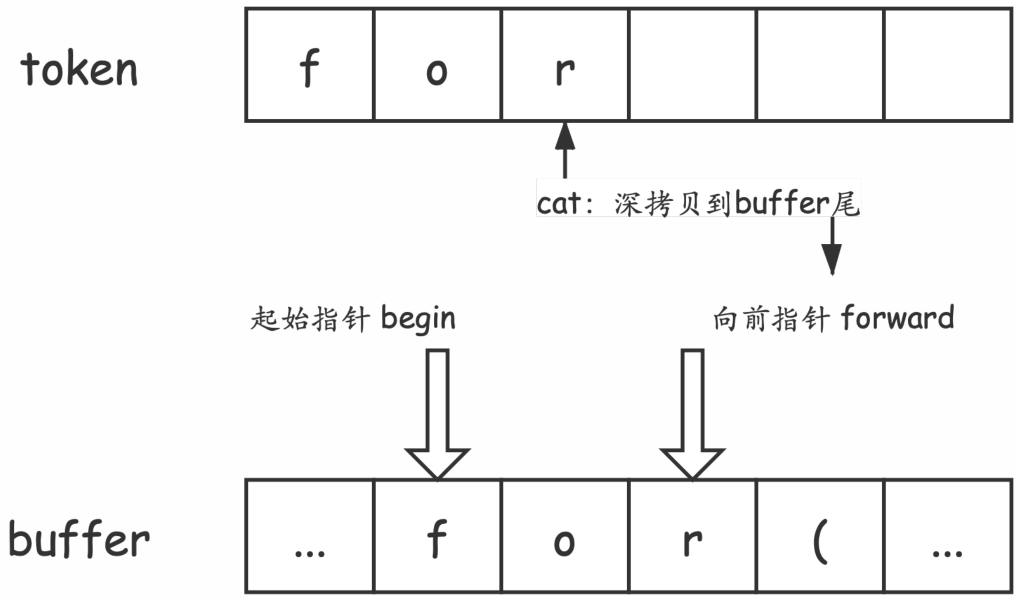
   双缓冲输入模式的介绍：



   缓冲区分为左右两半，开始指针和向前指针在初始阶段都指向下一个单词符号的起始字符，之后向前指针向前扫描，当向前指针到达左半区的终点时，则填充右半区，即将原先左半区开始指针到向前指针之间的内容移动到右半区来；当向前指针到达右半区的终点时，则填充左半区，注意左右半区是首尾连接的循环结构。



缓冲和单词的关系：



在左右半区终点处添加了eof标记后，这里给出伪代码：

```
while(...)
{
   向前指针移动一个位置
   if(向前指针指向EOF)
   {
      if(向前指针在左半区的终点)
      {
         向前指针向前移动一个位置   // 离开左半区的终点
         填充右半区
      }
      else if(向前指针在右半区终点)
      {
         向前指针指向缓冲区的开始位置
         填充左半区
      }
      else
      {
         终止词法分析
      }
   }
}
```

3. 词法分析程序的输出——记号

记号的种类：1. 关键字；2. 标识符；3. 常数；4. 运算符；5. 分界符。

分析出记号的方式：记号的模式，如记号的正则式。

词法分析的结果：记号和其对应的属性。

不同的记号的属性：

1. 标识符：符号表中的入口地址；
2. 常数：表示的值；
3. 关键字：一符一种，不同的关键字属性也不同，需要各个区分；
4. 运算符：一符一种；
5. 分界符：一符一种。

记号的文法表示，如下：

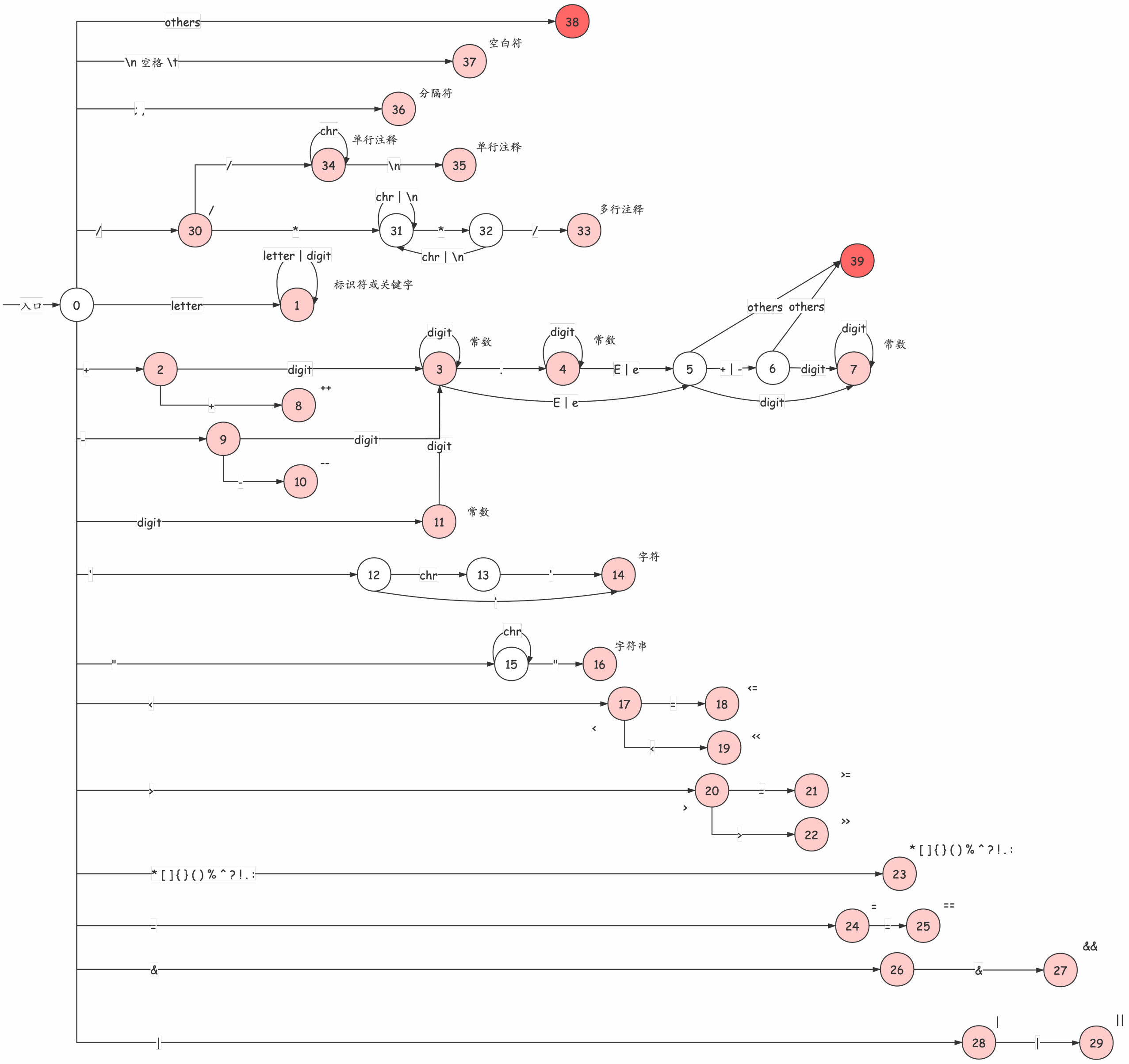
> 标识符：
> $$\begin{aligned} id &\rightarrow letter\ rid \\ rid &\rightarrow \epsilon \mid digit\ rid \mid letter\ rid \end{aligned}$$
>
> 常数——整数：$digits \rightarrow digit \mid digits\ digit$
>
> 常数——无符号数：
> $$\begin{gathered} num \rightarrow digits\ optional\_fraction\ optional\_exponent \\ optional\_fraction \rightarrow (.digits)? \\ optional\_exponent \rightarrow (E(+|-)?digits)? \end{gathered}$$
>
> 其右线性文法表达式为：
> $$\begin{gathered} num \rightarrow digit\ num1 \\ num1 \rightarrow digit\ num1 \mid .\ num2 \mid E\ num4 \mid \epsilon \\ num2 \rightarrow digit\ num3 \\ num3 \rightarrow digit\ num3 \mid E\ num4 \mid \epsilon \\ num4 \rightarrow +\ digits \mid -\ digits \mid digits \end{gathered}$$
>
> 运算符——关系运算符：$relop \rightarrow\ < \mid <= \mid == \mid > \mid >=$
>
> 运算符——赋值号：$assign\_option \rightarrow\ =$
>
> 运算符——算术运算符：$single \rightarrow\ + \mid - \mid * \mid / \mid (\mid) \mid : \mid ' \mid ;$

这里给出设计的状态转换图：

> 注意：
>
> 1. 这里的标识符在识别后会进入关键字表中查询，如果查找到，则记录为关键字。
> 2. 这里的浅红色的标记，表示该代码串被该模式分支识别；这里的深红色标记，表示该模式分支无法识别该代码串。

chr: [.]，表示除换行符外的其他字符，且在一定情况下会排除其所包含的字符，如字符的状态转移中chr会排除单引号"\'"。

others: 代表除当前已经列举的输入之外的输入符号，如常数的状态转移中5号的others代表非+，-或数字的输入。



这里给出关于C语言的词法分析程序（由于这里考虑的是C语言中的主要词法，程序可能存在某些不完善之处）：

- words_analysis.h

```
#ifndef _WORDS_ANALYSIS_H_
#define _WORDS_ANALYSIS_H_
#include <stdio.h>
#include <stdlib.h>
#include <stdbool.h>
#include <string.h>
#include <fcntl.h>
#include <unistd.h>
#define ulong   unsigned long long int
#define uint    unsigned int
/*------ relation operators ------*/
```

```
#define OPERATOR     0
#define LT      11
#define LE      12
#define GT      13
#define GE      14
#define EQ      15

/*------ assign operators ------*/
#define AS      16


/*------ algorithm operators ------*/
#define ADD     17
#define DEC     18
#define MUL     19
#define DIV     20
#define LB      21
#define RB      22
#define BLB     23
#define BRB     24
#define AND     25
#define OR      26
#define NOT     27
#define XOR     28
#define REVS    29
#define SQUT    30
#define QUT     31
#define MLB     32
#define MRB     33
#define SHL     34
#define SHR     35
#define COLON   36
/*------ keywords ------*/
#define KEYWORD     1
#define IF      41
#define ELSE    42
#define WHILE   43
#define SWITCH  44
#define CASE    45
#define BREAK   46

#define FOR     47
#define VOID    48
#define UNSIG   49
#define CHAR    50
#define SHORT   51
#define INT     52
#define FLOAT   53
#define LONG    54
#define DOUBLE  55
#define STATIC  56
#define EXTERN  57
```

```
#define CONTIU  58

/*------ constant ------*/
#define CONSTANT    2
#define NUM     61
#define STR     62
#define CHR     63

/*------ identifier ------*/
#define ID      3


/*------ separator ------*/
#define SEPARATOR   4
#define SEMCOL  71
#define COMMA   72


/*------ comment ------*/
#define COMMENT 5
#define SCMT    80
#define MCMT    81


/*------ whitespace ------*/
#define BLANK   6
#define FEED    7
#define TAB     8

/*------ error ------*/
#define ERROR   9

#define ILLEG   100
#define OTHER   110

// 关键字表大小
const static uint keywds_table_size = 20;
// 关键字表
const static char *keywds_table[] = {"if", "else", "when",
            "switch", "case", "for", "void", "char",
            "unsigned", "int", "short", "long", "float",
            "double", "return","extern","static", "const",
            "break", "continue"
        };

const static char *types[] = {"operator", "keyword", "constant",
            "identifier", "separator", "comment", "whitespace"
        };


// 判断当前字符是否为字母或下划线
bool is_letter();
```

```
// 判断当前字符是否为数字
bool is_digit();
// 判断当前单词是否为关键字
bool is_keywd();
// 判断当前字符是否为非换行符
bool is_chr();
// buffer后退一个字符
int retract();
// 从buffer中读取字符
int get_char();
// 将当前字符连接到当前单词后
int cat();
// 判断自动机分支
char branch();
// 将当前单词的属性进行封装，并提交到单词表
int fetch_word(uint type);
// 初始化单词缓冲区buffer和token
int init_buffer(char *filepath);
// 词法分析
int analysis();
// 词法分析结束判断
bool done();
// 输出结果统计信息
void print_statistics();

/*---------------- analysis_state.c ----------------*/
void state_0();
void state_1();
void state_2();
void state_3();
void state_4();
void state_5();
void state_6();
void state_7();
void state_8();
void state_9();
void state_10();
void state_11();
void state_12();
void state_13();
void state_14();
void state_15();
void state_16();
void state_17();
void state_18();
void state_19();
void state_20();
void state_21();
void state_22();
void state_23();
void state_24();
void state_25();
void state_26();
void state_27();
void state_28();
void state_29();
void state_30();
void state_31();
void state_32();
void state_33();
void state_34();
void state_35();
void state_36();
void state_37();
void state_38();
void state_39();

#endif
```

- words_analysis.c

```
#include "words_analysis.h"
#include "words_table.h"
#define IS_LETTER 65
#define IS_DIGIT 48

const static ulong buf_size = 1024 * 1024;
const static ulong tok_size = 1024;
static int fd;
static ulong code_size;
static char buffer[buf_size];
static char token[tok_size];
static ulong tok_len;
static char *begin;
static char *forward;
static struct word tempwd;

// 字符个数
ulong chars_cnt = 0;
// 行数
ulong line_cnt = 1;
// 单词个数
ulong words_cnt = 0;
// 常量个数
ulong consts_cnt = 0;
// 标识符个数
ulong ids_cnt = 0;
// 关键字个数
ulong keywds_cnt = 0;
// 运算符个数
ulong opts_cnt = 0;
// 分隔符个数
ulong septs_cnt = 0;
// 注释个数
```

```
ulong cmts_cnt = 0;
// 空格个数
ulong blks_cnt = 0;
// 换行符个数
ulong lfds_cnt = 0;
// 制表符个数
ulong tabs_cnt = 0;
// 错误个数
ulong errs_cnt = 0;
// 当前列号
ulong current_row = 1;
// 状态序号
uint state = 0;
// 当前读取的字符
char C;


bool is_letter()
{
    if((C <= 'Z' && C >= 'A') || (C >= 'a' && C <= 'z') || C == '_')
    {
        return true;
    }
    return false;
}

bool is_digit()
{

    if(C <= '9' && C >= '0')
    {
        return true;
    }
    return false;
}

bool is_chr()
{
    if(C == '\n')
    {
        return false;
    }
    return true;
}

bool is_keywd()
{
    bool flag = true;
    for(int i = 0; i < keywds_table_size && flag; i++)
    {
        if(strcmp(token, keywds_table[i]) == 0)
        {
            flag = false;
        }
    }
    if(flag == false)
    {
        return true;
    }
    return false;
}

int init_buffer()
{
    // 打开文件
    fd = open("example.c", O_RDONLY);
    // 读取文件数据
    code_size = read(fd, buffer, buf_size);
    // 初始化开始和向前指针
    tok_len = 0;
    begin = buffer;
    forward = begin;
    // 关闭文件
    close(fd);
    return 0;
}


int get_char()
{
    C = *forward;
    forward++;
    chars_cnt++;
    current_row++;
    if(chars_cnt >= code_size)
    {
        return -1;
    }
    return 0;
}

int cat()
{
    token[tok_len] = C;
    tok_len++;
    return 0;
}

int fetch_word(uint type)
{
    switch (type)
    {
        case OPERATOR:  opts_cnt++; words_cnt++;    break;
        case KEYWORD:   keywds_cnt++; words_cnt++;  break;
        case CONSTANT:  consts_cnt++; words_cnt++;  break;
        case ID:    ids_cnt++; words_cnt++;  break;
        case SEPARATOR: septs_cnt++; words_cnt++;    break;
        case COMMENT:   cmts_cnt++; break;
        case BLANK: blks_cnt++; break;
        case FEED:  lfds_cnt++; break;
        case TAB:   tabs_cnt++; break;
        case ERROR: errs_cnt++; break;
    }
    tempwd.type = type;
    tempwd.lineno = line_cnt;
    tempwd.rowno = current_row;
    strcpy(tempwd.value, token);
    insert_table(&tempwd);
    memset(token, 0, tok_len);
    tok_len = 0;
    return 0;
}

int main(int argc, char *argv[])
{
    init_buffer();
    init_words_table();
    // do {
    //     get_char();
    //     printf("%c", C);
    // } while(!done());
    analysis();
    print_table();
    print_statistics();
    return 0;
}

char branch()
{
    if(is_letter())
    {
        return IS_LETTER;
    }
    else if(is_digit())
    {
        return IS_DIGIT;
    }
    return C;
}

int retract()
{
    forward--;
    current_row--;
    chars_cnt--;
    return 0;
```

```
}

bool done()
{
    if(chars_cnt <= code_size)
    {
        return false;
    }
    return true;
}

int analysis()
{
    state = 0;
    while(!done())
    {
        // printf("code size\t%llu  chars_cnt\t%llu",code_size,chars_cnt);
        switch (state)
        {
            case 0: state_0();  break;
            case 1: state_1();  break;
            case 2: state_2();  break;
            case 3: state_3();  break;
            case 4: state_4();  break;
            case 5: state_5();  break;
            case 6: state_6();  break;
            case 7: state_7();  break;
            case 8: state_8();  break;
            case 9: state_9();  break;
            case 10: state_10();  break;
            case 11: state_11();  break;
            case 12: state_12();  break;
            case 13: state_13();  break;
            case 14: state_14();  break;
            case 15: state_15();  break;
            case 16: state_16();  break;
            case 17: state_17();  break;
            case 18: state_18();  break;
            case 19: state_19();  break;
            case 20: state_20();  break;
            case 21: state_21();  break;
            case 22: state_22();  break;
            case 23: state_23();  break;
            case 24: state_24();  break;
            case 25: state_25();  break;
            case 26: state_26();  break;
            case 27: state_27();  break;
            case 28: state_28();  break;
            case 29: state_29();  break;
            case 30: state_30();  break;
            case 31: state_31();  break;
            case 32: state_32();  break;
            case 33: state_33();  break;
            case 34: state_34();  break;
            case 35: state_35();  break;
            case 36: state_36();  break;
            case 37: state_37();  break;
            case 38: state_38();  break;
            case 39: state_39();  break;
        }
    }
    return 0;
}

void print_statistics()
{
    printf("-----------------------------\n");
    printf(" Words Analysis Statistics: \n");
    printf("-----------------------------\n");
    printf("* line count    \t%llu\n", line_cnt);
    printf("* character count\t%llu\n", chars_cnt);
    printf("* word count    \t%llu\n", words_cnt);
    printf("* operator count\t%llu\n", opts_cnt);
    printf("* constant count\t%llu\n", consts_cnt);
    printf("* identifier count\t%llu\n", ids_cnt);
    printf("* keywords count\t%llu\n", keywds_cnt);
    printf("* separator count\t%llu\n", septs_cnt);
    printf("* comment count \t%llu\n",cmts_cnt);
    printf("* blank count   \t%llu\n",blks_cnt);
    printf("* line feed count\t%llu\n",lfds_cnt);
    printf("* tab count     \t%llu\n", tabs_cnt);
    printf("* error count   \t%llu\n",errs_cnt);
    printf("-----------------------------\n");

}
```

- words_table.h

```
#ifndef _WORDS_TABLE_H_
#define _WORDS_TABLE_H_
#include <stdio.h>
#include <stdbool.h>
#define ulong unsigned long long int
#define uint  unsigned int
const static ulong max_entry = 1024 * 8;
const static uint value_max_len = 1024;

struct word
{
    // 单词的类别
    uint type;
    // 单词所在行数
    uint lineno;
    // 单词所在列数
    uint rowno;
    // 单词的值
    char value[value_max_len];
};

// 初始化单词表
int init_words_table();
// 向单词表中插入某个单词表项
int insert_table(struct word *unit);
// 打印单词表中的所有内容
int print_table();
#endif
```

- words_table.c

```
#include "words_table.h"

char *types[] = {"operator", "keyword", "constant",
            "identifier", "separator", "comment",
            "blankspace", "linefeed", "tab", "error"
        };

static struct word words_table[max_entry];
static uint current;

int init_words_table()
{
    current = 0;
    return 0;
}


int insert_table(struct word *unit)
{
    words_table[current] = *unit;
    current++;
    return 0;
}

int print_table()
{
    for(int i = 0; i < current; i++)
    {
        printf("%d:%d <%s,\"%s\">\n", words_table[i].lineno,
words_table[i].rowno, types[words_table[i].type], words_table[i].value);
    }
    return 0;
}
```

- analysis_state.c

```
#include "words_analysis.h"
#include "words_table.h"
#define IS_LETTER 65
#define IS_DIGIT 48

const static ulong buf_size = 1024 * 1024;
const static ulong tok_size = 1024;
static int fd;
static ulong code_size;
static char buffer[buf_size];
static char token[tok_size];
static ulong tok_len;
static char *begin;
static char *forward;
static struct word tempwd;

// 字符个数
ulong chars_cnt = 0;
// 行数
ulong line_cnt = 1;
// 单词个数
ulong words_cnt = 0;
// 常量个数
ulong consts_cnt = 0;
// 标识符个数
ulong ids_cnt = 0;
// 关键字个数
ulong keywds_cnt = 0;
// 运算符个数
ulong opts_cnt = 0;
// 分隔符个数
ulong septs_cnt = 0;
// 注释个数
ulong cmts_cnt = 0;
// 空格个数
ulong blks_cnt = 0;
// 换行符个数
ulong lfds_cnt = 0;
// 制表符个数
ulong tabs_cnt = 0;
// 错误个数
ulong errs_cnt = 0;
// 当前列号
ulong current_row = 1;
// 状态序号
uint state = 0;
// 当前读取的字符
char C;


bool is_letter()
{
```

```c
    if((C <= 'Z' && C >= 'A') || (C >= 'a' && C <= 'z') || C == '_')
    {
        return true;
    }
    return false;
}

bool is_digit()
{

    if(C <= '9' && C >= '0')
    {
        return true;
    }
    return false;
}

bool is_chr()
{
    if(C == '\n')
    {
        return false;
    }
    return true;
}

bool is_keywd()
{
    bool flag = true;
    for(int i = 0; i < keywds_table_size && flag; i++)
    {
        if(strcmp(token, keywds_table[i]) == 0)
        {
            flag = false;
        }
    }
    if(flag == false)
    {
        return true;
    }
    return false;
}

int init_buffer(char *filepath)
{
    // 打开文件
    fd = open(filepath, O_RDONLY);
    // 读取文件数据
    code_size = read(fd, buffer, buf_size);
    // 初始化开始和向前指针
    tok_len = 0;
    begin = buffer;
    forward = begin;
    // 关闭文件
    close(fd);
    return 0;
}


int get_char()
{
    C = *forward;
    forward++;
    chars_cnt++;
    current_row++;
    if(chars_cnt >= code_size)
    {
        return -1;
    }
    return 0;
}

int cat()
{
    token[tok_len] = C;
    tok_len++;
    return 0;
}

int fetch_word(uint type)
{
    switch (type)
    {
        case OPERATOR:  opts_cnt++; words_cnt++;    break;
        case KEYWORD:   keywds_cnt++; words_cnt++;  break;
        case CONSTANT:  consts_cnt++; words_cnt++;  break;
        case ID:    ids_cnt++; words_cnt++;  break;
        case SEPARATOR: septs_cnt++; words_cnt++;    break;
        case COMMENT:   cmts_cnt++; break;
        case BLANK: blks_cnt++; break;
        case FEED:  lfds_cnt++; break;
        case TAB:   tabs_cnt++; break;
        case ERROR: errs_cnt++; break;
    }
    tempwd.type = type;
    tempwd.lineno = line_cnt;
    tempwd.rowno = current_row;
    strcpy(tempwd.value, token);
    insert_table(&tempwd);
    memset(token, 0, tok_len);
    tok_len = 0;
    return 0;
}
```

```
int main(int argc, char *argv[])
{
    if(argc != 3 || strcmp(argv[1],"-s"))
    {
        printf("arguement error!\n");
        printf("format: -s ${source filepath}!\n");
        return -1;
    }
    init_buffer(argv[2]);
    init_words_table();
    analysis();
    print_table();
    print_statistics();
    return 0;
}

char branch()
{
    if(is_letter())
    {
        return IS_LETTER;
    }
    else if(is_digit())
    {
        return IS_DIGIT;
    }
    return C;
}

int retract()
{
    forward--;
    current_row--;
    chars_cnt--;
    return 0;
}

bool done()
{
    if(chars_cnt <= code_size)
    {
        return false;
    }
    return true;
}

int analysis()
{
    state = 0;
    while(!done())
    {
        switch (state)
        {
            case 0: state_0();  break;
            case 1: state_1();  break;
            case 2: state_2();  break;
            case 3: state_3();  break;
            case 4: state_4();  break;
            case 5: state_5();  break;
            case 6: state_6();  break;
            case 7: state_7();  break;
            case 8: state_8();  break;
            case 9: state_9();  break;
            case 10: state_10();  break;
            case 11: state_11();  break;
            case 12: state_12();  break;
            case 13: state_13();  break;
            case 14: state_14();  break;
            case 15: state_15();  break;
            case 16: state_16();  break;
            case 17: state_17();  break;
            case 18: state_18();  break;
            case 19: state_19();  break;
            case 20: state_20();  break;
            case 21: state_21();  break;
            case 22: state_22();  break;
            case 23: state_23();  break;
            case 24: state_24();  break;
            case 25: state_25();  break;
            case 26: state_26();  break;
            case 27: state_27();  break;
            case 28: state_28();  break;
            case 29: state_29();  break;
            case 30: state_30();  break;
            case 31: state_31();  break;
            case 32: state_32();  break;
            case 33: state_33();  break;
            case 34: state_34();  break;
            case 35: state_35();  break;
            case 36: state_36();  break;
            case 37: state_37();  break;
            case 38: state_38();  break;
            case 39: state_39();  break;
        }
    }
    return 0;
}

void print_statistics()
{
    printf("-----------------------------\n");
    printf(" Words Analysis Statistics: \n");
    printf("-----------------------------\n");
    printf("* line count    \t%llu\n", line_cnt);
    printf("* character count\t%llu\n", chars_cnt);
    printf("* word count    \t%llu\n", words_cnt);
    printf("* operator count\t%llu\n", opts_cnt);
    printf("* constant count\t%llu\n", consts_cnt);
    printf("* identifier count\t%llu\n", ids_cnt);
    printf("* keywords count\t%llu\n", keywds_cnt);
    printf("* separator count\t%llu\n", septs_cnt);
    printf("* comment count \t%llu\n",cmts_cnt);
    printf("* blank count   \t%llu\n",blks_cnt);
    printf("* line feed count\t%llu\n",lfds_cnt);
    printf("* tab count     \t%llu\n", tabs_cnt);
    printf("* error count   \t%llu\n",errs_cnt);
    printf("-----------------------------\n");

}
```

- 这里给出测试用例：
- example.c

```
/*  example.c  */
double a = 1.e1;
double b = 1.e2;
// error
double c = 1.e;
// main
int main(void)
{
    a = a * b;
    a = a + b;
}
```

- 给出编译运行脚本
- compile-C.sh

```
gcc words_analysis.c words_table.c analysis_state.c -o words_analysis
./words_analysis
```

- 运行结果：

```
1:18 <comment,"/*  example.c  */">
1:19 <linefeed,"
">
2:7 <keyword,"double">
2:8 <blankspace," ">
2:9 <identifier,"a">
2:10 <blankspace," ">
2:11 <operator,"=">
2:12 <blankspace," ">
2:16 <constant,"1.e1">
2:17 <separator,";">
```

```
2:18 <linefeed,"
">
3:7 <keyword,"double">
3:8 <blankspace," ">
3:9 <identifier,"b">
3:10 <blankspace," ">
3:11 <operator,"=">
3:12 <blankspace," ">
3:16 <constant,"1.e2">
3:17 <separator,";">
3:18 <linefeed,"
">
5:1 <comment,"// error
">
5:7 <keyword,"double">
5:8 <blankspace," ">
5:9 <identifier,"c">
5:10 <blankspace," ">
5:11 <operator,"=">
5:12 <blankspace," ">
5:16 <error,"1.e;">
5:17 <linefeed,"
">
7:1 <comment,"// main
">
7:4 <keyword,"int">
7:5 <blankspace," ">
7:9 <identifier,"main">
7:10 <operator,"(">
7:14 <keyword,"void">
7:15 <operator,")">
7:16 <linefeed,"
">
8:2 <operator,"{">
8:3 <linefeed,"
">
9:2 <blankspace," ">
9:3 <blankspace," ">
9:4 <blankspace," ">
9:5 <blankspace," ">
9:6 <identifier,"a">
9:7 <blankspace," ">
9:8 <operator,"=">
9:9 <blankspace," ">
9:10 <identifier,"a">
9:11 <blankspace," ">
9:12 <operator,"*">
9:13 <blankspace," ">
9:14 <identifier,"b">
9:15 <separator,";">
9:16 <linefeed,"
">
10:2 <blankspace," ">
10:3 <blankspace," ">
10:4 <blankspace," ">
10:5 <blankspace," ">
10:6 <identifier,"a">
10:7 <blankspace," ">
10:8 <operator,"=">
10:9 <blankspace," ">
10:10 <identifier,"a">
10:11 <blankspace," ">
10:12 <operator,"+">
10:13 <blankspace," ">
10:14 <identifier,"b">
10:15 <separator,";">
10:16 <linefeed,"
">
11:2 <operator,"}">
-----------------------------
 Words Analysis Statistics:
-----------------------------
* line count            11
* character count       134
* word count            32
* operator count        11
* constant count        2
* identifier count      10
* keywords count        5
* separator count       4
* comment count         3
* blank count           26
* line feed count       8
* tab count             0
* error count           1
-----------------------------
```

以上是使用C语言编写的词法分析程序，现在使用LEX编写词法分析器生成程序。

这里按照C语言语法给出各种记号的正则表达式：

```
/*  基本元素 basic  */
  // 换行符和空白符
  delim   [ \n\t]
  // 空白区域
  ws      [delim]+
  // 字母和下划线
  letter  [A-Za-z_]
  // 数字
  digit   [0-9]


/*  常量 constant  */
  // 定点数
  number  [+-]?{digit}+([\.]{digit}+)?([Ee][+-]?{digit}+)?
  // 字符串
  str     ("[\s\S]*")
  // 字符
  chr     ('[\s\S]?')


/*  标识符 identifier  */
id      {letter}[{letter}{digit}]*


/*  运算符 operator  */
  // +,-,*,/,(,){,},%,&,|,^,!,~,=,<,>,<=,>=,==,:
  // 由于运算符语法是固定的，故不需要使用正则表达式描述，直接使用字符串描述即可

/*  关键字 keyword  */
  // if,else,when,for,do,void,unsigned,char,short,int,float,long,double,return,
  // switch,case,break,static,extern,const,continue
  // 由于关键字语法是固定的，故不需要使用正则表达式描述，直接使用字符串描述即可


/*  分隔符 separator  */
  // ,和;
  // 由于分隔符语法是固定的，故不需要使用正则表达式描述，直接使用字符串描述即可


/*  注释 comment  */
  // 单行注释
  sgl_cmt   (//[\s\S]*)
  // 多行注释，限制符后跟? ，表示最短匹配
  mul_cmt   (/\*(.|\s)*?\*/)
```

这里给出LEX程序：

- words_analysis.l

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

/*------ relation operators ------*/
#define LT      1
#define LE      2
#define GT      3
#define GE      4
#define EQ      5

/*------ assign operators ------*/
#define AS      6


/*------ algorithm operators ------*/
```

```
#define ADD     7
#define DEC     8
#define MUL     9
#define DIV     10
#define LB      11
#define RB      12
#define BLB     13
#define BRB     14
#define AND     15
#define OR      16
#define NOT     17
#define XOR     18
#define REVS    19
#define SQUT    20
#define QUT     21
#define MLB     22
#define MRB     23
#define SHL     24
#define SHR     25
#define COLON   26
/*------ keywords ------*/
#define IF      30
#define ELSE    31
#define WHILE   32
#define SWITCH  33
#define CASE    34
#define BREAK   35

#define FOR     36
#define VOID    37
#define UNSIG   38
#define CHAR    39
#define SHORT   40
#define INT     41
#define FLOAT   42
#define LONG    43
#define DOUBLE  44
#define STATIC  45
#define EXTERN  46
#define CONTIU  47

/*------ constant ------*/
#define NUM     50
#define STR     51
#define CHR     52

/*------ whitespace ------*/
#define WS      53


/*------ identifier ------*/
#define ID      54
```

```
/*------ comment ------*/
#define SCMT    55
#define MCMT    56

/*------ separator ------*/
#define SEMCOL  57
#define COMMA   58

#define ILEG    90


// 行数
int line_cnt = 0;
// 字符个数
int chars_cnt = 0;
// 单词个数
int words_cnt = 0;
// 常量个数
int consts_cnt = 0;
// 标识符个数
int ids_cnt = 0;
// 关键字个数
int keywds_cnt = 0;
// 运算符个数
int opts_cnt = 0;
// 分隔符个数
int septs_cnt = 0;
// 注释个数
int cmts_cnt = 0;
// 空白符个数
int ws_cnt = 0;
// 其他无法识别符号数
int ilegs_cnt = 0;
%}
%option yylineno
/*------ Regular Expressions ------*/

delim       [ \t\n]
ws          {delim}+
digit       [0-9]
letter      [A-Za-z_]
id          {letter}({letter}|{digit})*
/*  [+-]?[0-9]+([\.][0-9]+)?([Ee][+-]?[0-9]+)?   */
/* number      [+-]?{digit}+([\.]{digit})?([Ee][+-]?[{digit}+)? */
number      [+-]?[0-9]+[.]?([0-9]+)?([Ee][+-]?[0-9]+)?
str         (\"(.*)\")
chr         (\'[.]\')

sgl_cmt     (\/\/.*[\n])
mul_cmt     (\/\*((.|\n)*?)\*\/)
```

```
others5     [^0-9+-]
others6     [^0-9]
illeg5      [+-]?[0-9]+[.]?([0-9]+)?([Ee]{others5})?
illeg6      [+-]?[0-9]+[.]?([0-9]+)?([Ee][+-]?{others6})?


/*------ modes and operations ------*/
%%
"<"         {return (LT);}
"<="        {return (LE);}
">"         {return (GT);}
">="        {return (GE);}
"=="        {return (EQ);}
"<<"        {return (SHL);}
">>"        {return (SHR);}
"+"         {return (ADD);}
"-"         {return (DEC);}
"*"         {return (MUL);}
"/"         {return (DIV);}
"("         {return (LB);}
")"         {return (RB);}
"{"         {return (BLB);}
"}"         {return (BRB);}
"&"         {return (AND);}
"|"         {return (OR);}
"!"         {return (NOT);}
"^"         {return (XOR);}
"~"         {return (REVS);}
"["         {return (MLB);}
"]"         {return (MRB);}
"\""        {return (QUT);}
"'"         {return (SQUT);}
":"         {return (COLON);}
"="         {return (AS);}

"if"        {return (IF);}
"else"      {return (ELSE);}
"while"     {return (WHILE);}
"for"       {return (FOR);}
"switch"    {return (SWITCH);}
"case"      {return (CASE);}
"break"     {return (BREAK);}
"void"      {return (VOID);}
"unsigned"  {return (UNSIG);}
"char"      {return (CHAR);}
"short"     {return (SHORT);}
"int"       {return (INT);}
"float"     {return (FLOAT);}
"long"      {return (LONG);}
"double"    {return (DOUBLE);}

";"         {return (SEMCOL);}
```

```
","         {return (COMMA);}


{ws}        {return (WS);}


{number}    {return (NUM);}
{str}       {return (STR);}
{chr}       {return (CHR);}


{id}        {return (ID);}


{sgl_cmt}   {return (SCMT);}
{mul_cmt}   {return (MCMT);}

{illeg5}    {return (ILEG);}
{illeg6}    {return (ILEG);}
%%

void word_storge(int c)
{
    switch(c)
    {
        case LT:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n", yylineno,
yytext);
            break;
        case LE:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n", yylineno,
yytext);
            break;
        case GT:
            break;
        case GE:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n", yylineno,
yytext);
            break;
        case EQ:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n", yylineno,
yytext);
            break;
        case SHL:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case SHR:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case ADD:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
            break;
        case DEC:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case MUL:
            break;
        case DIV:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case LB:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n", yylineno,
yytext);
            break;
        case RB:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n", yylineno,
yytext);
            break;
        case BLB:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case BRB:
            break;
        case AND:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case OR:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n", yylineno,
yytext);
            break;
        case NOT:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case XOR:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case REVS:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case AS:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n", yylineno,
yytext);
            break;
        case SQUT:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case QUT:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case MLB:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case MRB:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;
        case COLON:opts_cnt++;fprintf(stdout, "%d: <operator:\t\"%s\">\n",
yylineno, yytext);
            break;

        case IF:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
```

```
            break;
        case ELSE:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case WHILE:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case FOR:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case SWITCH:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case CASE:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case BREAK:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case VOID:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case UNSIG:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case CHAR:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case SHORT:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case INT:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case FLOAT:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case LONG:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case DOUBLE:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case STATIC:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case EXTERN:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case CONTIU:keywds_cnt++;fprintf(stdout, "%d: <keyword:\t\"%s\">\n",
yylineno, yytext);
            break;
        case SEMCOL:septs_cnt++;fprintf(stdout, "%d: <separator:\t\"%s\">\n", 
yylineno, yytext);
            break;
        case COMMA:septs_cnt++;fprintf(stdout, "%d: <separator:\t\"%s\">\n", 
yylineno, yytext);
            break;

        case WS:ws_cnt = ws_cnt + yyleng;fprintf(stdout, "%d: 
<whitespace:\t\"%s\">\n", yylineno, yytext);
            break;

        case NUM:consts_cnt++;fprintf(stdout, "%d: <constant:\t\"%s\">\n", 
yylineno, yytext);
            break;
        case STR:consts_cnt++;fprintf(stdout, "%d: <constant:\t\"%s\">\n", 
yylineno, yytext);
            break;
        case CHR:consts_cnt++;fprintf(stdout, "%d: <constant:\t\"%s\">\n", 
yylineno, yytext);
            break;

        case ID:ids_cnt++;fprintf(stdout, "%d: <identifier:\t\"%s\">\n", 
yylineno, yytext);
            break;

        case SCMT:cmts_cnt++;fprintf(stdout, "%d: <comment:\t\"%s\">\n", 
yylineno, yytext);
            break;
        case MCMT:cmts_cnt++;fprintf(stdout, "%d: <comment:\t\"%s\">\n", 
yylineno, yytext);
            break;
        case ILEG:ilegs_cnt++; fprintf(stdout, "%d: <illegal:\t\"%s\">\n", 
yylineno, yytext);
            break;
    }
}

int yywrap()
{
    return 1;
}

void print_info()
{
    printf("----------------------------\n");
    printf("+     lines count:     \t%d\n", line_cnt);
    printf("+     words count:     \t%d\n", words_cnt);
    printf("+     chars count:     \t%d\n", chars_cnt);
    printf("+     constant count:  \t%d\n", consts_cnt);
    printf("+     comment count:   \t%d\n", cmts_cnt);
    printf("+     keyword count:   \t%d\n", keywds_cnt);
    printf("+     operator count:  \t%d\n", opts_cnt);
    printf("+     separator count: \t%d\n", septs_cnt);
    printf("+     identifier count:\t%d\n", ids_cnt);
    printf("+     whitespace count:\t%d\n", ws_cnt);
  printf("+     illegal count:\t%d\n", ilegs_cnt);
    printf("----------------------------\n");
}


int main(void)
{
    yyin = fopen("example.c","r");
    int c = yylex();
    while(c)
    {
        word_storge(c);
        if(c != WS)
        {
            words_cnt++;
        }
        chars_cnt = chars_cnt + yyleng;
        c = yylex();
    }
    line_cnt = yylineno;
    print_info();
    fclose(yyin);
    return 0;
}
```

- example.c

```
/*  example.c  */
double a = 1.e1;
double b = 1.e2;
// error
double c = 1.e;
// main
int main(void)
{
    a = a * b;
    a = a + b;
}
```

- 编译运行脚本：`sh compile-lex.sh`
- compile-lex.sh

```
flex words_analysis.l
gcc -o a.out lex.yy.c
./a.out
```

- 运行结果:

```
1: <comment:    "/*  example.c  */">
2: <whitespace: "
">
2: <keyword:    "double">
2: <whitespace: " ">
2: <identifier: "a">
2: <whitespace: " ">
2: <operator:   "=">
2: <whitespace: " ">
2: <constant:   "1.e1">
2: <separator:  ";">
3: <whitespace: "
">
3: <keyword:    "double">
3: <whitespace: " ">
3: <identifier: "b">
3: <whitespace: " ">
3: <operator:   "=">
3: <whitespace: " ">
3: <constant:   "1.e2">
3: <separator:  ";">
4: <whitespace: "
">
5: <comment:    "// error
">
5: <keyword:    "double">
5: <whitespace: " ">
5: <identifier: "c">
5: <whitespace: " ">
5: <operator:   "=">
5: <whitespace: " ">
5: <illegal:    "1.e;">
6: <whitespace: "
">
7: <comment:    "// main
">
7: <keyword:    "int">
7: <whitespace: " ">
7: <identifier: "main">
7: <operator:   "(">
7: <keyword:    "void">
7: <operator:   ")">
8: <whitespace: "
">
8: <operator:   "{">
9: <whitespace: "
    ">
9: <identifier: "a">
9: <whitespace: " ">
9: <operator:   "=">
```

```
9: <whitespace: " ">
9: <identifier: "a">
9: <whitespace: " ">
9: <whitespace: " ">
9: <identifier: "b">
9: <separator:  ";">
10: <whitespace:        "
    ">
10: <identifier:        "a">
10: <whitespace:        " ">
10: <operator:  "=">
10: <whitespace:        " ">
10: <identifier:        "a">
10: <whitespace:        " ">
10: <operator:  "+">
10: <whitespace:        " ">
10: <identifier:        "b">
10: <separator: ";">
11: <whitespace:        "
">
----------------------------
 Words Analysis Statistics:
----------------------------
+     lines count:      11
+     words count:      36
+     chars count:      133
+     constant count:   2
+     comment count:    3
+     keyword count:    5
+     operator count:   9
+     separator count:  4
+     identifier count: 10
+     whitespace count: 34
+     illegal count:    1
----------------------------
```