词法分析、语法分析程序实验

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实验目的

扩充已有的样例语言TINY，为扩展TINY语言TINY＋构造词法分析和语法分析程序，从而掌握词法分析和语法分析程序的构造方法

实验内容

了解样例语言TINY及TINY编译器的实现，了解扩展TINY语言TINY＋，用EBNF描述TINY＋的语法，用C语言扩展TINY的词法分析和语法分析程序，构造TINY＋的语法分析器。

实验要求

将TINY＋源程序翻译成对应的TOKEN序列，并能检查一定的词法错误。将TOKEN序列转换成语法分析树，并能检查一定的语法错误。

实验步骤

扩充语言

Tiny语言参考https://jlu.myweb.cs.uwindsor.ca/214/language.htm。再其上增加了几个功能：

1. while循环语句
2. 使用and 和 or的表达式
3. bool表达式增加大于小于，大于等于，小于等于的情况
4. 支持负整数和负实数

增加后变化的产生式如下：

```
Statement -> Block
    | LocalVarDecl
    | AssignStmt
    | ReturnStmt
    | IfStmt
    | WriteStmt
    | ReadStmt
    | WhileStmt
    ;
WhileStmt -> WHILE '(' BoolExpression ')' Statement
    ;
BoolExpression -> Expression Eq Expression
    | Expression Ne Expression
    | Expression '>' Expression
    | Expression '<' Expression
    | Expression Le Expression
    | Expression Ge Expression
    | BoolExpression And BoolExpression
    | BoolExpression Or BoolExpression
    ;
```

本次实验使用了linux下的flex和bison。

语法树定义

语法树是与分析部分无关的内容，在语法分析时作为副作用顺便生成语法树。包含三个功能，创建，遍历和删除。由于语法树是多叉树，而且分支个数不确定，因此使用二叉树来实现。具体做法是同一层次的其他叶节点按顺序依次生成右叶节点。下一层的叶节点生成在当前节点的左叶节点。定义如下：

```c
struct AST
{
    int lineNo;
    char* name;
    struct AST *leftNode;
    struct AST *rightNode;
    union
    {
        char* idName;
        int intVal;
        float floatVal;
    };
};
```

标识符这样的语法单元在打印时需要打印具体值，因此使用union保存。

创建语法树节点

由于分支个数不确定，我使用了变长参数的函数。

```c
struct AST *createASTNode(char *name, int num, ...)
{
    va_list valist;
    struct AST *root = (struct AST *)malloc(sizeof(struct AST));
    root->idName=NULL;
    root->leftNode=NULL;
    root->rightNode=NULL;
    //examine if alloc failed
    if (!root)
    {
        yyerror("RUN OUT OF MEMORY.");
        exit(0);
    }
    root->name = name;
    // init variable args
    va_start(valist, num);
    if (num > 0)
    {
        // get next argument
        struct AST *child = va_arg(valist, struct AST *);
        root->leftNode = child;
        // synthesize lineNo property from child
        root->lineNo = child->lineNo;
        if (num > 1)
        {
            for (int i = 0; i < num - 1; ++i)
            {
                // generate other branch as child for tree of same level(use
binary tree to simulate tree of multiple branch)
                child->rightNode = va_arg(valist, struct AST *);
                child = child->rightNode;
            }
        }
    }
    else
    {
        int arg = va_arg(valist, int);
        root->lineNo = arg;
        /* 3 case of terminal:
        *   string
        *   int
        *   float
        */
        if (!strcmp(root->name, "Identifier") || !strcmp(root->name,
"StringConstant"))
        {
            root->idName = (char *)malloc(sizeof(char) * BUFFSIZE);
            strcpy(root->idName, yytext);
        }
        else if (!strcmp(root->name, "IntConstant"))
            root->intVal = atoi(yytext);
        else if (!strcmp(root->name, "RealConstant"))
            root->floatVal = atof(yytext);
    }
    return root;
}
```

遍历

遍历我使用的是扁平化的显示方法，同一层次的节点都对应同样大小的缩进，使用前序遍历。

```
void traverse(struct AST *root, int level)
{
    if (!root)
        return;
    for (int i = 0; i < level; ++i)
        printf("\t");
    if (root->lineNo != -1)
    {
        printf("%s ", root->name);
        if ((!strcmp(root->name, "Identifier")))
            printf(":%s ", root->idName);
        else if (!strcmp(root->name, "StringConstant"))
            printf(":%s", root->idName);
        else if (!strcmp(root->name, "IntConstant"))
            printf(":%d", root->intVal);
        else if (!strcmp(root->name, "Real"))
            printf(":%f", root->floatVal);
        else
            printf("(%d)", root->lineNo);
    }
    printf("\n");
    traverse(root->leftNode, level + 1);
    traverse(root->rightNode, level);
}
```

删除

使用后序遍历。

```
void destroy(struct AST *root){
    if(!root)return;
    if(root->leftNode)
        destroy(root->leftNode);
    if(root->rightNode)
        destroy(root->rightNode);
    free(root);
```

语法分析

虽然原理上是先词法分析再语法分析，但是实际上是从产生式才知道需要哪些token，所以先做语法分析。

将所有产生式转换为对应的语法，并添加生成语法树的语义动作。调用上面实现的创建函数即可。产生式的左端是非终端符号。右端出现的终端符号都需要定义为token，**无论**是终端符号还是非终端符号都需要声明为**语法树节点类型**。错误处理可以使用error语法，在对应的语法下方增加一个产生式，用yyerror输出错误信息。

syn_tree.y代码如下，%left代表运算符的优先级，实际上出现冲突时bison也会自动选择一种处理方式：

```
%{
#include<stdio.h>
#include "syn_tree.h"
%}
%union{
struct AST* a;
}

%token <a> Le  Ge  Eq  Ne Def  And  Or  IntConstant RealConstant REAL
 StringConstant  Identifier  Void  INT  WHILE  If  Else  Return Operator
BEGIN_KEY END_KEY MAIN WRITE READ
%type  <a> Programs Program MethodDecl FormalParams FormalParam Block
Statements Statement LocalVarDecl
Type AssignStmt  ReturnStmt IfStmt WriteStmt ReadStmt  BoolExpression
Expression MultiplicativeExpr
PrimaryExpr ActualParams WhileStmt

%left '+' '-'
%left '*' '/'
%left And Or

%%
Programs :
    Program{$$=createASTNode("Programs",1,$1);printf("Syntax tree
:\n");traverse($$,0);destroy($$);}
    ;
Program : MethodDecl {$$=createASTNode("Program",1,$1);}
    |MethodDecl Program {$$=createASTNode("Program",2,$1,$2);}
    ;

```

```
MethodDecl : Type Identifier '(' FormalParams ')' Block{$$=createASTNode("MethodDecl",4,$1,$2,$4,$6);}
    | Type MAIN Identifier '(' FormalParams ')' Block{$$=createASTNode("MethodDecl",5,$1,$2,$3,$5,$7);}
    ;
FormalParams : FormalParams  ',' FormalParam{$$=createASTNode("FormalParams",2,$1,$3);}
    | FormalParam{$$=createASTNode("FormalParams",1,$1);}
    | /* empty */{$$=createASTNode("FormalParams",0,-1);}
    ;
FormalParam : Type Identifier{$$=createASTNode("FormalParam",2,$1,$2);}
    ;


Block : BEGIN_KEY Statements END_KEY {$$=createASTNode("Block",3,$1,$2,$3);}
    | error  { yyerror("keyword typo? \n"); }
    ;

Statements :Statements Statement{$$=createASTNode("Statements",2,$1,$2);}
    | Statement{$$=createASTNode("Statements",1,$1);}
    ;

Statement : Block{$$=createASTNode("Statement",1,$1);}
    | LocalVarDecl{$$=createASTNode("Statement",1,$1);}
    | AssignStmt{$$=createASTNode("Statement",1,$1);}
    | ReturnStmt{$$=createASTNode("Statement",1,$1);}
    | IfStmt{$$=createASTNode("Statement",1,$1);}
    | WriteStmt{$$=createASTNode("Statement",1,$1);}
    | ReadStmt{$$=createASTNode("Statement",1,$1);}
    | WhileStmt{$$=createASTNode("Statement",1,$1);}
    ;



LocalVarDecl : Type Identifier ';' {$$=createASTNode("LocalVarDecl",2,$1,$2);}
    | Type AssignStmt  {$$=createASTNode("LocalVarDecl",2,$1,$2);}
    | Type error ';' { yyerror("Maybe missing Identifier? \n"); }
    ;

WhileStmt : WHILE '(' BoolExpression ')' Statement{$$=createASTNode("WhileStmt",3,$1,$3,$5);}
    ;


Type : INT{$$=createASTNode("Type",1,$1);}
    | REAL{$$=createASTNode("Type",1,$1);}
    | StringConstant{$$=createASTNode("Type",1,$1);}
    ;

AssignStmt  : Identifier Def Expression ';'{$$=createASTNode("AssignStmt",3,$1,$2,$3);}
    |  Identifier Def StringConstant ';'{$$=createASTNode("AssignStmt",3,$1,$2,$3);}
    | error ';' { yyerror("Maybe missing ';'? \n"); }
    ;
ReturnStmt : Return Expression ';'{$$=createASTNode("ReturnStmt",2,$1,$2);}
```

```
    ;
IfStmt : If '(' BoolExpression ')' Statement{$$=createASTNode("IfStmt",3,$1,$3,$5);}
    | If '(' BoolExpression ')' Statement Else Statement{$$=createASTNode("IfStmt",5,$1,$3,$5,$6,$7);}
    ;
WriteStmt : WRITE '(' Expression ',' StringConstant ')' ';'{$$=createASTNode("WriteStmt",3,$1,$3,$5);}
    | WRITE error ';' { yyerror("Maybe missing Identifier or StringConstant? \n"); }
    ;
ReadStmt  : READ '(' Identifier ',' StringConstant ')' ';'{$$=createASTNode("ReadStmt",3,$1,$3,$5);}
    | READ error ';' { yyerror("Maybe missing Identifier or StringConstant? \n"); }
    ;

BoolExpression : Expression Eq Expression {$$=createASTNode("BoolExpression",3,$1,$2,$3);}
    | Expression Ne Expression {$$=createASTNode("BoolExpression",3,$1,$2,$3);}
    | Expression '>' Expression{$$=createASTNode("BoolExpression",3,$1,createASTNode("Operator(>)",0,yylineno),$3);}
    | Expression '<' Expression{$$=createASTNode("BoolExpression",3,$1,createASTNode("Operator(<)",0,yylineno),$3);}
    | Expression Le Expression{$$=createASTNode("BoolExpression",3,$1,$2,$3);}
    | Expression Ge Expression{$$=createASTNode("BoolExpression",3,$1,$2,$3);}
    | BoolExpression And BoolExpression{$$=createASTNode("BoolExpression",3,$1,$2,$3);}
    | BoolExpression Or BoolExpression{$$=createASTNode("BoolExpression",3,$1,$2,$3);}
    ;

Expression : Expression  '+' MultiplicativeExpr {$$=createASTNode("Expression",3,$1,createASTNode("Operator(+)",0,yylineno),$3);}
    | Expression '-' MultiplicativeExpr{$$=createASTNode("Expression",3,$1,createASTNode("Operator(-)",0,yylineno),$3);}
    | MultiplicativeExpr{$$=createASTNode("Expression",1,$1);}
    | error ';' { yyerror("Maybe missing ';' or operand? \n"); }
    ;
MultiplicativeExpr : MultiplicativeExpr '*' PrimaryExpr{$$=createASTNode("MultiplicativeExpr",3,$1,createASTNode("Operator(*)",0,yylineno),$3);}
    | MultiplicativeExpr '/'  PrimaryExpr{$$=createASTNode("MultiplicativeExpr",3,$1,createASTNode("Operator(/)",0,yylineno),$3);}
    | PrimaryExpr{$$=createASTNode("MultiplicativeExpr",1,$1);}
    ;
PrimaryExpr : IntConstant {$$=createASTNode("PrimaryExpr",1,$1);}
    | RealConstant {$$=createASTNode("PrimaryExpr",1,$1);}
    | Identifier {$$=createASTNode("PrimaryExpr",1,$1);}
    | '(' Expression ')' {$$=createASTNode("PrimaryExpr",1,$2);}
    | Identifier '(' ActualParams ')'{$$=createASTNode("PrimaryExpr",2,$1,$3);}
    ;
ActualParams : ActualParams  ',' Expression{$$=createASTNode("ActualParams",2,$1,$3);}
    |  Expression{$$=createASTNode("ActualParams",1,$1);}
    ;
%%
```

词法分析

词法分析用到的token都在语法分析时决定了，因此将其声明在规则中，在后面追加一个语法块决定捕获到token时执行的动作，对于生成语法树来说需要生成叶节点供语法分析时使用。对于单纯的词法分析只需要返回token枚举。lexer.l代码如下：

```
%{
#include "syn_tree.h"
#include "syn_tree.tab.h"
int cur_line_num = 1;
void lex_error(char* msg, int line);
%}
%option yylineno

POSITIVE            ([0-9]+)
INT                 [+-]?{POSITIVE}
REAL                {INT}.{POSITIVE}
STRING              (\042[^\042\n]*\042)
OPERATOR            ([+*-/%=,;!<>(){}])
SINGLE_COMMENT1     ("//"[^\n]*)
SINGLE_COMMENT2     (\/\*(?:[^\*]|\*+[^\/\*])*\*+\/)
Identifier          ([_a-zA-Z][_a-zA-Z0-9]*)

%%

[\n]                { cur_line_num++;                       }
[ \t\r\a]+          { /* ignore all spaces */               }
{SINGLE_COMMENT1}   { /* skip for single line comment */    }
{SINGLE_COMMENT2}   { /* skip for single line commnet */    }

{OPERATOR}          { yylval.a=createASTNode("OP",0,yylineno);return yytext[0];       }

"<="                { yylval.a=createASTNode("Le",0,yylineno);return Le;    }
">="                { yylval.a=createASTNode("Ge",0,yylineno);return Ge;    }
":="                { yylval.a=createASTNode("Def",0,yylineno);return Def;  }
"=="                { yylval.a=createASTNode("Eq",0,yylineno);return Eq;    }
"!="                { yylval.a=createASTNode("Ne",0,yylineno);return Ne;    }
```

```
"&&"                    { yylval.a=createASTNode("And",0,yylineno);return And;                    }
"||"                    { yylval.a=createASTNode("Or",0,yylineno);return Or;                    }
"INT"                   { yylval.a=createASTNode("INT",0,yylineno);return INT;                    }
"REAL"                  { yylval.a=createASTNode("REAL",0,yylineno);return REAL;                    }
"WHILE"                 { yylval.a=createASTNode("WHILE",0,yylineno);return WHILE;                    }
"IF"                    { yylval.a=createASTNode("If",0,yylineno);return If;                    }
"ELSE"                  { yylval.a=createASTNode("Else",0,yylineno);return Else;                    }
"RETURN"                { yylval.a=createASTNode("Return",0,yylineno);return Return;                    }
"WRITE"                 { yylval.a=createASTNode("WRITE",0,yylineno);return WRITE;                    }
"READ"                  { yylval.a=createASTNode("READ",0,yylineno);return READ;                    }
"BEGIN"                 { yylval.a=createASTNode("BEGIN",0,yylineno);return BEGIN_KEY;                    }
"END"                   { yylval.a=createASTNode("END",0,yylineno);return END_KEY;                    }
"MAIN"                  { yylval.a=createASTNode("MAIN",0,yylineno);return MAIN;                    }
{INT}                   { yylval.a=createASTNode("IntConstant",0,yylineno);return IntConstant;      }
{REAL}                  { yylval.a=createASTNode("RealConstant",0,yylineno);return RealConstant;    }
{STRING}                { yylval.a=createASTNode("StringConstant",0,yylineno);return StringConstant;}
{Identifier}            { yylval.a=createASTNode("Identifier",0,yylineno);return Identifier;         }

<<EOF>>                 { return 0;                     }

.                       { lex_error("Unrecognized content", cur_line_num);                    }

%%

void lex_error(char* msg, int line) {
    printf("\nError at line %-3d: %s\n\n", line, msg);
}

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

生成代码使用makefile，如下：

```
CC=gcc
TARGET= main
LEXER= lex
TESTFILE=test.cpp
```

```
all: $(TARGET) lex


lex_test: lex
    ./$(LEXER) < $(TESTFILE)

$(LEXER): lex_only.yy.c main.c
    $(CC) -o $@  $^ -DLEX

syn_test: $(TARGET) $(TESTFILE)
    ./$(TARGET) < $(TESTFILE)

$(TARGET): main.c syn_tree.tab.c lex.yy.c syn_tree.c

syn_tree.tab.c:syn_tree.y
    bison -d  $<

lex_only.yy.c: lex_only.l
    flex -o $@ $<

lex.yy.c: lexer.l
    flex $<

check:$(TARGET)
    valgrind --leak-check=full \
            --show-leak-kinds=all \
            --track-origins=yes \
            --verbose \
            --log-file=valgrind-out.txt \
            ./$(TARGET)<$(TESTFILE)

clean:
    rm valgrind-out.txt *.log *.tab.c *.yy.c *.tab.h $(LEXER) $(TARGET) 2> /dev/null || echo > /dev/null

```

实验结果

使用网站提供的测试代码，修改11行加入新特性。

```
 1  /** this is a comment line in the sample program **/
 2   INT f2(INT x, INT y )
 3   BEGIN
 4      INT z;
 5      z := x*x - y*y;
 6      RETURN z;
 7   END
 8   INT MAIN f1()
 9   BEGIN
10      INT x;
11      WHILE(x<3 && y>3) READ(x, "A41.input");
12      REAL y:=-2112.0;
13      READ(y, "A42.input");
14      INT z;
15      z := f2(x,y) + f2(y,x);
16      WRITE (z, "A4.output");
17   END
```

词法分析

使用下面的命令进行词法分析，

```
make lex_test > test.log
```

test.log中的结果如下：

```
flex -o lex_only.yy.c lex_only.l
gcc -o lex  lex_only.yy.c main.c -DLEX
./lex < test.cpp
(INT,INT)
(Identifier,f2)
((,()
(INT,INT)
(Identifier,x)
(,,,)
(INT,INT)
(Identifier,y)
(),))
(BEGIN_KEY,BEGIN)
(INT,INT)
(Identifier,z)
(;,;)
(Identifier,z)
(Def,:=)
(Identifier,x)
(*,*)
(Identifier,x)
(-,-)
(Identifier,y)
(*,*)
(Identifier,y)
(;,;)
(Return,RETURN)
(Identifier,z)
(;,;)
(END_KEY,END)
(INT,INT)
(MAIN,MAIN)
(Identifier,f1)
((,()
(),))
(BEGIN_KEY,BEGIN)
(INT,INT)
(Identifier,x)
(;,;)
(WHILE,WHILE)
((,()
(Identifier,x)
(<,<)
(IntConstant,3)
(And,&&)
(Identifier,y)
(>,>)
(IntConstant,3)
(),))
(READ,READ)
((,()
(Identifier,x)
(,,,)
(StringConstant,"A41.input")
(),))
(;,;)
(REAL,REAL)
(Identifier,y)
(Def,:=)
(RealConstant,-2112.0)
(;,;)
(READ,READ)
((,()
(Identifier,y)
(,,,)
(StringConstant,"A42.input")
(),))
(;,;)
(INT,INT)
(Identifier,z)
(;,;)
(Identifier,z)
(Def,:=)
(Identifier,f2)
((,()
(Identifier,x)
(,,,)
(Identifier,y)
(),))
(+,+)
(Identifier,f2)
((,()
(Identifier,y)
(,,,)
(Identifier,x)
(),))
(;,;)
(WRITE,WRITE)
((,()
(Identifier,z)
(,,,)
(StringConstant,"A4.output")
(),))
(;,;)
(END_KEY,END)
```

语法分析

使用下面的命令进行语法分析，

```
make syn_test >test.log
```

test.log中的结果如下：

```
flex lexer.l
gcc     main.c syn_tree.tab.c lex.yy.c syn_tree.c   -o main
./main < test.cpp
>Syntax tree :
Programs (2)
  Program (2)
    MethodDecl (2)
      Type (2)
        INT (2)
      Identifier :f2
      FormalParams (2)
        FormalParams (2)
          FormalParam (2)
            Type (2)
              INT (2)
            Identifier :x
        FormalParam (2)
          Type (2)
            INT (2)
          Identifier :y
      Block (3)
        BEGIN (3)
        Statements (4)
          Statements (4)
            Statements (4)
              Statement (4)
                LocalVarDecl (4)
                  Type (4)
                    INT (4)
                  Identifier :z
            Statement (5)
              AssignStmt (5)
                Identifier :z
                Def (5)
                Expression (5)
                  Expression (5)
                    MultiplicativeExpr (5)
                      MultiplicativeExpr (5)
                        PrimaryExpr (5)
                          Identifier :x
                      Operator(*) (5)
                      PrimaryExpr (5)
                        Identifier :x
                  Operator(-) (5)
                  MultiplicativeExpr (5)
                    MultiplicativeExpr (5)
                      PrimaryExpr (5)
                        Identifier :y
                    Operator(*) (5)
                    PrimaryExpr (5)
                      Identifier :y
          Statement (6)
            ReturnStmt (6)
              Return (6)
              Expression (6)
                MultiplicativeExpr (6)
                  PrimaryExpr (6)
```

```
                    Identifier :z
        END (7)
    Program (8)
      MethodDecl (8)
        Type (8)
          INT (8)
        MAIN (8)
        Identifier :f1

        Block (9)
          BEGIN (9)
          Statements (10)
            Statements (10)
              Statements (10)
                Statements (10)
                  Statements (10)
                    Statements (10)
                      Statements (10)
                        Statement (10)
                          LocalVarDecl (10)
                            Type (10)
                              INT (10)
                            AssignStmt (10)
                              Identifier :x
                              Def (10)
                              Expression (10)
                                MultiplicativeExpr (10)
                                  PrimaryExpr (10)
                                    RealConstant :-333.329987
                      Statement (11)
                        WhileStmt (11)
                          WHILE (11)
                          BoolExpression (11)
                            BoolExpression (11)
                              Expression (11)
                                MultiplicativeExpr (11)
                                  PrimaryExpr (11)
                                    Identifier :x
                              Operator(<) (11)
                              Expression (11)
                                MultiplicativeExpr (11)
                                  PrimaryExpr (11)
                                    IntConstant :3
                            And (11)
                            BoolExpression (11)
                              Expression (11)
                                MultiplicativeExpr (11)
                                  PrimaryExpr (11)
                                    Identifier :y
                              Operator(>) (11)
                              Expression (11)
                                MultiplicativeExpr (11)
                                  PrimaryExpr (11)
                                    IntConstant :3
                          Statement (11)
                            ReadStmt (11)
                              READ (11)
                              Identifier :x
                              StringConstant :"A41.input"
                    Statement (12)
                      LocalVarDecl (12)
                        Type (12)
                          REAL (12)
                        AssignStmt (12)
                          Identifier :y
                          Def (12)
                          Expression (12)
                            MultiplicativeExpr (12)
                              PrimaryExpr (12)
                                IntConstant :2112
                  Statement (13)
                    ReadStmt (13)
                      READ (13)
                      Identifier :y
                      StringConstant :"A42.input"
                Statement (14)
                  LocalVarDecl (14)
                    Type (14)
                      INT (14)
                    Identifier :z
              Statement (15)
                AssignStmt (15)
                  Identifier :z
                  Def (15)
                  Expression (15)
                    Expression (15)
                      MultiplicativeExpr (15)
                        PrimaryExpr (15)
                          Identifier :f2
                          ActualParams (15)
                            ActualParams (15)
                              Expression (15)
                                MultiplicativeExpr (15)
                                  PrimaryExpr (15)
                                    Identifier :x
                            Expression (15)
                              MultiplicativeExpr (15)
                                PrimaryExpr (15)
                                  Identifier :y
                    Operator(+) (15)
                    MultiplicativeExpr (15)
                      PrimaryExpr (15)
                        Identifier :f2
                        ActualParams (15)
                          ActualParams (15)
                            Expression (15)
                              MultiplicativeExpr (15)
                                PrimaryExpr (15)
                                  Identifier :y
                          Expression (15)
                            MultiplicativeExpr (15)
                              PrimaryExpr (15)
                                Identifier :x
            Statement (16)
              WriteStmt (16)
                WRITE (16)
```

```
                    Expression (16)
                      MultiplicativeExpr (16)
                        PrimaryExpr (16)
                          Identifier :z
                    StringConstant :"A4.output"
              END (17)

```

错误处理

词法错误处理

使用下面的代码进行错误处理测试，错误为：

1. 第10行的#3为非法串
2. 第13行漏了引号

```
 1  /** this is a comment line in the sample program **/
 2  INT f2(INT x, INT y )
 3  BEGIN
 4     INT z;
 5     z := x*x - y*y;
 6     RETURN z;
 7  END
 8  INT MAIN f1()
 9  BEGIN
10     INT #3;
11     WHILE(x<3 && y>3) READ(x, "A41.input");
12     INT y:=-2112.0;
13     READ(y, "A42.input);
14     INT z;
15     z := f2(x,y) + f2(y,x);
16     WRITE (z, "A4.output");
17  END
```

使用下面的命令进行测试

```
make lex_test > test.log
```

test.log中的结果如下：

```
flex -o lex_only.yy.c lex_only.l
gcc -o lex  lex_only.yy.c main.c -DLEX
./lex < test.cpp
(INT,INT)
(Identifier,f2)
((,()
(INT,INT)
(Identifier,x)
(,,,)
(INT,INT)
(Identifier,y)
(),))
(BEGIN_KEY,BEGIN)
(INT,INT)
(Identifier,z)
```

```
(;,;)
(Identifier,z)
(Def,:=)
(Identifier,x)
(*,*)
(Identifier,x)
(-,-)
(Identifier,y)
(*,*)
(Identifier,y)
(;,;)
(Return,RETURN)
(Identifier,z)
(;,;)
(END_KEY,END)
(INT,INT)
(MAIN,MAIN)
(Identifier,f1)
((,()
(),))
(BEGIN_KEY,BEGIN)
(INT,INT)

Error at line 10 : Unrecognized content

(IntConstant,3)
(;,;)
(WHILE,WHILE)
((,()
(Identifier,x)
(<,<)
(IntConstant,3)
(And,&&)
(Identifier,y)
(>,>)
(IntConstant,3)
(),))
(READ,READ)
((,()
(Identifier,x)
(,,,)
(StringConstant,"A41.input")
(),))
(;,;)
(INT,INT)
(Identifier,y)
(Def,:=)
(RealConstant,-2112.0)
(;,;)
(READ,READ)
((,()
(Identifier,y)
(,,,)

Error at line 13 : Unrecognized content

(Identifier,A42)
(.,.)
(Identifier,input)
(),))
(;,;)
(INT,INT)
(Identifier,z)
(;,;)
(Identifier,z)
(Def,:=)
(Identifier,f2)
((,()
(Identifier,x)
(,,,)
(Identifier,y)
(),))
(+,+)
(Identifier,f2)
((,()
(Identifier,y)
(,,,)
(Identifier,x)
(),))
(;,;)
(WRITE,WRITE)
((,()
(Identifier,z)
(,,,)

Error at line 16 : Unrecognized content

(Identifier,A4)
(.,.)
(Identifier,output)
(),))
(;,;)
(END_KEY,END)
```

可以发现，前面出现词法错误后，后面的词法分析结果也接连出现错误。

语法错误处理

在原来的代码中增加几个错误：

1. 11行没有第二个参数，即READ函数对应的文件的标识符。
2. 14行缺少变量名
3. 16行缺少分号

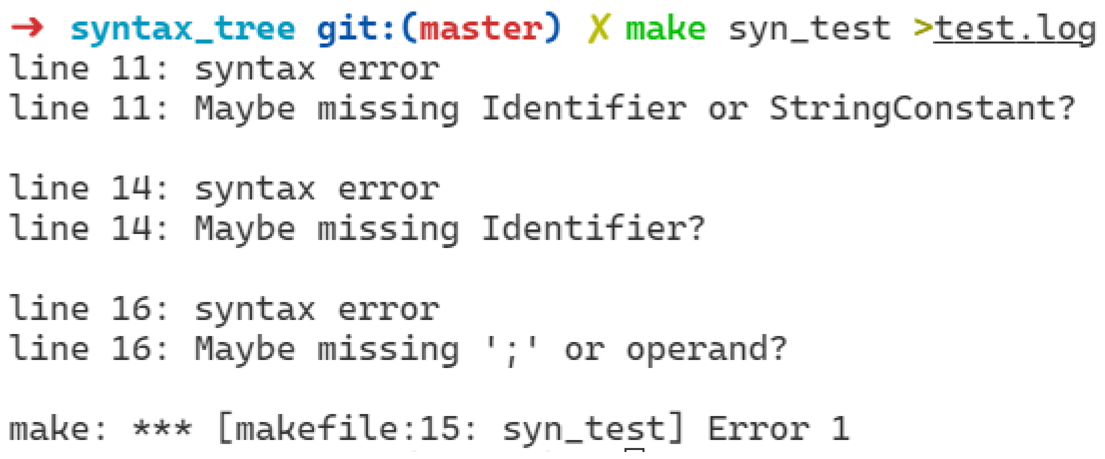
```
 1  /** this is a comment line in the sample program **/
 2   INT f2(INT x, INT y )
 3   BEGIN
 4      INT z;
 5      z := x*x - y*y;
 6      RETURN z;
 7   END
 8   INT MAIN f1()
 9   BEGIN
10      INT x;
```

```
    WHILE(x<3 && y>3) READ(x, );
    INT y;
    READ(y, "A42.input");
    INT ;
    z := f2(x,y) + f2(y,x);
    WRITE (z, "A4.output")
END
```

使用下面的命令进行测试

```
make syn_test > test.log
```

测试结果如下：



```
➜ syntax_tree git:(master) ✗ make syn_test >test.log
line 11: syntax error
line 11: Maybe missing Identifier or StringConstant?

line 14: syntax error
line 14: Maybe missing Identifier?

line 16: syntax error
line 16: Maybe missing ';' or operand?

make: *** [makefile:15: syn_test] Error 1
```

问题

由于进行了内存分配和回收，本次实验使用了valgrind工具检查内存问题。经过检查，发现bison生成的代码中存在内存泄露问题。使用下面的命令进行检查：

```
make check
```

查看valgrind-out.txt，其中有如下泄露：

```
==16662== HEAP SUMMARY:
==16662==     in use at exit: 17,978 bytes in 41 blocks
==16662==   total heap usage: 247 allocs, 210 frees, 31,258 bytes allocated
==16662==
==16662== Searching for pointers to 41 not-freed blocks
==16662== Checked 75,944 bytes
==16662==
==16662== 8 bytes in 1 blocks are still reachable in loss record 1 of 4
==16662==    at 0x483B7F3: malloc (in /usr/lib/x86_64-linux-gnu/valgrind/vgpreload_memcheck-amd64-linux.so)
==16662==    by 0x10CE82: yyalloc (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10C941: yyensure_buffer_stack (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10ACE4: yylex (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x109769: yyparse (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10943F: main (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
```

```
==16662==
==16662== 64 bytes in 1 blocks are still reachable in loss record 2 of 4
==16662==    at 0x483B7F3: malloc (in /usr/lib/x86_64-linux-gnu/valgrind/vgpreload_memcheck-amd64-linux.so)
==16662==    by 0x10CE82: yyalloc (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10C4B6: yy_create_buffer (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10AD0E: yylex (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x109769: yyparse (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10943F: main (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==
==16662== 1,520 bytes in 38 blocks are definitely lost in loss record 3 of 4
==16662==    at 0x483B7F3: malloc (in /usr/lib/x86_64-linux-gnu/valgrind/vgpreload_memcheck-amd64-linux.so)
==16662==    by 0x10CF83: createASTNode (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10AFAE: yylex (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x109769: yyparse (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10943F: main (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==
==16662== 16,386 bytes in 1 blocks are still reachable in loss record 4 of 4
==16662==    at 0x483B7F3: malloc (in /usr/lib/x86_64-linux-gnu/valgrind/vgpreload_memcheck-amd64-linux.so)
==16662==    by 0x10CE82: yyalloc (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10C4EB: yy_create_buffer (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10AD0E: yylex (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x109769: yyparse (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==    by 0x10943F: main (in /mnt/d/OneDrive/workspace/c++/compiler/exp/3_lex_yacc/syntax_tree/main)
==16662==
==16662== LEAK SUMMARY:
==16662==    definitely lost: 1,520 bytes in 38 blocks
==16662==    indirectly lost: 0 bytes in 0 blocks
==16662==      possibly lost: 0 bytes in 0 blocks
==16662==    still reachable: 16,458 bytes in 3 blocks
==16662==         suppressed: 0 bytes in 0 blocks
```

可以看到泄露的内存由yyalloc分配，这部分的代码实际上来源于bison和flex生成的代码。