编译原理实践第12次课
基于PLY的Python解析-2

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概述

使用 Python3 以及 PLY 库实现了简易的 Python 解析器。主要涉及的知识有语法分析，语法制导翻译。
除了赋值语句、完整的四则运算、print语句外，完成了以下内容的解析：选择语句、循环语句、列表、len函数、下标访问。

编程说明

- **语言**：Python3
- **文件编码**：UTF-8
- **依赖**：PLY
- **测试环境**：Python 3.8.10

Python程序的解析

设计了如下文法来实现词法分析：

```
运算符定义略
保留字：print len if elif while for break
ID -> [A-Za-z_][A-Za-z0-9_]*
NUMBER -> \d+
```

【注】这里NUMBER只能识别非负整数，对于负号的实现应该在语法分析中定义产生式来实现。（这里是上一个实验报告遗留的一个bug）但是样例中没有负数出现。因此，这一版本的代码暂不支持纯负数的解析（可以通过0-num来间接实现）。

> 识别 ID，首先检查是否为保留字，若是则申明其类型，否则为 ID

设计了如下语法来实现语法分析

```
program : statements
statements : statements statement | statement
statement : assignment | expr | print | if | while | for | break
assignment : leftval ASSIGN expr | leftval ASSIGN array
leftval : leftval LBRACKET expr RBRACKET | ID  # 左值，可以被赋值、读取值的符号
```

```
expr : expr PLUS term | expr MINUS term | term
term : term TIMES factor | term DIVIDE factor | term EDIVIDE factor | factor
factor : leftval | NUMBER | len | LPAREN expr RPAREN
exprs : exprs COMMA expr | expr
len : LEN LPAREN leftval RPAREN
print : PRINT LPAREN exprs RPAREN | PRINT LPAREN RPAREN
array : LBRACKET exprs RBRACKET | LBRACKET RBRACKET
selfvar : leftval DPLUS | leftval DMINUS
condition : expr LT expr | expr LE expr | expr GT expr | expr GE expr | expr EQ expr | expr NE expr | expr
if : IF LPAREN condition RPAREN LBRACE statements RBRACE
   | IF LPAREN condition RPAREN LBRACE statements RBRACE ELSE LBRACE statements RBRACE
   | IF LPAREN condition RPAREN LBRACE statements RBRACE ELIF LPAREN condition RPAREN LBRACE statements RBRACE ELSE LBRACE statements RBRACE
while : WHILE LPAREN condition RPAREN LBRACE statements RBRACE
for : FOR LPAREN assignment SEMICOLON condition SEMICOLON selfvar RPAREN LBRACE statements RBRACE
break : BREAK
```

其中：

- expr、term、factor 定义了四则运算的语法。
- exprs、print 实现了支持不定长参数的 print 函数。
- leftval 定义了ID和数组下标访问语法，使用了C++中左值的概念，为可读可写的引用，对其的读写需要同过符号表。
- len 定义了 Python 函数 len() 的语法，规定传入的只能是左值。
- array 利用 exprs 实现了 Python 的列表定义。
- selfvar 实现了对一个变量的右自增和自减。
  这里考虑到解析的代码中只是对变量进行自增，故未实现左自增（对称实现即可），也没有定义selfvar的返回值。
- condition 实现了判断中的条件。
- if、for、while 实现了分支和循环语句。
  【注】if多路分支只实现了 if-elif-else 的语法。

另外定义了一系列节点，与语法分析过程中相对应：

```python
class _node:
    """
    所有节点的基类
    """
```

```
    def __init__(self, data):
        self._data = data
        self._children = []
        self._value = NIL
    @property
    def value(self):
        return self._value
    @value.setter
    def value(self, value):
        self._value = value
    def child(self, i):
        assert -len(self._children) <= i < len(self._children)
        return self._children[i]
    @property
    def children(self):
        return self._children
    def add(self, node):
        self._children.append(node)
class NonTerminal(_node):
    """
    非终结符节点，提供type表示非终结符的类型，value（可选）为值
    """
    @property
    def type(self):
        return self._data
    def __str__(self):
        if len(self.children) == 0:
            children = ''
        else:
            children = ' ' + ' '.join(map(str, self.children))
        r = f"[{self.type}{children}]"
        return re.sub(r'\s+', ' ', r)
class LeftValue(NonTerminal):
    """
    左值节点，提供type表示非终结符的类型，id表示引用的变量
    """
    def __init__(self, data):
        super(LeftValue, self).__init__(data)
        self._id = None
        del self._value
    def __str__(self):
        if len(self.children) == 0:
            children = ''
```

```
        else:
            children = ' ' + ' '.join(map(str, self.children))
        r = f"[{self.type}{children}]"
        return re.sub(r'\s+', ' ', r)
    @property
    def id(self): return self._id
    @property
    def value(self):
        raise ValueError('LeftValue 的 value 属性不被允许使用，请通过检索符号表实现')
    @id.setter
    def id(self, i): self._id = i
class Number(_node):
    """
    数字节点，value为值
    """
    def __init__(self, data):
        super(Number, self).__init__(data)
        self._data = 'number'
        self._value = int(data)
    def __str__(self):
        return f'Number({self._value})'
class ID(_node):
    """
    标识符节点，提供id表示标识符名称，value为值
    """
    @property
    def id(self):
        return self._data
    def __init__(self, data):
        super(ID, self).__init__(data)
        self._value = NIL
    def __str__(self):
        id_ = self._data
        return f"ID('{id_}')"
class Terminal(_node):
    """
    除标识符以外的终结符节点，提供text表示其内容
    """
    @property
    def text(self):
        return self._data
    def __str__(self):
```

```
        s = str(self._data).replace('<=', '≤').replace('>=', '≥').replace('<', '＜').replace('>', '＞')
        if s in ('{', '}', '(', ')', '[', ']', 'while', 'for', ',', ';', '='):
            # 省略不必要的终结符，缩减树的规模
            return ''
        return f'[{s}]'
```

通过各节点的 `__str__` 可以将其转换为语法树的字符串表示。

语法制导翻译

如上一小节的代码所示，每个节点都有一个 value 属性（左值LeftVal的value属性被禁用，而是应该通过符号表来检索值），
用来保存节点的值。
（如没有值则为None，数值类型则会赋给一个自定义的单例NIL，表示未赋值的变量，且与None的区分）
另外设计了一个符号表，用以保存每个变量的值。
具体地，当使用赋值语句为一个变量赋值时，会在符号表中添加名为该变量名的记录；
当访问一个变量的值时，会到表中查找该变量的值，如不存在则报错。

关于符号表的检索，定义如下检索和插入的函数：

```
def get_value(tb, vid):
    name, sub = vid
    if not isinstance(name, tuple):
        if sub is None:
            return tb[name]
        return tb.get[name][sub]
    if sub is None:
        return get_value(tb, name)
    return get_value(tb, name)[sub]
def set_value(tb, vid, val):
    name, sub = vid
    if not isinstance(name, tuple):
        if sub is None:
            tb[name] = val
            return
        tb[name][sub] = val
        return
    if sub is None:
        set_value(tb, name, val)
        return
```

```
    get_value(tb, name)[sub] = val
```

其中，vid为形如 `((..., subscript), None)` 的二元组，
其中...为二元组，subscript为下标访问时的下标（最外层为None）。
从而可以实现下标访问的嵌套。

对于除if、for、while、break所对应的非终结符相应的产生式，定义了如下的动作：

```
assignment -> leftval ASSIGN expr | leftval ASSIGN array { value = expr.value; set_value(var_table, leftval.id, value); }
leftval -> leftval1 LLIST expr RLIST  { leftval.id = (leftval1.id, expr.value);
                                        leftval.value = get_value(var_table, leftval.id); }
leftval -> ID  { leftval.id = (ID.id, None);
                 if (ID.value != NIL) { set_value(var_table, leftval.id, ID.value); } }
leftval -> leftval1 LLIST expr RLIST  { leftval.id = (leftval1.id, expr.value); }
expr -> expr1 '+' term  { expr.value = expr1.value + term.value; }
expr -> expr1 '-' term  { expr.value = expr1.value - term.value; }
expr -> term  { expr.value = term.value; }
term -> term1 '*' factor  { term.value = term1.value * factor.value; }
term -> term1 '/' factor  { term.value = term1.value / factor.value; }
term -> term1 '//' factor  { term.value = term1.value // factor.value; }
term -> factor { term.value = factor.value; }
factor -> leftval  { value = get_value(var_table, leftval.id); factor.value = value; }
factor -> NUMBER  { factor.value = NUMBER.value; }
factor -> len  { factor.value = len.value; }
factor -> '(' expr ')'  { fact.value = expr.value; }
exprs -> exprs1 ',' expr  { exprs.value = exprs1.value + [expr.value]; }
exprs -> expr  { exprs.value = [expr.value]; }
print -> PRINT '(' exprs ')'  { print(*exprs.value); }
print -> PRINT '(' ')'  { print(); }
len -> LEN '(' leftval ')'  { len.value = len(get_value(var_table, leftval.id)) }
array -> '[' exprs ']'  { array.value = exprs.value; }
array -> '[' ']' { array.value = []; }
selfvar -> leftval '++'  { value = get_value(var_table, tree.child(0).id);
```

```
                            value = value + 1;
                            set_value(var_table, leftval.id, value); }
selfvar -> leftval '--'  { value = get_value(var_table,
tree.child(0).id);
                            value = value - 1;
                            set_value(var_table, leftval.id, value); }
condition -> expr '<' expr1  { condition.value = exp.value <
expr1.value; }
condition -> expr '<=' expr1  { condition.value = exp.value <=
expr1.value; }
condition -> expr '>' expr1  { condition.value = exp.value >
expr1.value; }
condition -> expr '>=' expr1  { condition.value = exp.value >=
expr1.value; }
condition -> expr '==' expr1  { condition.value = exp.value ==
expr1.value; }
condition -> expr '!=' expr1  { condition.value = exp.value !=
expr1.value; }
condition -> expr  { condition.value = bool(exp.value); }
```

对于if、for、while，提前翻译条件condition，根据结果来判断分支是否执行或循环是否继续。

对于循环，定义变量loop_flag用来标识循环的层数，大于0为循环层数，等于0为不在循环内，小于0非法。

对于break，定义变量break_flag来指示是否遇到了break，
如果遇到了，则后续节点都不翻译，并跳出循环。

以上代码实现详见 translate.py 。

其余部分，采用深度优先的顺序遍历整个语法树，具体实现详见代码。

运行

项目结构为：

```
.
├── README.pdf     # 本文档
├── binary_search.py     # 输入文件1
├── select_sort.py       # 输入文件2
├── main.py        # 主程序
├── node.py        # 节点定义文件
├── parser.out     # PLY生成的文件
├── parsetab.py    # PLY生成的文件
├── py_lex.py      # 词法分析文件
├── py_yacc.py     # 语法分析文件
└── translation.py     # 翻译器
```

主程序接受一个参数，为输入文件的路径。运行方法如下：

```
$ python3 main.py <py-file>
```

输入文件： binary_search.py

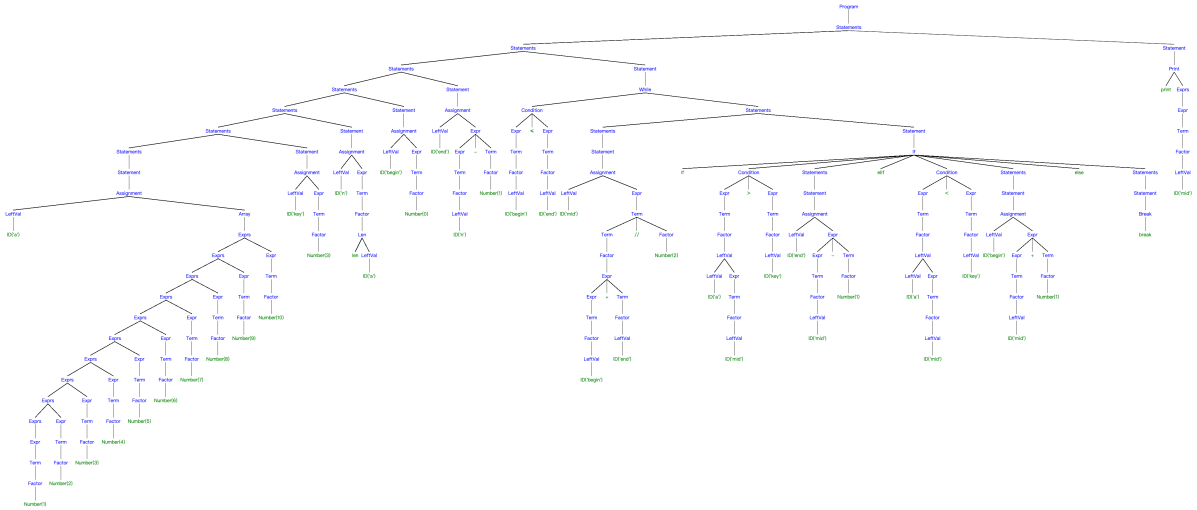
```
a=[1,2,3,4,5,6,7,8,9,10]

key=3

n=len(a)

begin=0
end=n-1

while(begin<=end){
    mid=(begin+end)//2
    if(a[mid]>key){
        end=mid-1
    }
    elif(a[mid]<key){
        begin=mid+1
    }
    else{
        break
    }
}
print(mid)
```

输出如下：

```
语法树： [Program [Statements [Statements [Statements [Statements [Statements [Statements [Statements [Statement [Assignment [LeftVal ID('a')] [Array [Exprs [Exprs [Exprs [Exprs [Exprs [Exprs [Exprs [Exprs [Exprs [Expr [Term [Factor Number(1)]]]]] [Expr [Term [Factor Number(2)]]]]] [Expr [Term [Factor Number(3)]]]]] [Expr [Term [Factor Number(4)]]]]] [Expr [Term [Factor Number(5)]]]]] [Expr [Term [Factor Number(6)]]]]] [Expr [Term [Factor Number(7)]]]]] [Expr [Term [Factor Number(8)]]]]] [Expr [Term [Factor Number(9)]]]]] [Expr [Term [Factor Number(10)]]]]] ]]]] [Statement [Assignment [LeftVal ID('key')] [Expr [Term [Factor Number(3)]]]]]] [Statement [Assignment [LeftVal ID('n')] [Expr [Term [Factor [Len [len] [LeftVal ID('a')] ]]]]]] [Statement [Assignment [LeftVal ID('begin')] [Expr [Term [Factor Number(0)]]]]]] [Statement [Assignment [LeftVal ID('end')] [Expr [Expr [Term [Factor [LeftVal ID('n')]]]] [-] [Term [Factor Number(1)]]]]]] [Statement [While [Condition [Expr [Term [Factor [LeftVal ID('begin')]]]] [≤] [Expr [Term [Factor [LeftVal ID('end')]]]]] [Statements [Statements [Statement [Assignment [LeftVal ID('mid')] [Expr [Term [Term [Factor [Expr [Expr [Term [Factor [LeftVal ID('begin')]]]] [+] [Term [Factor [LeftVal ID('end')]]]] ]] [//] [Factor Number(2)]]]]] [Statement [If [if] [Condition [Expr [Term [Factor [LeftVal [LeftVal ID('a')] [Expr [Term [Factor [LeftVal ID('mid')]]]] ]]]] [>] [Expr [Term [Factor [LeftVal ID('key')]]]]] [Statements [Statement [Assignment [LeftVal ID('end')] [Expr [Expr [Term [Factor [LeftVal ID('mid')]]]] [-] [Term [Factor Number(1)]]]]] [elif] [Condition [Expr [Term [Factor [LeftVal [LeftVal ID('a')] [Expr [Term [Factor [LeftVal ID('mid')]]]] ]]]] [<] [Expr [Term [Factor [LeftVal ID('key')]]]]] [Statements [Statement [Assignment [LeftVal ID('begin')] [Expr [Expr [Term [Factor [LeftVal ID('mid')]]]] [+] [Term [Factor Number(1)]]]]] [else] [Statements [Statement [Break [break]]]] ]]] ]]] [Statement [Print [print] [Exprs [Expr [Term [Factor [LeftVal ID('mid')]]]]] ]]]]
运行结果：
2
当前变量表： {'a': [1, 2, 3, 4, 5, 6, 7, 8, 9, 10], 'key': 3, 'n': 10, 'begin': 2, 'end': 3, 'mid': 2}
```

> 如果图片不清晰，请点击如下链接：http://repo.holgerbest.top/html/ply_python-2.html

语法树：



输入文件： select_sort.py

```
a=[1,2,4,3,6,5]

n=len(a)

for(i=0;i<n;i++){
    max_v=a[i]
    i_v=i

    for(j=i;j<n;j++){
        if(a[j]>max_v){
            max_v=a[j]
            i_v=j
        }
    }

    t=a[i]
    a[i]=a[i_v]
    a[i_v]=t
}

print(a)
```

输出：

```
语法树： [Program [Statements [Statements [Statements [Statements [Statement [Assignment [LeftVal ID('a')] [Array [Exprs [Exprs [Exprs [Exprs [Exprs [Exprs [Expr [Term [Factor Number(1)]]]] [Expr [Term [Factor Number(2)]]]] [Expr [Term [Factor Number(4)]]]] [Expr [Term [Factor Number(3)]]]] [Expr [Term [Factor Number(6)]]]] [Expr [Term [Factor Number(5)]]]] ]]]] [Statement [Assignment [LeftVal ID('n')] [Expr [Term [Factor [Len [len] [LeftVal ID('a')] ]]]]]] [Statement [For [Assignment [LeftVal ID('i')] [Expr [Term [Factor Number(0)]]]] [Condition [Expr [Term [Factor [LeftVal ID('i')]]]] [<] [Expr [Term [Factor [LeftVal ID('n')]]]]] [SelfVar [LeftVal ID('i')] [++]] [Statements [Statements [Statements [Statements [Statements [Statements [Statement [Assignment [LeftVal ID('max_v')] [Expr [Term [Factor [LeftVal [LeftVal ID('a')] [Expr [Term [Factor [LeftVal ID('i')]]]] ]]]]]]] [Statement [Assignment [LeftVal ID('i_v')] [Expr [Term [Factor [LeftVal ID('i')]]]]]]] [Statement [For [Assignment [LeftVal ID('j')] [Expr [Term [Factor [LeftVal ID('i')]]]]] [Condition [Expr [Term [Factor [LeftVal ID('j')]]]] [<] [Expr [Term [Factor [LeftVal ID('n')]]]]] [SelfVar [LeftVal ID('j')] [++]] [Statements [Statement [If [if] [Condition [Expr [Term [Factor [LeftVal [LeftVal ID('a')] [Expr [Term [Factor [LeftVal ID('j')]]]] ]]]] [>] [Expr [Term [Factor [LeftVal ID('max_v')]]]]] [Statements [Statements [Statement [Assignment [LeftVal ID('max_v')] [Expr [Term [Factor [LeftVal [LeftVal ID('a')] [Expr [Term [Factor [LeftVal ID('j')]]]] ]]]]]] [Statement [Assignment [LeftVal ID('i_v')] [Expr [Term [Factor [LeftVal ID('j')]]]]]] ]]] ]]] [Statement [Assignment [LeftVal ID('t')] [Expr [Term [Factor [LeftVal [LeftVal ID('a')] [Expr [Term [Factor [LeftVal ID('i')]]]] ]]]]]] [Statement [Assignment [LeftVal [LeftVal ID('a')] [Expr [Term [Factor [LeftVal ID('i')]]]] ] [Expr [Term [Factor [LeftVal [LeftVal ID('a')] [Expr [Term [Factor [LeftVal ID('i_v')]]]] ]]]]]] [Statement [Assignment [LeftVal [LeftVal ID('a')] [Expr [Term [Factor [LeftVal ID('i_v')]]]] ] [Expr [Term [Factor [LeftVal ID('t')]]]]]] ]]] [Statement [Print [print] [Exprs [Expr [Term [Factor [LeftVal ID('a')]]]]] ]]]]
运行结果：
[6, 5, 4, 3, 2, 1]
当前变量表： {'a': [6, 5, 4, 3, 2, 1], 'n': 6, 'i': 6, 'max_v': 1, 'i_v': 5, 'j': 6, 't': 1}
```

语法树：