表达式语法分析实验报告

计算机1202 张艺瀚
学号：20123852

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1 实验题目

表达式语法分析

2 实验目的

熟悉并设计一个表达式的语法分析器

3 实验内容

1. 设计表达式的语法分析器算法
2. 编写代码并上机调试运行通过

4 概要设计

本语法分析器实现了LR(1)和LL(1)语法分析方法，对给定文法自动生成LR(1)和LL(1)分析表，在几个简单文法的测试下正常运行。

下面介绍具体设计实现。

`SyntaxAnalyzer` 类定义（代码清单 1）如下：

```
class SyntaxAnalyzer
{
public:
  SyntaxAnalyzer(const string& filePath);

  Grammar G;

  void display(const LR0Item& item);
  void display(const LR1Item& item);
  void display(const set<LR0Item>& I);
  void display(const set<LR1Item>& I);
```

```
12
13
14    vector<set<LR1Item>> lr1ItemSetFamily;
15    vector<vector<LR1ActionTabItem>> lr1ActionTab;
16    vector<vector<unsigned int>> lr1GoToTab;
17    vector<unsigned int> lr1Stack;
18    string lr1Input;
19
20    set<LR0Item> LR0Closure(const set<LR0Item>& I);
21    set<LR1Item> LR1Closure(const set<LR1Item>& I);
22    set<LR1Item> LR1GoTo(const set<LR1Item>& I, char X);
23    void calLR1ItemSetFamily();
24    void buildLR1ParseTab();
25    bool lr1SyntaxAnalyze(const string& myLR1Input);
26
27
28    vector<vector<LL1Item>> ll1ParseTab;
29    vector<char> ll1Stack;
30    string ll1Input;
31
32    void buildLL1ParseTab();
33    bool ll1SyntaxAnalyze(const string& myLL1Input);
34
35  private:
36
37  };
```

Listing 1: `SyntaxAnalyzer` 类定义代码清单

构造函数和 `display` 多态函数不再赘述，下面分别介绍LR(1)和LL(1)分析器的构造。

4.1 LR(1)语法分析器的设计实现

4.1.1 LR1项的数据结构设计

代码如下（代码清单 2）如下：

```
1  class LR1Item
2  {
3  public:
4    LR1Item() = default;
5    LR1Item(const LR0Item& myLR0Item, char
       myLookaheadSymbol);
6    LR1Item(unsigned int myLProductionRuleIdx, unsigned
       int myRProductionRuleIdx, unsigned int myDotPos,
       char myLookaheadSymbol);
```

```
7
8     unsigned int lProductionRuleIdx;
9     unsigned int rProductionRuleIdx;
10    unsigned int dotPos;
11    char lookaheadSymbol;
12
13    friend bool operator < (const LR1Item& i1, const
       LR1Item& i2);
14    friend bool operator ==(const LR1Item& i1, const
       LR1Item& i2);
15    friend bool operator > (const LR1Item& i1, const
       LR1Item& i2);
16    friend bool operator !=(const LR1Item& i1, const
       LR1Item& i2);
17
18  private:
19
20  };
21
22  bool operator <(const LR1Item& i1, const LR1Item& i2)
23  {
24    return i1.lProductionRuleIdx < i2.lProductionRuleIdx
       ?
25      true: (i1.lProductionRuleIdx > i2.
       lProductionRuleIdx?
26        false: (i1.rProductionRuleIdx < i2.
       rProductionRuleIdx?
27          true: (i1.rProductionRuleIdx > i2.
       rProductionRuleIdx?
28            false: (i1.dotPos < i2.dotPos?
29              true: (i1.lookaheadSymbol < i2.
       lookaheadSymbol)))));
30  }
31
32  bool operator ==(const LR1Item& i1, const LR1Item& i2)
33  {
34    return i1.lProductionRuleIdx == i2.
       lProductionRuleIdx
35      && i1.rProductionRuleIdx == i2.rProductionRuleIdx
36      && i1.dotPos == i2.dotPos
37      && i1.lookaheadSymbol == i2.lookaheadSymbol;
38  }
39
40  bool operator >(const LR1Item& i1, const LR1Item& i2)
41  {
42    return !(i1 < i2) && !(i1 == i2);
```

```
43 }
44
45 bool operator !=(const LR1Item& i1, const LR1Item& i2)
46 {
47   return !(i1 == i2);
48 }
49
50 LR1Item::LR1Item(const LR0Item& myLR0Item, char
       myLookaheadSymbol):
51   lProductionRuleIdx(myLR0Item.lProductionRuleIdx),
       rProductionRuleIdx(myLR0Item.rProductionRuleIdx),
       dotPos(myLR0Item.dotPos),
52   lookaheadSymbol(myLookaheadSymbol)
53 {
54
55 }
56
57 LR1Item::LR1Item(unsigned int myLProductionRuleIdx,
       unsigned int myRProductionRuleIdx, unsigned int
       myDotPos, char myLookaheadSymbol):
58   lProductionRuleIdx(myLProductionRuleIdx),
       rProductionRuleIdx(myRProductionRuleIdx), dotPos(
       myDotPos), lookaheadSymbol(myLookaheadSymbol)
59 {
60
61 }
```

Listing 2: LR1项的数据结构设计代码清单

4.1.2 LR1Closure 成员函数的设计实现

LR1Closure 类定义（代码清单 3）如下:

```
1  set<LR1Item> SyntaxAnalyzer::LR1Closure(const set<
       LR1Item>& I)
2  {
3    set<LR1Item> ret;
4    for(auto ptr = I.begin(); ptr != I.end(); ++ptr)
5    {
6      ret.insert(*ptr);
7    }
8
9    bool updated = true;
10   while(updated)
11   {
12     updated = false;
```

```
13
14      for(auto ptr = ret.begin(); ptr != ret.end(); ++
    ptr)
15      {
16        if(ptr->dotPos < G.P[ptr->lProductionRuleIdx].
    rPartSet[ptr->rProductionRuleIdx].size()
17           && G.isNonTerminal(G.P[ptr->lProductionRuleIdx
    ].rPartSet[ptr->rProductionRuleIdx][ptr->dotPos]))
18        {
19          ProductionRule pr;
20          int prIdx = G.getProductionRuleByLeft(pr, G.P[
    ptr->lProductionRuleIdx].rPartSet[ptr->
    rProductionRuleIdx][ptr->dotPos]);
21          for(size_t i = 0; i < pr.rPartSet.size(); ++i)
22          {
23            string str;
24            if(ptr->dotPos + 1 < G.P[ptr->
    lProductionRuleIdx].rPartSet[ptr->
    rProductionRuleIdx].size())
25            {
26              str = G.P[ptr->lProductionRuleIdx].
    rPartSet[ptr->rProductionRuleIdx][ptr->dotPos + 1]
    + ch2str(ptr->lookaheadSymbol);
27            }
28            else
29            {
30              str = ch2str(ptr->lookaheadSymbol);
31            }
32            set<char> s = G.getFirst(str);
33            int oldSize = ret.size();
34            for(auto& sPtr: s)
35            {
36              if(sPtr != 'e')
37              {
38                ret.insert(LR1Item(prIdx, i, 0, sPtr));
39              }
40            }
41            int newSize = ret.size();
42            if(oldSize != newSize)
43            {
44              updated = true;
45            }
46          }
47        }
48      }
49    }
```

```
50
51    // cout << "LR1Closure:\n"; display(ret); cout <<
      endl;
52
53    return ret;
54  }
```

Listing 3: LR1Closure 成员函数代码清单

4.1.3 LR1GoTo 成员函数的设计实现

代码（代码清单 4）如下：

```
1  set<LR1Item> SyntaxAnalyzer::LR1GoTo(const set<LR1Item
       >& I, char X)
2  {
3    if(find(G.VN.begin(), G.VT.begin(), X) != G.VN.end()
4      || find(G.VT.begin(), G.VT.end(), X) != G.VT.end()
       )
5    {
6      set<LR1Item> ret;
7
8      for(auto ptr = I.begin(); ptr != I.end(); ++ptr)
9      {
10       if(ptr->dotPos < G.P[ptr->lProductionRuleIdx].
       rPartSet[ptr->rProductionRuleIdx].size()
11           && G.P[ptr->lProductionRuleIdx].rPartSet[ptr->
       rProductionRuleIdx][ptr->dotPos] == X)
12         {
13           ret.insert(LR1Item(ptr->lProductionRuleIdx,
       ptr->rProductionRuleIdx, ptr->dotPos + 1, ptr->
       lookaheadSymbol));
14         }
15     }
16
17     // cout << "LR1GoTo:\n"; display(LR1Closure(ret));
       cout << endl;
18
19     return LR1Closure(ret);
20   }
21   else
22   {
23     return set<LR1Item>();
24   }
25 }
```

Listing 4: LR1GoTo 成员函数代码清单

4.1.4 calLR1ItemSetFamily 成员函数的设计实现

代码（代码清单 5）如下：

```
void SyntaxAnalyzer::calLR1ItemSetFamily()
{
  G.P.push_back(ProductionRule('S', vector<string>({
   ch2str(G.S)})));
  sort(G.P.begin(), G.P.end(),
    [](const ProductionRule& pr1, const ProductionRule
   & pr2)
    {
      return pr1.lPart < pr2.lPart?
        true: (pr1.lPart > pr2.lPart?
          false: pr1.rPartSet[0] < pr2.rPartSet[0]);
    });

  G.VN.push_back('S');
  sort(G.VN.begin(), G.VN.end());

  G.S = 'S';

  G.nullable.clear();
  G.first.clear();
  G.follow.clear();
  G.nullable.assign(G.VN.size(), false);
  G.first.assign(G.VN.size() + G.VT.size(), set<char
   >());
  G.follow.assign(G.VN.size(), set<char>());

  G.display();

  G.calNullableFirstFollow();

  lr1ItemSetFamily.push_back(
    LR1Closure(
      set<LR1Item>({
        LR1Item(
          find_if(
            G.P.begin(), G.P.end(),
            [](const ProductionRule& pr)
            {
```

```
36                return pr.lPart == 'S';
37              }) - G.P.begin(),
38            0, 0, '$'
39            )
40          })
41      )
42    );
43
44  bool updated = true;
45  while(updated)
46  {
47    updated = false;
48
49    for(auto& itemSetPtr: lr1ItemSetFamily)
50    {
51      for(auto& symbolPtr: G.VN)
52      {
53        set<LR1Item> itemSet = LR1GoTo(itemSetPtr,
   symbolPtr);
54        if(!itemSet.empty()
55          && find_if(lr1ItemSetFamily.begin(),
   lr1ItemSetFamily.end(),
56            [itemSet](const set<LR1Item>& s)
57            {
58              if(s.size() != itemSet.size())
59              {
60                return false;
61              }
62              else
63              {
64                auto ptr1 = itemSet.begin();
65                auto ptr2 = s.begin();
66                for(; ptr1 != itemSet.end(); ++ptr1,
   ++ptr2)
67                {
68                  if(!(*ptr1 == *ptr2))
69                  {
70                    return false;
71                  }
72                }
73                return true;
74              }
75            }) == lr1ItemSetFamily.end())
76        {
77          lr1ItemSetFamily.push_back(itemSet);
78          updated = true;
```

```
79          }
80        }
81
82        for(auto& symbolPtr: G.VT)
83        {
84          set<LR1Item> itemSet = LR1GoTo(itemSetPtr,
    symbolPtr);
85          if(!itemSet.empty()
86            && find_if(lr1ItemSetFamily.begin(),
    lr1ItemSetFamily.end(),
87              [itemSet](const set<LR1Item>& s)
88              {
89                if(s.size() != itemSet.size())
90                {
91                  return false;
92                }
93                else
94                {
95                  auto ptr1 = itemSet.begin();
96                  auto ptr2 = s.begin();
97                  for(; ptr1 != itemSet.end(); ++ptr1,
    ++ptr2)
98                  {
99                    if(!(*ptr1 == *ptr2))
100                   {
101                     return false;
102                   }
103                 }
104                 return true;
105               }
106             }) == lr1ItemSetFamily.end())
107         {
108           lr1ItemSetFamily.push_back(itemSet);
109           updated = true;
110         }
111       }
112     }
113   }
114
115   // sort lr1ItemSetFamily
116   sort(lr1ItemSetFamily.begin(), lr1ItemSetFamily.end
    (),
117     [](const set<LR1Item>& itemSet1, const set<LR1Item
    >& itemSet2)
118     {
119       auto ptr1 = itemSet1.begin();
```

```
120         auto ptr2 = itemSet2.begin();
121         for(; ptr1 != itemSet1.end() && ptr2 != itemSet2
    .end(); ++ptr1, ++ptr2)
122         {
123           if(*ptr1 > *ptr2)
124           {
125             return false;
126           }
127           else if(*ptr1 < *ptr2)
128           {
129             return true;
130           }
131         }
132         if(ptr1 != itemSet1.end() && ptr2 == itemSet2.
    end())
133         {
134           return false;
135         }
136         else
137         {
138           return true;
139         }
140       });
141
142     cout << "item set family" << endl;
143     for(size_t i = 0; i < lr1ItemSetFamily.size(); ++i)
144     {
145       cout << "I" << i << endl;
146       display(lr1ItemSetFamily[i]);
147       cout << endl;
148     }
149
150     cout << "Goto graph" << endl;
151     for(size_t i = 0; i < lr1ItemSetFamily.size(); ++i)
152     {
153       for(size_t j = 0; j < G.VT.size(); ++j)
154       {
155         set<LR1Item> Ij = LR1GoTo(lr1ItemSetFamily[i], G
    .VT[j]);
156         if(!Ij.empty())
157         {
158           cout << "I" << i << endl;
159           display(lr1ItemSetFamily[i]);
160           cout << "receives " << G.VT[j] << ", goes to"
    << endl;
161           display(Ij);
```

```
162             cout << endl;
163           }
164         }
165
166         for(size_t j = 0; j < G.VN.size(); ++j)
167         {
168           set<LR1Item> Ij = LR1GoTo(lr1ItemSetFamily[i], G
    .VN[j]);
169           if(!Ij.empty())
170           {
171             cout << "I" << i << endl;
172             display(lr1ItemSetFamily[i]);
173             cout << "receives " << G.VN[j] << ", goes to"
    << endl;
174             display(Ij);
175             cout << endl;
176           }
177         }
178       }
179     }
```

Listing 5: calLR1ItemSetFamily代码清单

我们使用增广文法，即添加产生式$S' \to S$。这时，文法的终结符集，开始符，nullable 集，first 集和 follow 集均需重新计算。这些计算仅与文法相关，文法及其上操作的设计实现见 7 附录。

4.1.5 buildLR1ParseTab 成员函数的设计实现

代码（代码清单 6）如下：

```
1  void SyntaxAnalyzer::buildLR1ParseTab()
2  // notice that the lookahead symbol may be e!!!
3  {
4    lr1ActionTab.assign(lr1ItemSetFamily.size(), vector<
       LR1ActionTabItem>(G.VT.size() + 1, LR1ActionTabItem
       (ERR, 0, 0, 0)));
5    lr1GoToTab.assign(lr1ItemSetFamily.size(), vector<
       unsigned int>(G.VN.size(), lr1ItemSetFamily.size())
       );
6    // if an item in lr1GoToTab equals to the value of
       lr1ItemSetFamily.size(), it means this item is
       invalid
7
8    for(size_t i = 0; i < lr1ItemSetFamily.size(); ++i)
9    {
```

```
10      for(auto itemSetPtr = lr1ItemSetFamily[i].begin();
        itemSetPtr != lr1ItemSetFamily[i].end(); ++
    itemSetPtr)
11      {
12        auto VTPtr = find(G.VT.begin(), G.VT.end(),
    itemSetPtr->lookaheadSymbol);
13        auto VNPtr = find(G.VN.begin(), G.VN.end(),
    itemSetPtr->lookaheadSymbol);
14        if(itemSetPtr->dotPos < G.P[itemSetPtr->
    lProductionRuleIdx].rPartSet[itemSetPtr->
    rProductionRuleIdx].size())
15        {
16          if(G.P[itemSetPtr->lProductionRuleIdx].
    rPartSet[itemSetPtr->rProductionRuleIdx] == "e")
17          {
18            lr1ActionTab[i][(VTPtr == G.VT.end())? G.VT.
    size(): (VTPtr - G.VT.begin())] =
19              LR1ActionTabItem(REDUCE, itemSetPtr->
    lProductionRuleIdx, itemSetPtr->rProductionRuleIdx,
     0);
20          }
21
22          auto ptr = find(G.VT.begin(), G.VT.end(),
23            G.P[itemSetPtr->lProductionRuleIdx].rPartSet
    [itemSetPtr->rProductionRuleIdx][itemSetPtr->dotPos
    ]);
24          if(ptr != G.VT.end())
25          {
26            set<LR1Item> Ij = LR1GoTo(lr1ItemSetFamily[i
    ],
27              G.P[itemSetPtr->lProductionRuleIdx].
    rPartSet[itemSetPtr->rProductionRuleIdx][itemSetPtr
    ->dotPos]);
28            int lr1ActionTabCol = ptr - G.VT.begin();
29            lr1ActionTab[i][lr1ActionTabCol] =
    LR1ActionTabItem(
30              SHIFT, 0, 0,
31              find_if(lr1ItemSetFamily.begin(),
    lr1ItemSetFamily.end(),
32                [Ij](const set<LR1Item>& s)
33                {
34                  if(s.size() != Ij.size())
35                  {
36                    return false;
37                  }
38                  else
```

```
39                {
40                  auto ptr1 = Ij.begin();
41                  auto ptr2 = s.begin();
42                  for(; ptr1 != Ij.end(); ++ptr1, ++
    ptr2)
43                  {
44                    if(!(*ptr1 == *ptr2))
45                    {
46                      return false;
47                    }
48                  }
49                  return true;
50                }
51              }) - lr1ItemSetFamily.begin()
52            );
53        }
54      }
55      else
56      {
57        if(G.P[itemSetPtr->lProductionRuleIdx].lPart
    != 'S')
58        {
59          int lr1ActionTabCol = (VTPtr == G.VT.end())?
     G.VT.size(): (VTPtr - G.VT.begin());
60          lr1ActionTab[i][lr1ActionTabCol] =
    LR1ActionTabItem(REDUCE, itemSetPtr->
    lProductionRuleIdx, itemSetPtr->rProductionRuleIdx,
     0);
61        }
62        else
63        {
64          lr1ActionTab[i][G.VT.size()] =
    LR1ActionTabItem(ACCEPT, 0, 0, 0);
65        }
66      }
67    }
68  }
69
70  for(size_t i = 0; i < lr1ItemSetFamily.size(); ++i)
71  {
72    for(size_t A = 0; A < G.VN.size(); ++A)
73    {
74      set<LR1Item> Ij = LR1GoTo(lr1ItemSetFamily[i], G
    .VN[A]);
75      lr1GoToTab[i][A] = find_if(lr1ItemSetFamily.
    begin(), lr1ItemSetFamily.end(),
```

```
76          [Ij](const set<LR1Item>& s)
77          {
78            if(s.size() != Ij.size())
79            {
80              return false;
81            }
82            else
83            {
84              auto ptr1 = Ij.begin();
85              auto ptr2 = s.begin();
86              for(; ptr1 != Ij.end(); ++ptr1, ++ptr2)
87              {
88                if(!(*ptr1 == *ptr2))
89                {
90                  return false;
91                }
92              }
93              return true;
94            }
95          }) - lr1ItemSetFamily.begin();
96      }
97    }
98
99    cout << "lr1ActionTab" << endl;
100   for(size_t i = 0; i < lr1ActionTab.size(); ++i)
101   {
102     for(size_t j = 0; j < lr1ActionTab[i].size(); ++j)
103     {
104       cout << "lr1ActionTab[" << i << "," << ((j == G.
      VT.size())? '$': G.VT[j]) << "] = ";
105       switch(lr1ActionTab[i][j].action)
106       {
107         case SHIFT: cout << "SHIFT " << lr1ActionTab[i
      ][j].itemSetIdx << endl; break;
108         case REDUCE: cout << "REDUCE "; G.P[
      lr1ActionTab[i][j].lProductionRuleIdx].display();
      cout << endl; break;
109         case ACCEPT: cout << "ACCEPT" << endl; break;
110         default: cout << "ERR" << endl;
111       }
112     }
113   }
114   cout << endl;
115
116   cout << "lr1GoToTab" << endl;
117   for(size_t i = 0; i < lr1GoToTab.size(); ++i)
```

```
118   {
119     for(size_t j = 0; j < lr1GoToTab[i].size(); ++j)
120     {
121       cout << "lr1GoToTab[" << i << "," << G.VN[j] <<
      "] = "
122            << ((lr1GoToTab[i][j] == lr1ItemSetFamily.
      size())? " ": to_string(lr1GoToTab[i][j])) << endl;
123     }
124   }
125 }
```

Listing 6: buildLR1ParseTab 成员函数代码清单

4.1.6 lr1SyntaxAnalyze 成员函数的设计实现

代码（代码清单 7）如下：

```
1  bool SyntaxAnalyzer::lr1SyntaxAnalyze(const string&
       myLR1Input)
2  {
3    if(myLR1Input.size() == 0)
4    {
5      cout << "Input is empty!" << endl;
6      return false;
7    }
8
9    cout << "Parsing " << myLR1Input << "..." << endl;
10
11   lr1Stack.push_back(
12     find_if(
13       lr1ItemSetFamily.begin(), lr1ItemSetFamily.end()
       ,
14       [this](const set<LR1Item>& s)
15       {
16         return find_if(s.begin(), s.end(),
17           [this](const LR1Item& i)
18           {
19             return G.P[i.lProductionRuleIdx].lPart ==
       'S';
20           }) != s.end();
21       }
22       ) - lr1ItemSetFamily.begin()
23     );
24
25   string str = myLR1Input;
26   reverse(str.begin(), str.end());
```

```
27    lr1Input = "$" + str;
28
29    int idx = lr1Input.size() - 1;
30    char a = lr1Input[idx];
31    for(;;)
32    {
33      unsigned int s = lr1Stack[lr1Stack.size() - 1];
34      auto ptr = find(G.VT.begin(), G.VT.end(), a);
35      int aIdx = (ptr == G.VT.end())? G.VT.size(): ptr -
        G.VT.begin();
36      LR1ActionTabItem curAction = lr1ActionTab[s][aIdx
       ];
37      cout << "Begin a new pass..." << endl;
38      cout << "Current state(top of the stack): "
39           << lr1Stack[lr1Stack.size() - 1] << endl;
40      display(lr1ItemSetFamily[lr1Stack[lr1Stack.size()
       - 1]]);
41      cout << "Current input symbol: " << a << endl <<
       endl;
42      if(curAction.action == SHIFT)
43      {
44        lr1Stack.push_back(curAction.itemSetIdx);
45        cout << "Push back state " << curAction.
       itemSetIdx << endl;
46        display(lr1ItemSetFamily[curAction.itemSetIdx]);
47        --idx;
48        a = lr1Input[idx];
49        cout << "Shift and now the input symbol is " <<
       a << endl << endl;
50      }
51      else if(curAction.action == REDUCE)
52      {
53        cout << "Reduce using production rule "
54             << G.P[curAction.lProductionRuleIdx].lPart
       << "->"
55             << G.P[curAction.lProductionRuleIdx].
       rPartSet[curAction.rProductionRuleIdx] << endl;
56        int num = (G.P[curAction.lProductionRuleIdx].
       rPartSet[curAction.rProductionRuleIdx] == "e")?
57          0: G.P[curAction.lProductionRuleIdx].rPartSet[
       curAction.rProductionRuleIdx].size();
58        for(int i = 0; i < num; ++i)
59        {
60          lr1Stack.erase(lr1Stack.end() - 1);
61        }
62        cout << "Pop " << num << " state(s) out of the
```

```
    stack" << endl;
63      cout << "Now the stack top is state " <<
    lr1Stack[lr1Stack.size() - 1] << endl;
64      display(lr1ItemSetFamily[lr1Stack[lr1Stack.size
    () - 1]]);
65      int t = lr1Stack[lr1Stack.size() - 1];
66      lr1Stack.push_back(lr1GoToTab[t][find(G.VN.begin
    (), G.VN.end(), G.P[curAction.lProductionRuleIdx].
    lPart) - G.VN.begin()]);
67      cout << "lr1GoToTab[" << t << "," << G.P[
    curAction.lProductionRuleIdx].lPart << "] = "
68           << ((lr1GoToTab[t][find(G.VN.begin(), G.VN.
    end(), G.P[curAction.lProductionRuleIdx].lPart) - G
    .VN.begin()] == lr1ItemSetFamily.size())?
69               " ": to_string(lr1GoToTab[t][find(G.VN
    .begin(), G.VN.end(), G.P[curAction.
    lProductionRuleIdx].lPart) - G.VN.begin()]));
70      cout << ", so we push back state "
71           << lr1GoToTab[t][find(G.VN.begin(), G.VN.
    end(), G.P[curAction.lProductionRuleIdx].lPart) - G
    .VN.begin()] << endl;
72      display(lr1ItemSetFamily[lr1GoToTab[t][find(G.VN
    .begin(), G.VN.end(), G.P[curAction.
    lProductionRuleIdx].lPart) - G.VN.begin()]]);
73      cout << endl;
74    }
75    else if(curAction.action == ACCEPT)
76    {
77      cout << "Parsing succeed!" << endl << endl;
78      return true;
79    }
80    else
81    {
82      cout << "Parsing error!" << endl;
83      cout << "In state " << lr1Stack[lr1Stack.size()
    - 1] << endl;
84      display(lr1ItemSetFamily[lr1Stack[lr1Stack.size
    () - 1]]); cout << endl;
85      return false;
86    }
87  }
88 }
```

Listing 7: `lr1SyntaxAnalyze` 成员函数代码清单

我们使用$作为分析栈初始栈顶符号。

5 LL(1)语法分析器的设计实现

5.0.7 buildLL1ParseTab 成员函数的设计实现

代码（代码清单 8）如下：

```
void SyntaxAnalyzer::buildLL1ParseTab()
{
  ll1ParseTab.assign(G.VN.size(), vector<LL1Item>(G.VT.size() + 1, LL1Item(G.P.size(), 0)));

  for(size_t i = 0; i < G.P.size(); ++i)
  {
    unsigned int AIdx = find(G.VN.begin(), G.VN.end(), G.P[i].lPart) - G.VN.begin();

    for(size_t j = 0; j < G.P[i].rPartSet.size(); ++j)
    {
      set<char> firstAlpha = G.getFirst(G.P[i].rPartSet[j]);

      for(auto& p: firstAlpha)
      {
        unsigned int aIdx = find(G.VT.begin(), G.VT.end(), p) - G.VT.begin();
        if(aIdx < G.VT.size())
        {
          ll1ParseTab[AIdx][aIdx] = LL1Item(i, j);
        }
      }

      if(find(firstAlpha.begin(), firstAlpha.end(), 'e') != firstAlpha.end())
      {
        set<char> followA = G.getFollow(G.P[i].lPart);

        for(auto& p: followA)
        {
          unsigned int bIdx = find(G.VT.begin(), G.VT.end(), p) - G.VT.begin();
          ll1ParseTab[AIdx][bIdx] = LL1Item(i, j);
        }

        if(find(followA.begin(), followA.end(), '$') != followA.end())
        {
```

```
            ll1ParseTab[AIdx][G.VT.size()] = LL1Item(i, j);
          }
        }
      }
    }

    for(size_t i = 0; i < ll1ParseTab.size(); ++i)
    {
      for(size_t j = 0; j < ll1ParseTab[i].size(); ++j)
      {
        cout << "ll1ParseTab[" << G.VN[i] << ", " << ((j == G.VT.size())? '$': G.VT[j]) << "] = ";
        if(ll1ParseTab[i][j].i < G.P.size())
        {
          cout << G.P[ll1ParseTab[i][j].i].lPart << "->" << G.P[ll1ParseTab[i][j].i].rPartSet[ll1ParseTab[i][j].j];
        }
        cout << endl;
      }
    }
}
```

Listing 8: buildLL1ParseTab 成员函数代码清单

5.0.8 ll1SyntaxAnalyze 成员函数的设计实现

代码（代码清单 9）如下：

```
bool SyntaxAnalyzer::ll1SyntaxAnalyze(const string& myLL1Input)
{
  if(myLL1Input.size() == 0)
  {
    cout << "Input is empty!" << endl;
    return false;
  }

  cout << "Parsing " << myLL1Input << "..." << endl;

  string str = myLL1Input;
  reverse(str.begin(), str.end());
  ll1Input = '$' + str;
  ll1Stack.push_back('$');
  ll1Stack.push_back(G.S);
```

```
16  int ip = ll1Input.size() - 1;
17  char x = ll1Stack[ll1Stack.size() - 1];
18
19  while(x != '$')
20  {
21    if(x == ll1Input[ip])
22    {
23      ll1Stack.erase(ll1Stack.end() - 1);
24      --ip;
25    }
26    else if(find(G.VT.begin(), G.VT.end(), x) != G.VT.
    end())
27    {
28      cout << "Parsing error!" << endl;
29      return false;
30    }
31    else
32    {
33      unsigned int row = find(G.VN.begin(), G.VN.end()
    , x) - G.VN.begin();
34      unsigned int col = (ll1Input[ip] == '$')? G.VT.
    size(): (find(G.VT.begin(), G.VT.end(), ll1Input[ip
    ]) - G.VT.begin());
35
36      if(ll1ParseTab[row][col].i >= G.P.size())
37      {
38        cout << "Parsing error!" << endl;
39        return false;
40      }
41      else
42      {
43        cout << G.P[ll1ParseTab[row][col].i].lPart <<
    "->" << G.P[ll1ParseTab[row][col].i].rPartSet[
    ll1ParseTab[row][col].j] << endl;
44        ll1Stack.erase(ll1Stack.end() - 1);
45        if(!(G.P[ll1ParseTab[row][col].i].rPartSet[
    ll1ParseTab[row][col].j].size() == 1 &&
46          G.P[ll1ParseTab[row][col].i].rPartSet[
    ll1ParseTab[row][col].j][0] == 'e'))
47        {
48          for(int cnt = G.P[ll1ParseTab[row][col].i].
    rPartSet[ll1ParseTab[row][col].j].size() - 1; cnt
    >= 0; --cnt)
49          {
50            ll1Stack.push_back(G.P[ll1ParseTab[row][
    col].i].rPartSet[ll1ParseTab[row][col].j][cnt]);
```

```
            }
          }
        }
      }
      x = ll1Stack[ll1Stack.size() - 1];
    }

    cout << "Parsing succeed!" << endl;
    return true;
}
```

Listing 9: `ll1SyntaxAnalyze` 成员函数代码清单

我们使用$作为分析栈初始栈顶符号。

6 测试数据及运行结果

该语法分析器对下面的3个测试语法正确运行。

文法 1:

$$\begin{aligned} &E \to TA \\ &A \to +TA|-TA|\varepsilon \\ &T \to FB \\ &B \to *FB|/FB|\varepsilon \\ &F \to (E)|0|1|2|3|4|5|6|7|8|9 \end{aligned} \tag{1}$$

文法 2:

$$\begin{aligned} &E \to E+T|E-T|T \\ &T \to T*F|T/F|F \\ &F \to (E)|0|1|2|3|4|5|6|7|8|9 \end{aligned} \tag{2}$$

文法 3:

$$\begin{aligned} &Z \to AA \\ &A \to aA|b \end{aligned} \tag{3}$$

对于文法 3 和含左递归的文法 2，LR(1)语法分析器可正确生成分析表，对于不含左递归的文法 1，LL(1)语法分析器可正确生成分析表。利用自动生成的分析表，LR(1)和LL(1)语法分析器均可正确解析下面的书写正确的复杂的一位数含括号四则运算表达式:

```
1+(1-3*(2-(8+9-7*6/2)/3+9+(1+3)-2)+1)/4
```

均不能正确解析书写错误的表达式（最后一个4之前缺少一个运算符）：

```
1+(1-3*(2-(8+9-7*6/2)/3+9+(1+3)-2)+1)4
```

运行结果截图如下:

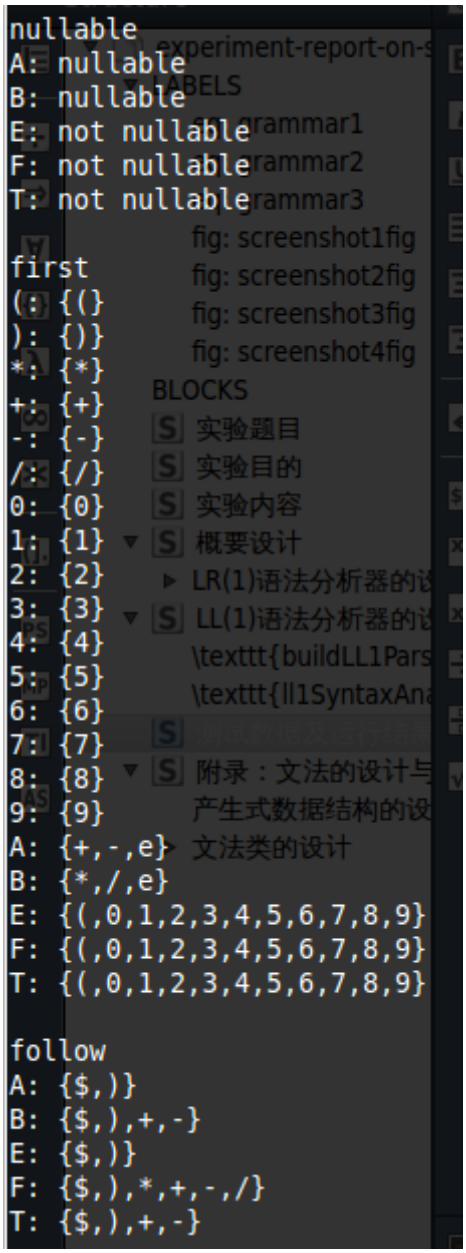
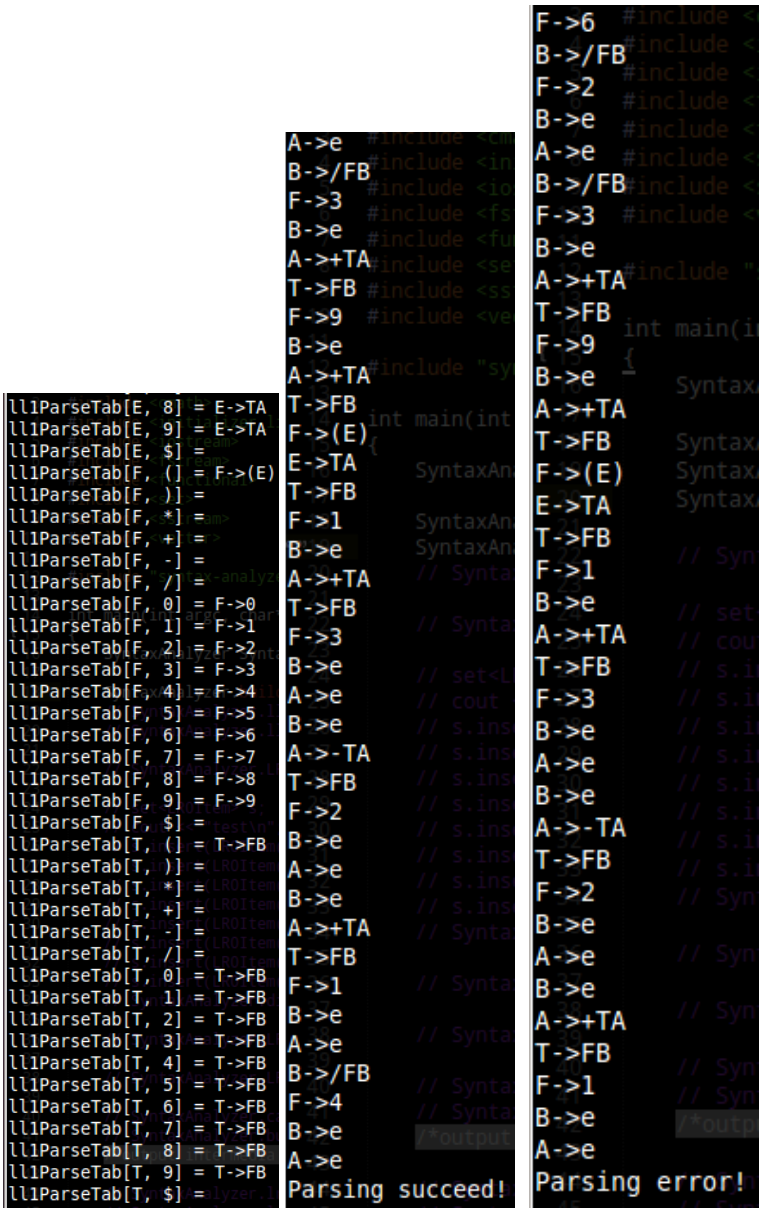
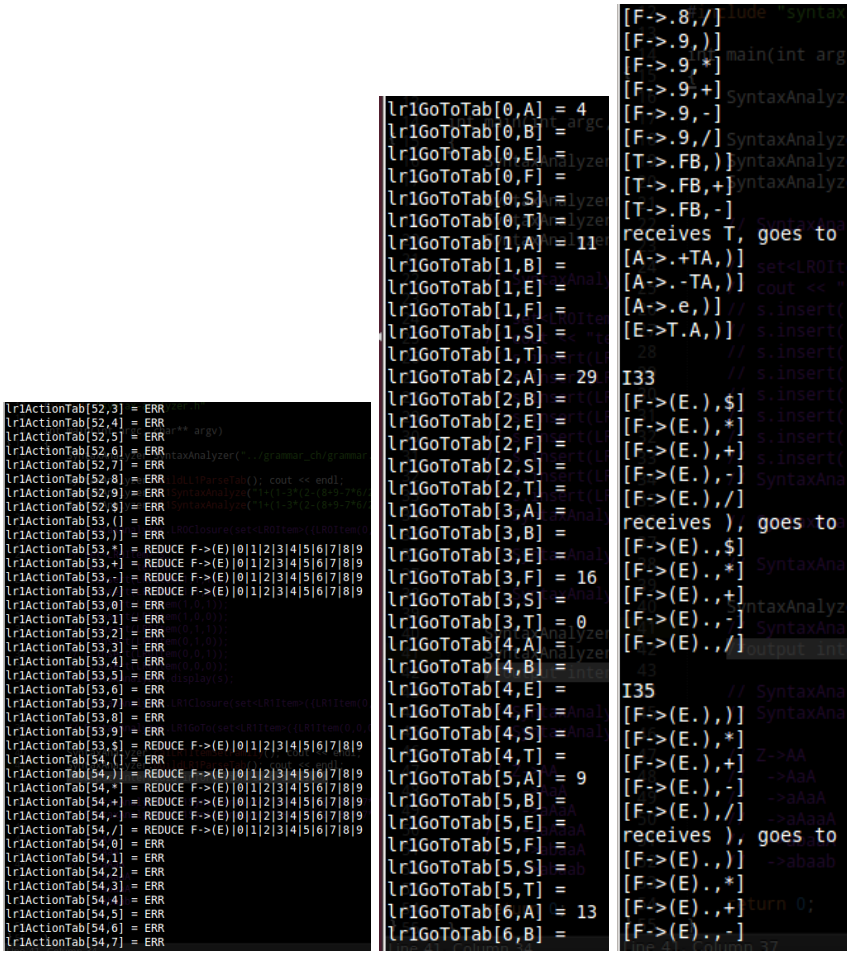

nullable
A: nullable
B: nullable
E: not nullable
F: not nullable
T: not nullable
first
(: {(}
): {)}
: {}
+: {+}
-: {-}
/: {/}
0: {0}
1: {1}
2: {2}
3: {3}
4: {4}
5: {5}
6: {6}
7: {7}
8: {8}
9: {9}
A: {+,-,e}
B: {*,/,e}
E: {(,0,1,2,3,4,5,6,7,8,9}
F: {(,0,1,2,3,4,5,6,7,8,9}
T: {(,0,1,2,3,4,5,6,7,8,9}
follow
A: {$,)}
B: {$,),+,-}
E: {$,)}
F: {$,),*,+,-,/}
T: {$,),+,-}
LABELS
grammar1
grammar2
grammar3
fig: screenshot1fig
fig: screenshot2fig
fig: screenshot3fig
fig: screenshot4fig
BLOCKS
实验题目
实验目的
实验内容
概要设计
LR(1)语法分析器的设
LL(1)语法分析器的设
\texttt{buildLL1Pars
\texttt{ll1SyntaxAna
附录：文法的设计与
产生式数据结构的设
文法类的设计

Figure 1: 文法



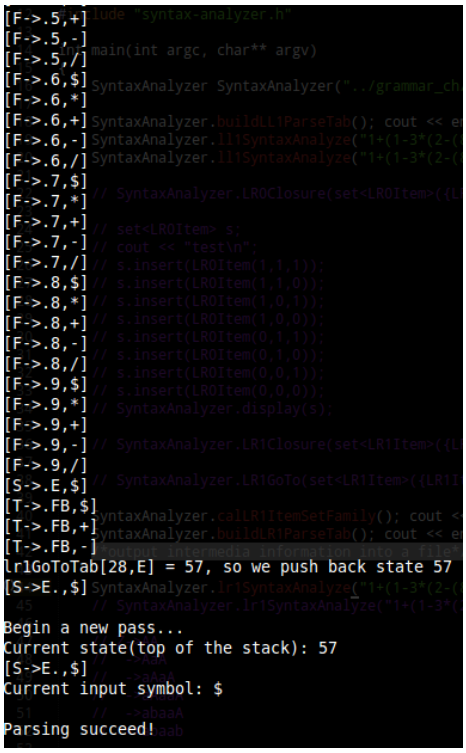
(a) LL(1)分析表　　(b) LL(1)解析成功　　(c) LL(1)解析失败

Figure 2: LL(1)语法分析器运行结果截图



(a) LR(1)Action分析表 (b) LR(1)Goto分析表 (c) LR(1)项集族

Figure 3: LR(1)语法分析器运行结果截图1



(a) LR(1)解析成功　　(b) LR(1)解析失败

Figure 4: LR(1)语法分析器运行结果截图2

7 附录：文法的设计与实现

7.1 产生式数据结构的设计

代码（代码清单 10）如下：

```
class ProductionRule
{
public:
  ProductionRule();
  ProductionRule(const char& l, const vector<string>&
   r);

  void display();

  char lPart;
  vector<string> rPartSet;

private:

};

ProductionRule::ProductionRule()
{

}

ProductionRule::ProductionRule(const char& l, const
   vector<string>& r): lPart(l), rPartSet(r)
{

}

void ProductionRule::display()
{
  cout << lPart << "->";
  for(size_t i = 0; i < rPartSet.size(); ++i)
  {
    cout << rPartSet[i];
    if(i != rPartSet.size() - 1)
    {
      cout << "|";
    }
  }
}
```

Listing 10: 产生式数据结构的设计代码清单

7.2 文法类的设计

代码（代码清单 11）如下：

```
class Grammar
{
public:
  Grammar(const string& filePath);

  void calNullableFirstFollow();

  void display();
  bool isNonTerminal(char ch);
  int getProductionRuleByLeft(ProductionRule& pr, char
    lPart); // return index of production rule which
   has lPart as left part
  set<char> getFirst(char ch);
  set<char> getFirst(string str);
  set<char> getFollow(char ch);

  vector<char> VN;
  vector<char> VT;
  vector<ProductionRule> P;
  char S;

  vector<bool> nullable; // for symbols in VN and VT,
   elements in VT are followed by elements in VN
  vector<set<char>> first; // for symbols in VN and VT
   , elements in VT are followed by elements in VN
  vector<set<char>> follow; // only for symbols in VN

private:

};
```

Listing 11: 文法类的设计代码清单

我们仅介绍构造函数 `calNullableFirstFollow` 成员函数的设计实现，其他函数仅用于输出信息和帮助对类的封装，不再赘述。

7.2.1 构造函数的设计实现

代码（代码清单 12）如下：

```
Grammar::Grammar(const string& filePath)
{
```

```
3   ifstream f(filePath);
4   assert(f);
5
6   // file format
7   // VNSize VN
8   // VTSize VT
9   // PSize
10  // P
11  // S
12
13  int VNSize;
14  f >> VNSize;
15  VN.resize(VNSize);
16  for(int i = 0; i < VNSize; ++i)
17  {
18    f >> VN[i];
19  }
20
21  int VTSize;
22  f >> VTSize;
23  VT.resize(VTSize);
24  for(int i = 0; i < VTSize; ++i)
25  {
26    f >> VT[i];
27  }
28
29  struct functor: public binary_function<
     ProductionRule, char, bool>{
30  public:
31    bool operator ()(const ProductionRule pr, const
     char ch) const {
32      return (pr.lPart == ch);
33    }
34  };
35
36  int PSize;
37  f >> PSize;
38  string str;
39  for(int i = 0; i < PSize; ++i)
40  {
41    f >> str;
42    vector<string> v_pr = split(str, '>');
43    v_pr[0].erase(v_pr[0].end() - 1);
44    vector<string> v_pr_r = split(v_pr[1], '|');
45
46    functor myFunctor;
```

```
47      auto itr = find_if(P.begin(), P.end(), bind2nd(
    myFunctor, *(v_pr[0].begin())));
48      if(itr == P.end())
49      {
50        ProductionRule pr;
51        pr.lPart = *(v_pr[0].begin());
52        for(size_t j = 0; j < v_pr_r.size(); ++j)
53        {
54          pr.rPartSet.push_back(v_pr_r[j]);
55        }
56        P.push_back(pr);
57      }
58      else
59      {
60        for(size_t j = 0; j < v_pr_r.size(); ++j)
61        {
62          P[itr - P.begin()].rPartSet.push_back(v_pr_r[j
    ]);
63        }
64      }
65
66    }
67
68    f >> S;
69
70    f.close();
71
72    sort(VN.begin(), VN.end());
73    sort(VT.begin(), VT.end());
74    for(size_t i = 0; i < P.size(); ++i)
75    {
76      sort(P[i].rPartSet.begin(), P[i].rPartSet.end());
77    }
78    sort(P.begin(), P.end(),
79      [](ProductionRule pr1, ProductionRule pr2)
80      {
81        return pr1.lPart < pr2.lPart?
82          true: (pr1.lPart > pr2.lPart?
83            false: pr1.rPartSet[0] < pr2.rPartSet[0]);
84      });
85
86    nullable.assign(VN.size(), false);
87    first.assign(VN.size() + VT.size(), set<char>());
88    follow.assign(VN.size(), set<char>());
89
90    display();
```

```
91
92    calNullableFirstFollow();
93  }
```

Listing 12: 构造函数的设计实现代码清单

该文法类从格式化文本中读入信息并解析后完成初始化。

7.2.2 calNullableFirstFollow 成员函数的设计实现

代码（代码清单 13）如下：

```
1  void Grammar::calNullableFirstFollow()
2  {
3    // calculate nullable
4
5    for(size_t i = 0; i < P.size(); ++i)
6    {
7      for(size_t j = 0; j < P[i].rPartSet.size(); ++j)
8      {
9        if(P[i].rPartSet[j].size() == 1 && *(P[i].
     rPartSet[j].begin()) == 'e')
10       {
11         nullable[i] = true;
12         break;
13       }
14     }
15   }
16
17   bool updated = true;
18   while(updated)
19   {
20     updated = false;
21
22     for(size_t i = 0; i < P.size(); ++i)
23     {
24       for(size_t j = 0; j < P[i].rPartSet.size(); ++j)
25       {
26         bool allNullable = true;
27         for(size_t k = 0; k < P[i].rPartSet[j].size();
     ++k)
28           {
29             auto ptr = find(VN.begin(), VN.end(), P[i].
     rPartSet[j][k]);
30             if(ptr == VN.end() || !nullable[ptr - VN.
     begin()])
```

```
          {
            allNullable = false;
            break;
          }
        }

        if(allNullable && !nullable[i])
        {
          updated = true;
          nullable[i] = true;
          break;
        }
      }
    }
  }

  // calculate first

  for(size_t i = 0; i < VT.size(); ++i)
  {
    first[i].insert(VT[i]);
  }

  updated = true;
  while(updated)
  {
    updated = false;

    for(size_t i = 0; i < P.size(); ++i)
    {
      for(size_t j = 0; j < P[i].rPartSet.size(); ++j)
      {
        int idx = find(VN.begin(), VN.end(), P[i].
   lPart) - VN.begin() + VT.size();

        int l = 0;
        for(size_t k = 0; k < P[i].rPartSet[j].size();
    ++k)
        {
          auto ptr = find(VN.begin(), VN.end(), P[i].
   rPartSet[j][k]);
          if(ptr == VN.end() || !nullable[ptr - VN.
   begin()])
          {
            break;
          }
```

```
73            else
74            {
75              ++l;
76
77              int oldSize = first[idx].size();
78              int newSize = 0;
79              auto ptr = find(VN.begin(), VN.end(), P[i
    ].rPartSet[j][k]);
80              setUnion(first[idx], first[ptr - VN.begin
    () + VT.size()]);
81              newSize = first[idx].size();
82              if(oldSize != newSize)
83              {
84                updated = true;
85              }
86            }
87          }
88
89          ////////////////////////////////
90          // cout << P[i].lPart << "->" << P[i].rPartSet
    [j] << " " << l << endl;
91
92          int oldSize = first[idx].size();
93          int newSize = 0;
94          if(l >= P[i].rPartSet[j].size())
95          {
96            first[idx].insert('e');
97            newSize = first[idx].size();
98          }
99          else
100         {
101           auto ptr = find(VN.begin(), VN.end(), P[i].
    rPartSet[j][l]);
102           if(ptr == VN.end())
103           {
104             if(P[i].rPartSet[j][l] != 'e')
105             {
106               setUnion(first[idx], first[find(VT.begin
    (), VT.end(), P[i].rPartSet[j][l]) - VT.begin()]);
107
108               ////////////////////////////////
109               // cout << i << " " << idx << " ";
110               // ::display(first[find(VT.begin(), VT.
    end(), P[i].rPartSet[j][l]) - VT.begin()]); cout <<
     endl << endl;
111             }
```

```
112             else
113             {
114               setUnion(first[idx], set<char>({'e'}));
115             }
116           }
117           else
118           {
119             setUnion(first[idx], first[ptr - VN.begin
    () + VT.size()]);
120           }
121
122           newSize = first[idx].size();
123         }
124
125         if(oldSize != newSize)
126         {
127           updated = true;
128         }
129       }
130     }
131   }
132
133   // sth about $ and e
134
135   follow[find(VN.begin(), VN.end(), S) - VN.begin()].
     insert('$');
136
137   updated = true;
138   while(updated)
139   {
140     updated = false;
141
142     for(size_t i = 0; i < P.size(); ++i)
143     {
144       for(size_t j = 0; j < P[i].rPartSet.size(); ++j)
145       {
146         int idx = find(VN.begin(), VN.end(), P[i].
    lPart) - VN.begin();
147
148         for(size_t k = 0; k < P[i].rPartSet[j].size();
     ++k)
149         {
150           bool allNullable1 = true;
151           for(size_t cnt = k + 1; cnt < P[i].rPartSet[
    j].size(); ++cnt)
152           {
```

```
153             if(P[i].rPartSet[j][cnt] != 'e')
154             {
155               auto cntPtr = find(VN.begin(), VN.end(),
     P[i].rPartSet[j][cnt]);
156               if(cntPtr == VN.end() || !nullable[
    cntPtr - VN.begin()])
157               {
158                 allNullable1 = false;
159                 break;
160               }
161             }
162             else
163             {
164               break;
165             }
166           }
167           if(allNullable1)
168           {
169             auto kPtr = find(VN.begin(), VN.end(), P[i
    ].rPartSet[j][k]);
170             if(kPtr != VN.end())
171             {
172               int oldSize = follow[kPtr - VN.begin()].
    size();
173               setUnion(follow[kPtr - VN.begin()],
    follow[idx]);
174               int newSize = follow[kPtr - VN.begin()].
    size();
175               if(oldSize != newSize)
176               {
177                 updated = true;
178               }
179             }
180           }
181
182           for(size_t l = k + 1; l < P[i].rPartSet[j].
    size(); ++l)
183           {
184             bool allNullable2 = true;
185             for(int cnt = k + 1; cnt < l - 1; ++cnt)
186             {
187               if(P[i].rPartSet[j][cnt] != 'e')
188               {
189                 auto cntPtr = find(VN.begin(), VN.end
    (), P[i].rPartSet[j][cnt]);
190               if(cntPtr == VN.end() || !nullable[
```

```
    cntPtr - VN.begin()])
                {
                  allNullable2 = false;
                  break;
                }
              }
              else
              {
                break;
              }
            }
            if(allNullable2)
            {
              auto kPtr = find(VN.begin(), VN.end(), P
[i].rPartSet[j][k]);
              if(kPtr != VN.end())
              {
                auto lPtr = find(VN.begin(), VN.end(),
 P[i].rPartSet[j][l]);
                int lIdx = (lPtr == VN.end())?
                  (find(VT.begin(), VT.end(), P[i].
rPartSet[j][l]) - VT.begin()):
                  (lPtr - VN.begin() + VT.size());
                int oldSize = follow[kPtr - VN.begin()
].size();
                set<char> __first__ = first[lIdx];
                __first__.erase('e');
                setUnion(follow[kPtr - VN.begin()],
__first__);
                int newSize = follow[kPtr - VN.begin()
].size();
                if(oldSize != newSize)
                {
                  updated = true;
                }
              }
            }
          }
        }
      }
    }
  }

  // display nullable
  cout << "nullable" << endl;
  for(size_t i = 0; i < nullable.size(); ++i)
```

```
230   {
231     cout << VN[i] << ": " << ((nullable[i])? "nullable
       ": "not nullable") << endl;
232   }
233   cout << endl;
234
235   // display first
236   cout << "first" << endl;
237   for(size_t i = 0; i < first.size(); ++i)
238   {
239     if(i < VT.size())
240     {
241       cout << VT[i] << ": ";
242       ::display(first[i]);
243       cout << endl;
244     }
245     else
246     {
247       cout << VN[i - VT.size()] << ": ";
248       ::display(first[i]);
249       cout << endl;
250     }
251   }
252   cout << endl;
253
254   // display follow
255   cout << "follow" << endl;
256   for(size_t i = 0; i < follow.size(); ++i)
257   {
258     cout << VN[i] << ": ";
259     ::display(follow[i]);
260     cout << endl;
261   }
262   cout << endl;
263 }
```

Listing 13: `calNullableFirstFollow` 成员函数代码清单

递归的计算方法要求指定求值顺序这一问题，为了避开这一棘手的问题，我们使用迭代至不懂点的方法求 `nullable` 集，`first` 集和 `follow`集。需要说明的是，我们使用字符 `e` 表示空串，并对它进行不同于其他终结符的特殊处理。