CSC4180 Assignment 3: Parsing Techniques

Release Date: March 21, 2024
Due Date: April 10, 2023

Any kind of plagiarism is not tolerated and will get zero point!!!

Q1: Resolve Ambiguity for Micro Language's Grammar (20%)

Recall the context-free grammar of Micro Language that we worked on in Assignment 1, you may now notice that the grammar turns out to be ambiguous, which means there exists multiple different parse trees for the same input string. **Please answer the following questions:**

1. An tricky way to argue that a grammar is ambiguous is to give a counter-example input that can be parsed in at least two different ways. Can you come up with such an example for Micro's grammar to show that the grammar is ambiguous? (10%)
2. However, to determine whether a grammar is not ambiguous can be hard, but we can take advantage of the LL(1) parsing table.
   (a) If there are multiply defined entries in the LL(1) parsing table of the grammar, can we say this grammar must be ambiguous? Answer "Yes" or "No" and briefly explain why within 50 words. (5%)
   (b) If there is no multiply defined entry in the LL(1) parsing table of the grammar, can we say this grammar is definitedly not ambiguous? Answer "Yes" or "No" and briefly explain why within 50 words. (5%)

Recall: Micro's Context-Free Grammar

Here is the extended CFG defining Micro Language:

```
1. <program> → BEGIN <statement list> END
2. <statement list> → <statement> {<statement>}
3. <statement> → ID ASSIGNOP <expression>;
4. <statement> → READ LPAREN <id list> RPAREN;
5. <statement> → WRITE LPAREN<expr list> RPAREN;
6. <id list > → ID {COMMA ID}
7. <expr list > → <expression> {COMMA <expression>}
8. <expression> → <primary> {<add op> <primary>}
9. <primary> → LPAREN <expression> RPAREN
10. <primary> → ID
11. <primary> → INTLITERAL
12. <add op> → PLUOP
13. <add op> → MINUSOP
14. <system goal> → <program> SCANEOF
```

Contents inside {} means that it can appear 0, 1 or multiple times.

Q2: Simple LL(1) and LR(0) Parsing Exercises (30%)

In this section, you are required to play with the web demos of LL(1) and LR(0) provided by Princeton University, and do some exercises related to these two parsing techniques.

LL(1) Parser Visualization Web Demo

LR(0) Parser Visualization Web Demo

Please answer this question according to the following step-by-step instruction:

LL(1) Grammar (20%)

Here is a simple grammar and a corresponding input string to parse.

```
E -> T | T + E
T -> int | int * T | ( E )
```

```
Input String: int + int * int
```

1. Modify the grammar to make it LL(1)
   - You can use the LL(1) web demo to see which entries in the parsing table are multiply defined.
   - Recall your answer in Q1, find out what the problem is to the grammar and how to fix it. **(Hints: left recursion elimination or left factoring?)**
2. Translate your LL(1) grammar in the format that the LL(1) web demo can recognize, and then generate all intermediate tables, and parse the input string.
   - Notice that ϵ(empty string) should be denoted as two consequent single-quotes instead of one double-quotes.
   - Take a screenshot of the two tables (one is nullable, first and follow sets, and the other is parsing table) and include them in your report.
3. Perform the parsing step by step in the playground to get the final parse tree.
   - Take a screenshot of the parse tree generated in the web demo, and include it in your report.

LR(0) Grammar (10%)

1. Play with the LR(0) web demo with its default grammar
   - Take a screenshot of the LR(0) automaton (both table and DFA diagram), and include it in your report.
2. Try in web demos and see if the default LR(0) grammar also LL(1), if the sample LL(1) grammar also LR(0)
   - Briefly explain why the LL(1) grammar is not LR(0) with the help of the LR parsing table. You need to clearly specify which conflict occurs in LR(0) parsing and why that conflict fails the LR parsing instead of telling me that there is a red row in the parsing table.

Q3: Implement LL(1) Parser by hand for Oat v.1 (50%)

As a top-down parsing algorithm, LL(1) parsing is very intuitive and is easy to implement by hand. In this section, you are required to implement a top-down LL(1) parser by hand with the LL(1) grammar of Oat v.1 Language provided. No template will be provided and you can write your programs in anyway you like.

Important Checkpoints and Grading

1. Read the input LL(1) grammar file and parse its format correctly (10%)
2. Compute the nullable and first set correctly (10%)
3. Compute the follow set correctly (10%)
4. Construct the LL(1) parsing table correctly (10%)
5. Parse input token streams correctly (10%)
6. A very brief report that only covers how to compile and execute your program to get expected output.

Important Suggestions

- **Generating a parse tree is enough. Abstract syntax tree (AST) is only for bonus.**
- The provided LL(1) grammar is well formatted for the web demo. Feel free to try the grammar online and verify all the intermediate results you generated with the ones shown in the web demo to make sure that you are on the right track.
- Constructing the LL(1) grammar for Oat v.1 Language is pretty hard. It has been tested on some of the testcases in Assignment 2, but it may fails to some other Oat v.1 programs. If you find any errors, please let the TA know and he will change the grammar.

Review of LL(1) Parsing Algorithm

1. Compute First and Follow Set

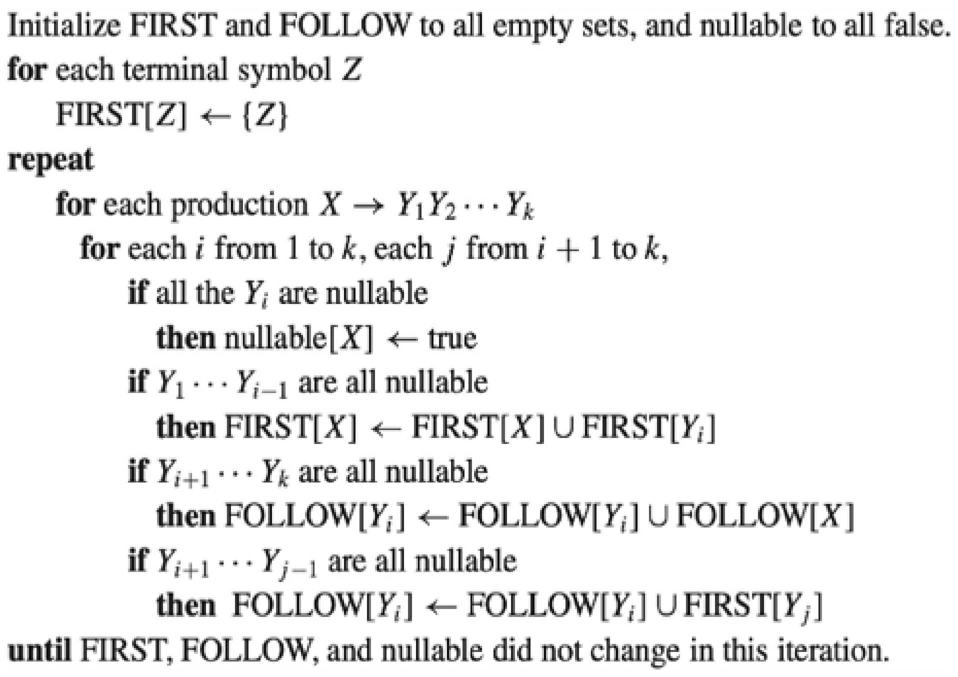
Refer to Figure 1: Algorithm to Compute Nullable, First and Follow Set

2. Construct the Parsing Table

Once we have the first and follow sets, we build a table M with the leftmost column labeled with all the nonterminals in the grammar, and the top row labeled with all the terminals in the grammar, along with \$. The following algorithm fills in the table cells:

1. For each production rule $A \to u$ of the grammar, do steps 2 and 3
2. For each terminal a in First(u), add $A \to u$ to M[A,a]
3. If ϵ in First(u), (i.e. A is nullable) add $A \to u$ to M[A,b] for each terminal b in Follow(A), If ϵ in First(u), and \$ is in Follow(A), add $A \to u$ to M[A,\$]
4. All undefined entries are errors

The concept used here is to consider a production $A \to u$ with a in First(u). The parser should expand A to u when the current input symbol is a. It is a little trickier when $u = \epsilon$ or $u \to *\epsilon$. In this case, we should expand A to u if the current input symbol is in Follow(A), or if the \$ at the end of the input has been reached, and \$ is in Follow(A). If the procedure ever tries to fill in an entry of the table that already has a nonerror entry, the procedure fails— the grammar is not LL(1).



```
Initialize FIRST and FOLLOW to all empty sets, and nullable to all false.
for each terminal symbol $Z$
    FIRST[Z] $\leftarrow$ {Z}
repeat
    for each production $X \rightarrow Y_1 Y_2 \cdots Y_k$
      for each $i$ from 1 to $k$, each $j$ from $i+1$ to $k$,
        if all the $Y_i$ are nullable
          then nullable[$X$] $\leftarrow$ true
        if $Y_1 \cdots Y_{i-1}$ are all nullable
          then FIRST[$X$] $\leftarrow$ FIRST[$X$] $\cup$ FIRST[$Y_i$]
        if $Y_{i+1} \cdots Y_k$ are all nullable
          then FOLLOW[$Y_i$] $\leftarrow$ FOLLOW[$Y_i$] $\cup$ FOLLOW[$X$]
        if $Y_{i+1} \cdots Y_{j-1}$ are all nullable
          then FOLLOW[$Y_i$] $\leftarrow$ FOLLOW[$Y_i$] $\cup$ FIRST[$Y_j$]
until FIRST, FOLLOW, and nullable did not change in this iteration.
```

Figure 1: Algorithm to Compute Nullable, First and Follow Set

3. The LL(1) Parsing Algorithm

Suppose a grammar has start symbol S and LL(1) parsing table T. We want to parse string ω in the following way:

1. Initialize a stack containing $S\omega$
2. Repeat until the stack is empty:
    - Let the next character of ω be t.
    - If the top of the stack is a terminal symbol r:
        - If r and t do not match, report an error.
        - Otherwise, consume the character t and pop r from the stack.
    - Otherwise, the top of the stack is a non-terminal symbol A:
        - If T[A, t] is undefined, report an error.
        - Replace the top of the stack with T[A, t].

Oat v.1 Language Specification

- Oat v.1 Language Specification Document (Reserved Words Highlighted)
- Oat v.1 Detailed Explanation by Prof.Steve Zdancewic, COS320: Compiling Techniques, University of Princeton

LL(1) Grammar for Oat v.1 Language (in LL(1) web demo format)

The txt file of the following LL(1) grammar for Oat v.1 Language has been uploaded to BlackBoard and our GitHub repository as well.

```
prog ::= decl prog
prog ::= ''
decl ::= gdecl
decl ::= fdecl
gdecl ::= global id = gexp ;
```

```
fdecl ::= t id ( args ) block
vdecls ::= vdecl vdecls'
vdecls ::= ''
vdecls' ::= , vdecls
vdecls' ::= ''
vdecl ::= var id = exp
args ::= ''
args ::= arg args'
args' ::= , args
args' ::= ''
arg ::= t id
block ::= { stmts }

t ::= primary_t t_arr
t_arr ::= [ ]
t_arr ::= ''
primary_t ::= int
primary_t ::= bool
primary_t ::= string

gexps ::= gexp gexps'
gexps ::= ''
gexps' ::= , gexps
gexps' ::= ''
gexp ::= intliteral
gexp ::= stringliteral
gexp ::= t null
gexp ::= true
gexp ::= false
gexp ::= new t { gexps }

stmts ::= stmt stmts
stmts ::= ''
stmt ::= id stmt'
stmt' ::= = exp ;
stmt' ::= ( exps ) lhs_idx
lhs_idx ::= [ exp ] = exp ;
lhs_idx ::= ;
stmt ::= vdecl ;
stmt ::= return exp ;
stmt ::= if_stmt
stmt ::= for ( vdecls ; exp_opt ; stmt_opt ) block
stmt ::= while ( exp ) block
stmt_opt ::= stmt
stmt_opt ::= ''
exp_opt ::= exp
exp_opt ::= ''
if_stmt ::= if ( exp ) block else_stmt
else_stmt ::= ''
else_stmt ::= else else_body
else_body ::= block
else_body ::= if_stmt

exps ::= exp exps'
exps ::= ''
exps' ::= , exps
exps' ::= ''

exp ::= exp_30
exp_30 ::= exp_40 exp_30'
exp_30' ::= bop_30 exp_40 exp_30'
exp_30' ::= ''
```

```
exp_40 ::= exp_50 exp_40'
exp_40' ::= bop_40 exp_50 exp_40'
exp_40' ::= ''
exp_50 ::= exp_60 exp_50'
exp_50' ::= bop_50 exp_60 exp_50'
exp_50' ::= ''
exp_60 ::= exp_70 exp_60'
exp_60' ::= bop_60 exp_70 exp_60'
exp_60' ::= ''
exp_70 ::= exp_80 exp_70'
exp_70' ::= bop_70 exp_80 exp_70'
exp_70' ::= ''
exp_80 ::= exp_90 exp_80'
exp_80' ::= bop_80 exp_90 exp_80'
exp_80' ::= ''
exp_90 ::= exp_100 exp_90'
exp_90' ::= bop_90 exp_100 exp_90'
exp_90' ::= ''
exp_100 ::= term exp_100'
exp_100' ::= bop_100 term exp_100'
exp_100' ::= ''

bop_100 ::= *
bop_90 ::= +
bop_90 ::= -
bop_80 ::= <<
bop_80 ::= >>
bop_80 ::= >>>
bop_70 ::= <
bop_70 ::= <=
bop_70 ::= >
bop_70 ::= >=
bop_60 ::= ==
bop_60 ::= !=
bop_50 ::= &
bop_40 ::= |
bop_30 ::= [ bop_30'
bop_30' ::= | ]
bop_30' ::= & ]

term ::= primary
term ::= uop primary
primary ::= id id'
id' ::= ''
id' ::= ( exps )
primary ::=  intliteral
primary ::=  stringliteral
primary ::= t null
primary ::= true
primary ::= false
primary ::= ( exp )

uop ::= -
uop ::= !
uop ::= ~
```

Bonus: (Extra Credits 10%)

If some of you want to challenge yourself and do something harder, here are some alternatives that you can refer to:

1. Implement a Bottom-Up Parser using Bison (LALR) for Oat v.1 Language

- Take advantage of the flex scanner you implemented in Assignment 2.
- Be careful when dealing with the left associativity and precedence for binary operators in bison.
- You can choose parser generators other than bison to finish this task.
- Other extra work that you have done in Q3: handwritten LL(1) parser will also receive some extra credits.

2. Generate Abstract Syntax Tree from the Parse Tree

Obviously, there are too many redundant information and nodes in the generated parse tree, and you may remove those redundancy and get a clean version of AST.

Other extra work that you have done in Q3: handwritten LL(1) parser will also receive some extra credits.

Extra Credit Policy

The extra credits are not going to be added to your final grade since this is an elective course and many of you are interested in compiler and want to do some advanced work. In other words, the extra credits you earn cannot be added to the grade of any programming assignment to make it higher. However, these credits can serve as a proof of your interest and hard work for this course, and I will try my best to offer as high A- rate as I can, probably higher than 40%, by consulting with Prof.CHUNG.

Submission

Policy of Late Submission

- Late submission within 10 minutes after then DDL is tolerated for possible network issues during submission.
- 10 Points deducted for each day after the DDL (11 minutes late will be considered as one day, so be careful)
- Zero point if you submitted your project late for more than two days

Submission with Source Code

There is no template for task 3 and 4, so you can submit your codes in any format you like.

```
csc4180—a2—118010200.zip
|—
|——— csc4180—a2—118010200—report.pdf
|—
|——— testcases
|—
|——— src
                  | All  your  source   files
```

Submission with Docker

If you want to submit your program in a docker, your submission should look like:

```
csc4180—a2—118010200.zip
|—
|——— csc4180—a2—118010200.Dockerfile
|—
|——— csc4180—a2—118010200—report.pdf
|—
|——— src
          |—
          |———Makefile
          |—
          |———run_compiler.sh
          |—
          |———Other possible files
```