POLITECNICO DI TORINO

(01JEUHT) Formal Languages and Compilers

Laboratory N°3

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Cup Advanced Use

- Grammars with ambiguities
- Lists
- Operator precedence
- Handling syntax errors

Ambiguous grammars in CUP

- Conflicts can arise when the grammar is ambiguous
- This implies that the parser must choose between two or more alternative actions.
- The problem can be solved by modifying the grammar (in order to make it non-ambiguous) or by instructing the parser on how to handle ambiguity.
- The latter option requires that the parsing algorithm is fully understood, in order to avoid unwanted / wrong behaviors.

Ambiguous Grammar

- A grammar is ambiguous if there is at least one sequence of symbols for which two or more distinct parse trees exist.
- Exercise: find all parse trees for

```
if (i==1) if (j==2) a=0; else a=1;
```

given the grammar:

- S ::= M ;
- M ::= ‘if’ C M ;
- M ::= ‘if’ C M ‘else' M ;
- M ::= ID ‘=‘ NUM ‘;’ | ID ‘=‘ ID ‘;’ ;
- C ::= ‘(‘ VAR ‘==‘ NUM ‘)’

Non-ambiguous grammar: if-then-else statement

- It is possible to write a non-ambiguous grammar for the if-else statements, as follows:
  - S ::= M | U ;
  - U ::= ‘if’ C S ;
  - U ::= ‘if’ C M ‘else’ U ;
  - M ::= ‘if’ C M ‘else’ M ;
  - M ::= ID ‘=‘ NUM ‘;’ | ID ‘=‘ ID ‘;’ ;
  - C ::= ‘(‘ ID‘==‘ NUM ‘)’ ;
- `if (i==1) if (j==2) a=0; else a=1;`

Non-ambiguous grammar : Algebraic expressions

- The non-ambiguous grammar that describes algebraic expressions is:

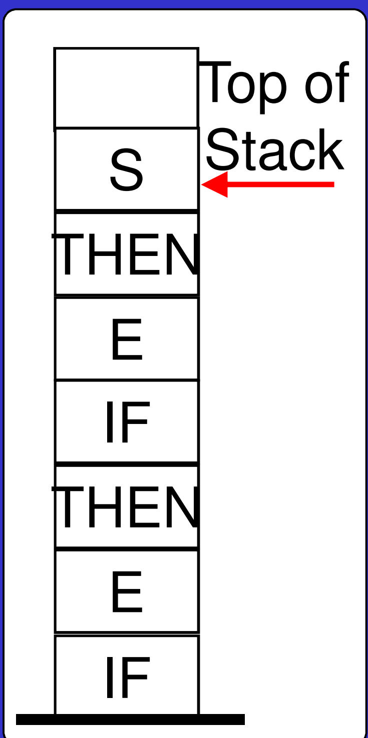
```
S ::= E
E ::= E '+' T
E ::= E '-' T
E ::= T
T ::= T '*' F
T ::= T '/' F
T ::= F
F ::= '(' E ')'
F ::= NUM
```

- The symbols T and F are used to solve the ambiguity given by the priority of operators ‘*’ and ‘/’ over the operators ‘+’ e ‘-’ .

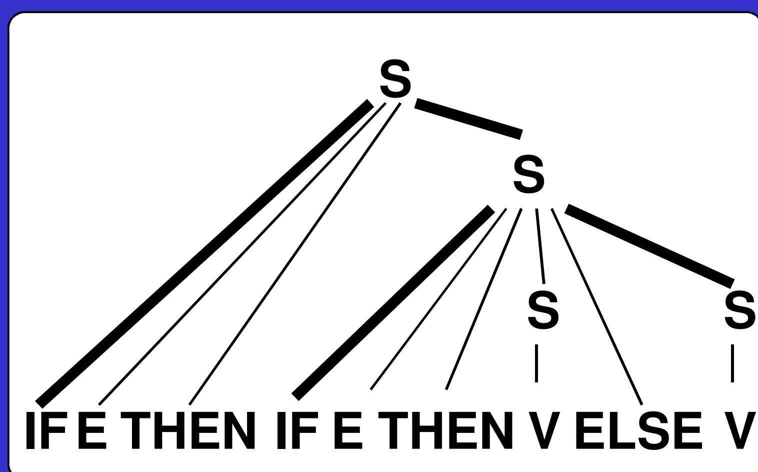
Ambiguous grammars in Cup: shift-reduce conflict (I)

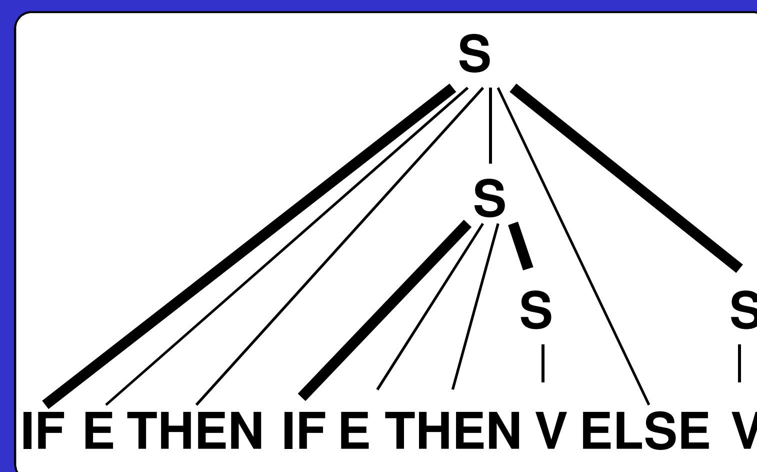
1) S ::= IF E THEN S
2) S ::= IF E THEN S ELSE S
3) S ::= V

- Input: IF E THEN IF E THEN S (*) ELSE S
- The next token is 'ELSE'
- 2 possible actions:



- **SHIFT 'ELSE' token into the Stack**
  => Rule 2
- **REDUCE the first 4 top elements of the Stack**
  => Rule 1



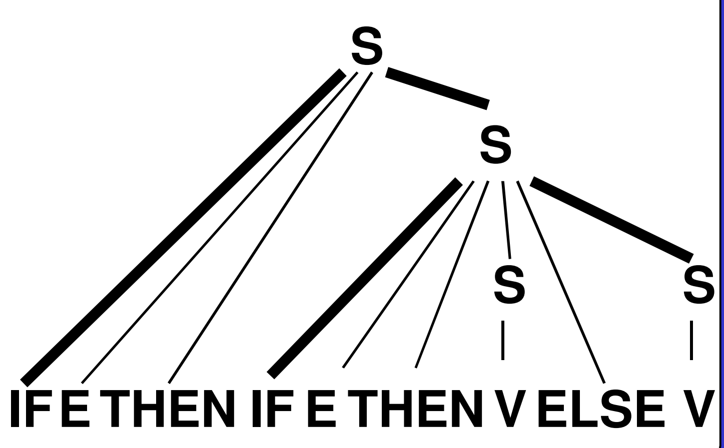


Ambiguous grammars in Cup: shift-reduce conflict (II)

1) S ::= IF E THEN S
2) S ::= IF E THEN S ELSE S
3) S ::= V

Input

IF E THEN IF E THEN V ELSE V



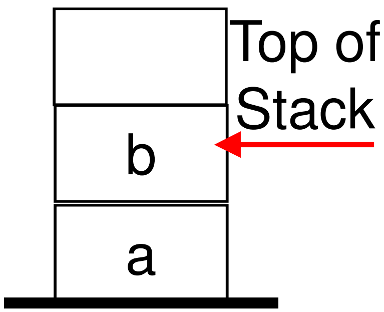
*** Shift/Reduce conflict found in state #8
between S ::= IF E THEN S (*)
and S ::= IF E THEN S (*) ELSE S
under symbol ELSE

Resolved in favor of shifting.

Cup performs a ***shift*** action.

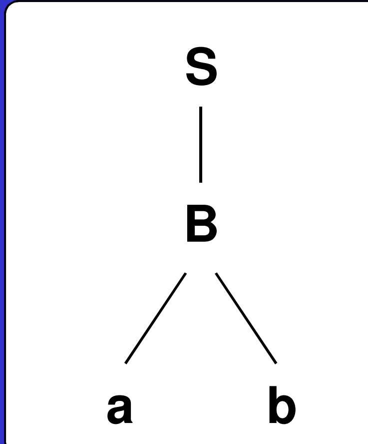
Ambiguous grammars in Cup: reduce-reduce conflict (I)

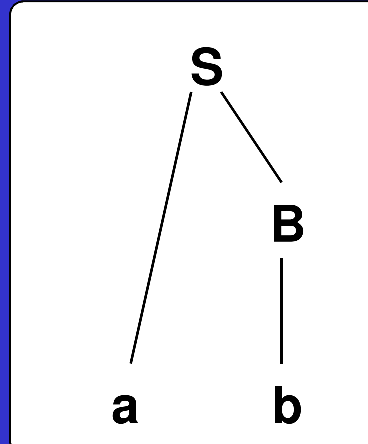
Input
a b



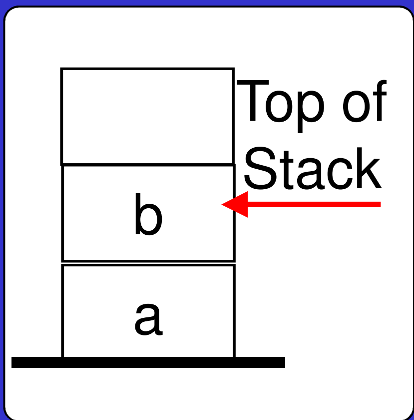
1) S ::= a B
2) S ::= B
3) B ::= a b
4) B ::= b

- The next token is EOF
- 2 possible actions:
  - **REDUCE the first 2 top elements of the Stack**
    => Rule 3
  - **REDUCE the first top element of the Stack**
    => Rule 4





Ambiguous grammars in Cup: reduce-reduce conflict (II)



1) S ::= a B
2) S ::= B
3) B ::= a b
4) B ::= b

```
***  Reduce/Reduce conflict found in state #7
         between B ::= b (*)
         and B ::= a  b (*)
         under  symbols: {EOF}

Resolved in favor of the second production.
```

Cup performs a reduction using the first defined rule (3) .

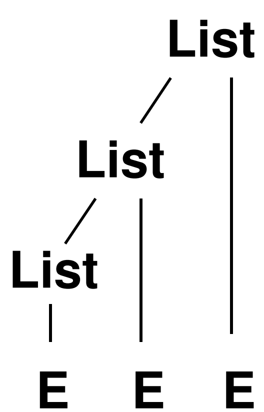
Lists (I)

- Examples of lists:
  - List with at least one element E, separated with commas C:

```
List ::= List  E | E ; //without C
List ::= List  C E | E ;
```

Parse tree

List of 3 E (without C)

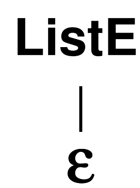


  - List of elements, possibly empty (first example):

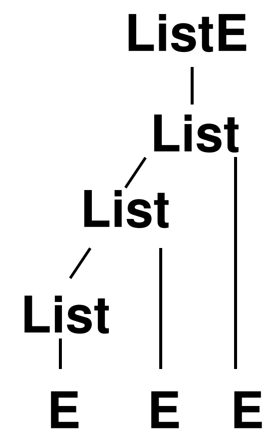
```
ListE ::=  ε | List ;
List ::= List  E | E ;
```

Parse tree

Empty list



List of 3 E

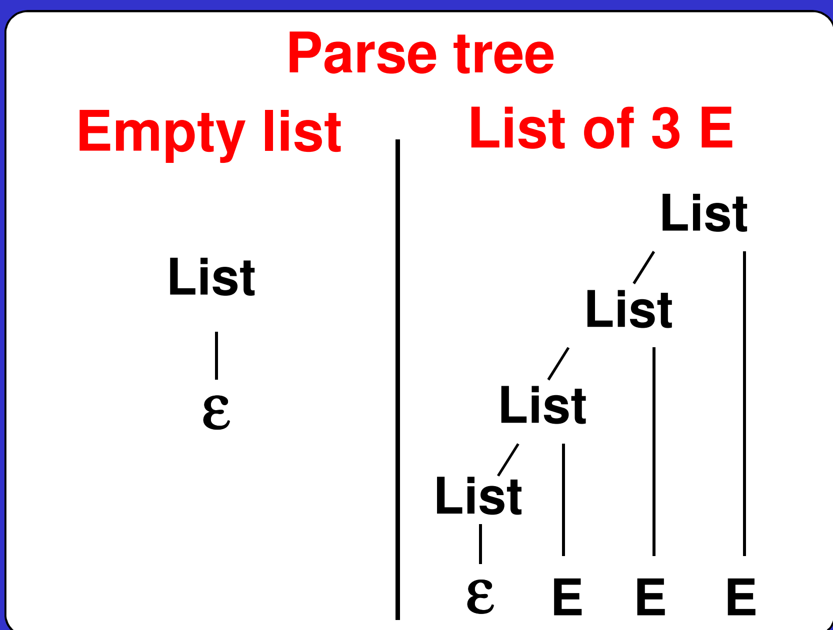


Lists (II)

Same sequence of input tokens, 2 different parse trees => AMBIGUOUS GRAMMAR

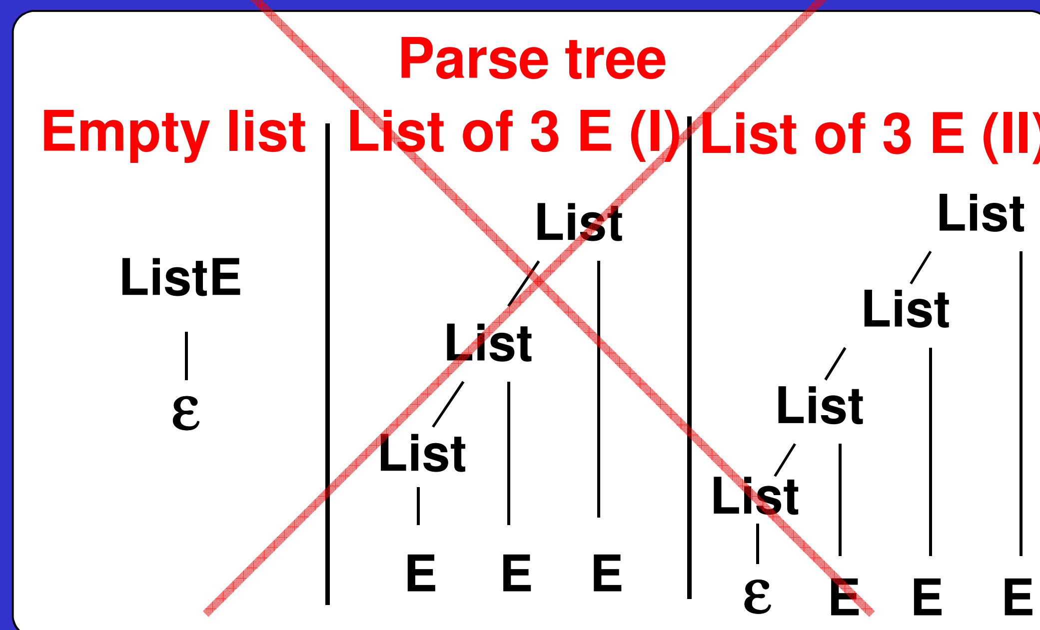
- Examples of lists:
  - List of elements, possibly empty (second example):

    List ::= List E | ε ;



  - List of elements, possibly empty (WRONG example):

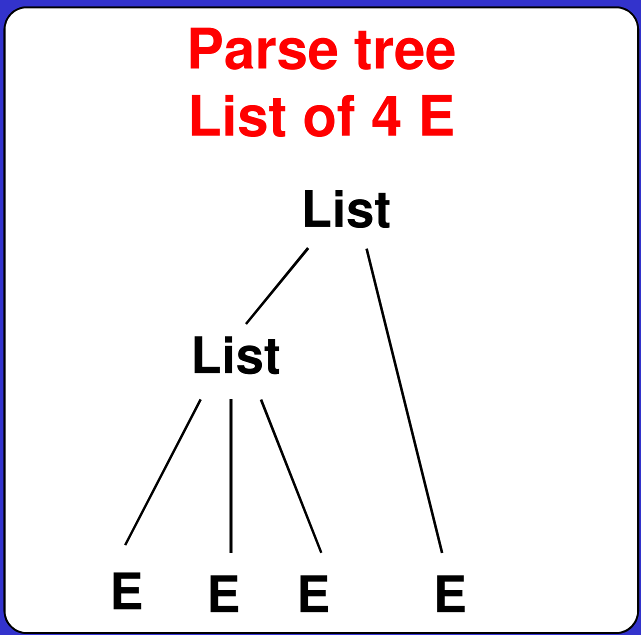
    ~~List ::= List E | E | ε ;~~



Lists (III)

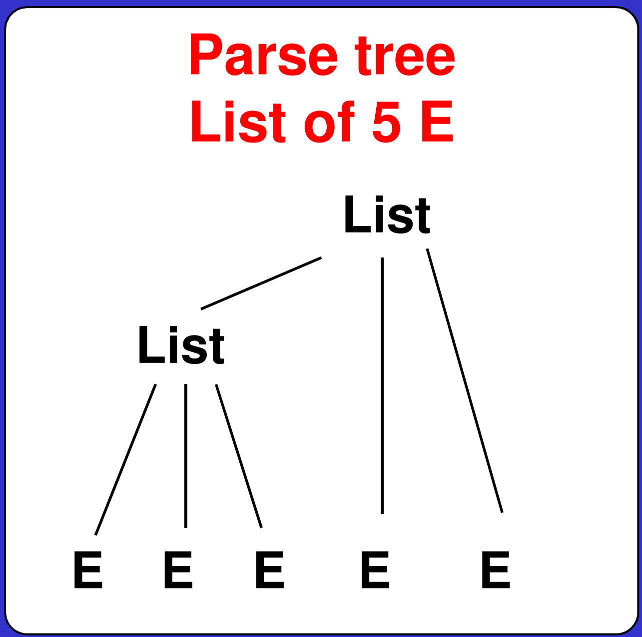
- Examples of lists:
  - List of at least 3 elements:

```
List ::= List  E |  E E E ;
```



  - List of at least 3 elements in an odd number:

```
List ::= List  E E  |  E E E;
```



Precedence Section: Ambiguous grammars

- Ambiguous grammars can result in fewer, simpler rules, and hence can be sometimes preferred.
- It is necessary to provide disambiguating rules in those cases.
- A typical example is given by algebraic expressions:

Non-ambiguous grammar

```
S ::= E
E ::= E '+' T
E ::= E '-' T
E ::= T
T ::= T '*' F
T ::= T '/' F
T ::= F
F ::= '(' E ')'
F ::= INTEGER
```

Ambiguous grammar

```
E ::= E '+' E
E ::= E '-' E
E ::= E '*' E
E ::= E '/' E
E ::= '(' E ')'
E ::= INTEGER
```

Associativity

- Left-associative operator (E ::= E ‘+’ E)
  - 1+2+3+4 → 3+3+4 → 6+4 → 10
- Right-associative operator (E ::= E ‘+’ E)
  - 1+2+3+4 → 1+2+7 → 1+9 → 10
- The assignment operator ‘=‘ is right-associative:
  - a = b = 3
  - The power operator is also right-associative
  - 3^2^2 → 3^4 → 81

Precedence Section: Operators

1) E ::= E '+' E
2) E ::= E '*' E
3) E ::= '(' E ')'
4) E ::= INT

- Rule #1 (as well as Rule #2) is ambiguous
  - Associativity of the '+' ('*') operator is not specified
- Moreover, the precedence of the '+' and '*' is not specified by Rules #1 and #2
- It is possible to make these rules non-ambiguous by adding information in the precedence section.
- The keyword precedence left defines a left-associative operator, precedence right a right-associative operator, whereas precedence nonassoc defines a non-associative operators.
- The order in which precedence keywords are declared is inversely proportional to their priority.

Precedence Section: Disambiguating rules

- To each production that contains at least one terminal defined as operator, Cup associates the precedence and associativity of the rightmost operator.
- If the rule is followed by the keyword `%prec`, the precedence and associativity are those of the specified operator.
- In the case of a shift-reduce conflict, the action corresponding to the highest precedence production is executed.
- If the precedence is the same, associativity is used: left-associativity results in a reduce action, right-associativity in a shift action.

Precedence Section: Example

```
terminal uminus;

precedence left '+', '-';   /* Low priority */
precedence left '*', '/';
precedence left uminus;     /* High priority */

start with E;

E ::=   E '+' E
      | E '-' E
      | E '*' E
      | E '/' E
      | '-' E    %prec uminus
      | '(' E ')'
      | INTEGER
;
```

User code

- Directives are available to insert user code directly in the parser.
- They are useful for
  - Personalizing the parser behavior
  - Adding code directly in the class that implements the parser
  - Using a scanner generator different from the default one (JFlex)

- They are:
  - init with {:   … :}
    - This code is executed before calling any scanner method, hence before any terminal symbol is passed to the parser
    - It is used to inizialize variables or to initialize the scanner in the case JFlex is not used.

User code (II)

- scan with {:   …   :}
  - Indicates to the parser which procedure to use to request the next terminal to the scanner
  - It must return an object of the class java_cup.runtime.Symbol
  - It is used for non-default scanner generators (different than JFlex)
  - scan with {: return scanner.next_token(); :}
- When CUP generates the java file that implements the parser, two classes are defined:
  - public class parser extends java_cup.runtime.lr_parser
    - parser is the java class that implements the parser and inherits different methods from the java_cup.runtime.lr_parser class
  - class CUP$parser$actions
    - CUP$parser$actions is the class where declared grammar rules are translated into a java program. Here, also semantic actions (i.e., the java code related to each rule) are reported

User code (III)

- The java_cup.runtime.lr_parser class is implemented in the file java_cup/runtime/lr_parser.java, in the CUP installation directory

- parser code {: … :}
  - The code is included in the parser class
  - It is used to include scanning methods within the parser but usually to override parser methods (e.g. to override methods for error handling)
- action code {: … :}
  - The code included in this directive is copied as is in the CUP$parser$actions class
  - The code is reachable only in the semantic actions associated with grammar rules
  - It is used to define procedures and variables to be used in the actions associated to the grammar (e.g., symbol table)

scanner.flex

Errors: Printing line and column

```
import java_cup.runtime.*;
…
%%
%cup
%line
%column

%{
    private Symbol symbol(int type){
            return new Symbol(type, yyline, yycolumn);
    }
    private Symbol symbol(int type, Object value){          //Semantic analysis
            return new Symbol(type, yyline, yycolumn,value);
    }
%}
…
%%
[a-z]           { return symbol(sym.EL); }
','             { return symbol(sym.CM); }
```

Symbol constructors:

public Symbol(int sym_id)
public Symbol(int sym_id, int left, int right)
public Symbol(int sym_id, Object o)
public Symbol(int sym_id, int left, int right, Object o)

parser.cup

Errors: Printing line and column

```
import java_cup.runtime.*;

parser code {:
    public void report_error(String message, Object info) {
        StringBuffer m = new StringBuffer(message);
        if (info instanceof Symbol) {
            if (((Symbol)info).left != -1 && ((Symbol)info).right != -1) {
                int line = (((Symbol)info).left)+1;
                int column = (((Symbol)info).right)+1;
                m.append(" (line "+line+", column "+column+")");
            }
        }
        System.err.println(m);
    }
:}
```

Handling syntax error (I)

- Generally speaking, when a parser finds an error it should not immediately terminate the execution
  - A compiler usually tries to recover from the error in order to analyze the rest of the input and signal the highest possible number of errors
- As default, a CUP-generated parser when an error is detected:
  - Signals by means of the method public void syntax_error(Symbol cur_token) defined in the java_cup.runtime.lr_parser class a syntax error, writing “Syntax error” in stderr.
  - If the error is not managed by the parser through the predefined error symbol, the parser call the public void unrecovered_syntax_error(Symbol cur_token) method, also defined in java_cup.runtime.lr_parser. This function, after writing “Couldn't repair and continue parse” in stderr (to notify the user of an unrecoverable syntax error), stops the execution of the parser.

Handling syntax error (II)

Analyzing the two functions in detail:

- public void syntax_error(Symbol cur_token)
  - Calls the function report_error with the following parameters
    report_error("Syntax error", cur_token);
    - Where, when an error occurs, cur_token is the currently looahead symbol
- public void unrecovered_syntax_error(Symbol cur_token)
  - Calls the function report_fatal_error, with the following parameters
    report_fatal_error("Couldn't repair and continue parse", cur_token);
  - The report_fatal_error function calls with the same parameters report_error and it launches an exception that causes the end of the parser
- A suitable redefinition, in parser code {: … :}, of the listed functions, allow to customize errors management

‘error’ predefined symbol

- The ‘`error`’ predefined symbol signals an error condition. It can be used within the grammar in order to enable the parser to continue execution when an error is encountered.

- Example:

```
 ass ::= ID EQ E S
          | ID EQ error S
;
```

How does Cup handle the ‘error’ symbol?

- When an error occurs, the parser will start emptying the stack until a state is found in which the ‘**`error`**’ symbol is allowed
  - In the previous example, uncorrect E (i.e. symbol sequences that cannot be reduced as E) are removed from the stack, until the terminal EQ is found on the top of the stack.
- The **`error`** token is *shifted* in the stack
- If the next token is acceptable, the parser resumes syntax analysis.
- Otherwise the parser will continue to read and discard tokens, until an acceptable one is found
  - In the prevoius example, the parser will read and discard all tokens until S is found.

Some general rules

- A simple strategy for error handling is skipping the current *statement:*

```
stmt ::= error ';'
```

- Sometimes it can be useful to find a closing symbol corresponding to an opening symbol:

```
expr     ::= '(' expr ')'
           | '(' error ')'
```

- Note: to limit the generation of spurious error messages, after an error occurs, error signaling is suspended until at least three consecutive tokens are *shifted*.

Grammar

```
file  ::= funcs
;

funcs ::= /* empty */
        | funcs func
;

func  ::= ID '(' ')'
      compound
;

compound ::= '{' stmts '}'
;
```

```
stmts ::= /* empty */
        | stmts stmt
;

stmt  ::= exp ';'
        | compound
;

exp   ::= NUM
        | exp '+' exp
        | exp '-' exp
        | exp '*' exp
        | exp '/' exp
        | '-' exp %prec NEG
        | `(` exp `)'
;
```

Statements and expressions

```
stmt ::= exp ';'
        | compound
        | error ';‘  {: System.err.println("syntax error in statement“); :}
;

compound ::= '{' stmts '}'
            | '{' stmts error '}‘  {: System.err.println("missing ; before '}‘ “); :}
;

exp ::= …
       | '(' error ')‘  {: System.err.println(" syntax error in expression"); :}
;
```