Project #2: Parser

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Project Goal

- **C-Minus Parser Implementation using Bison (Faster version of Yacc)**
  - The Parser reads an input source code string, tokenizes and parses it with C-Minus grammar, and returns (prints) abstract syntax tree (AST).
  - C-Minus scanner with LEX should be used.
  - Source code for the parser should be obtained using Bison.
    - Bison takes a CFG grammar as an input and generate a LALR(1) parser.
    - **Ambiguous grammar will cause conflicts.**
  - cminus.y, … -> cminus_parser

Grammar for C-Minus

1. *program* → *declaration-list*
2. *declaration-list* → *declaration-list declaration* | *declaration*
3. *declaration* → *var-declaration* | *fun-declaration*
4. *var-declaration* → *type-specifier* **ID** **;** | *type-specifier* **ID** **[** **NUM** **]** **;**
5. *type-specifier* → **int** | **void**
6. *fun-declaration* → *type-specifier* **ID** **(** *params* **)** *compound-stmt*
7. *params* → *param-list* | **void**
8. *param-list* → *param-list* **,** *param* | *param*
9. *param* → *type-specifier* **ID** | *type-specifier* **ID** **[** **]**
10. *compound-stmt* → **{** *local-declarations statement-list* **}**
11. *local-declarations* → *local-declarations var-declarations* | *empty*
12. *statement-list* → *statement-list statement* | *empty*
13. *statement* → *expression-stmt* | *compound-stmt* | *selection-stmt* | *iteration-stmt* | *return-stmt*
14. *expression-stmt* → *expression* **;** | **;**
15. *selection-stmt* → **if** **(** *expression* **)** *statement* | **if** **(** *expression* **)** *statement* **else** *statement*
16. *iteration-stmt* → **while** **(** *expression* **)** *statement*
17. *return-stmt* → **return** **;** | **return** *expression* **;**
18. *expression* → *var* **=** *expression* | *simple-expression*
19. *var* → **ID** | **ID** **[** *expression* **]**
20. *simple-expression* → *additive-expression relop additive-expression* | *additive-expression*
21. *relop* → **<=** | **<** | **>** | **>=** | **==** | **!=**
22. *additive-expression* → *additive-expression addop term* | *term*
23. *addop* → **+** | **-**
24. *term* → *term mulop factor* | *factor*
25. *mulop* → ***** | **/**
26. *factor* → **(** *expression* **)** | *var* | *call* | **NUM**
27. *call* → **ID** **(** *args* **)**
28. *args* → *arg-list* | *empty*
29. *arg-list* → *arg-list* **,** *expression* | *expression*

Dangling Else Problem

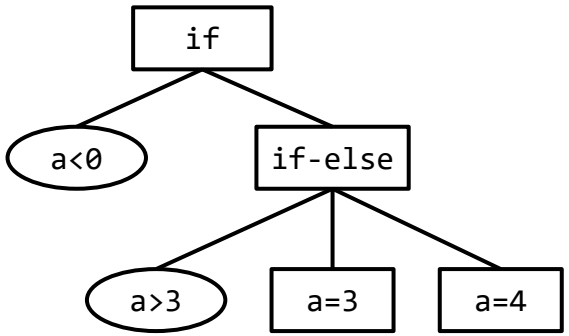
- Ambiguity in the grammar *15*

```
/* dangling else example */
void main(void) { if ( a < 0 )  if ( a > 3 ) a = 3;  else a = 4; }
```

(1) void main(void) { **if(a < 0)** if (a > 3) a = 3; **else a = 4;** }

(2) void main(void) { if(a < 0) **if (a > 3) a = 3; else a = 4;** }

- Rule: Associate the else with the nearest if

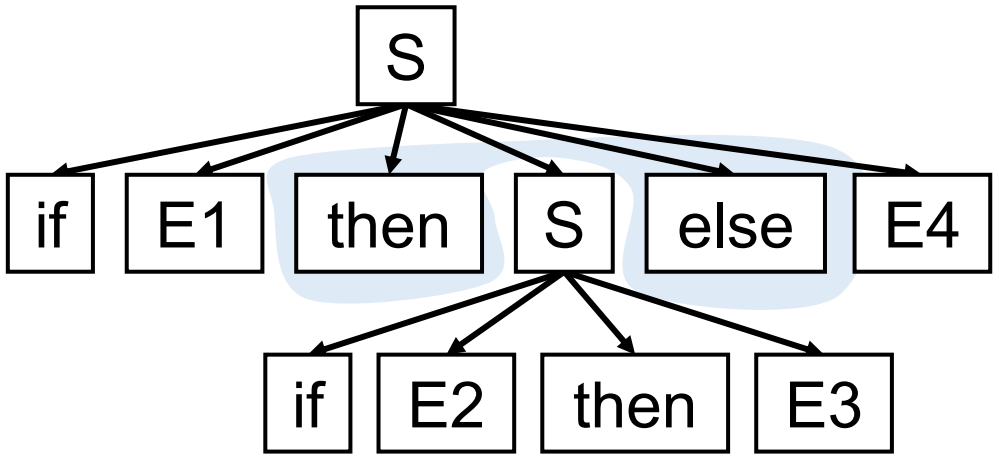


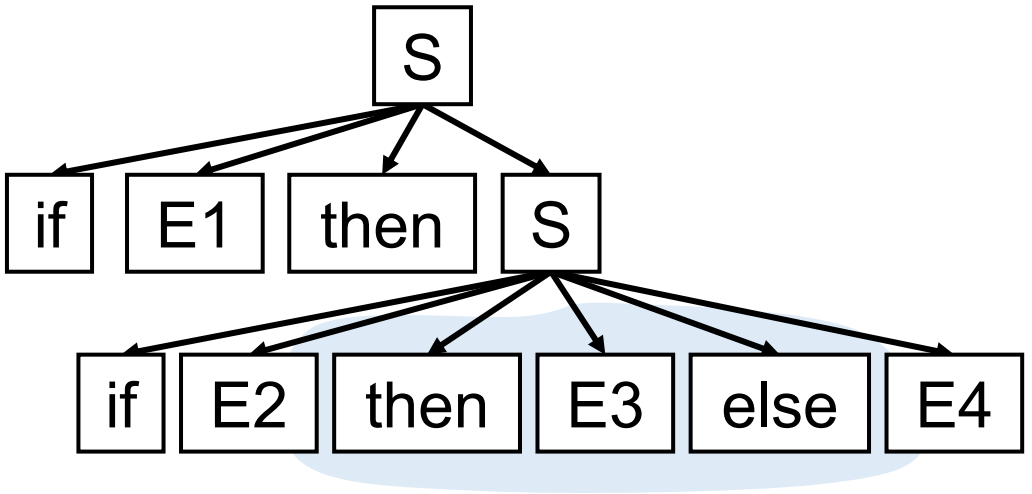

```
C-MINUS COMPILATION: ./test.cm

Syntax tree:
  Function Declaration: name = main, return type = void
    Void Parameter
    Compound Statement:
      If Statement:
        Op: <
          Variable: name = a
          Const: 0
      If-Else Statement:
        Op: >
          Variable: name = a
          Const: 3
        Assign:
          Variable: name = a
          Const: 3
        Assign:
          Variable: name = a
          Const: 4
```

Recall: If/Then/Else Example

- **If/Then/Else**
  - We need to find the correct closure if there are both if/then/else and if/then
  - Consider “if E1 then if E2 then E3 else E4”
    - S ➔ if E then S | if E then S else S | other
    - We should match else to the closest then

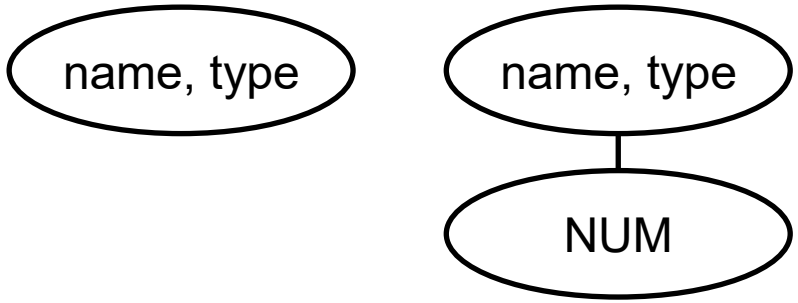




AST Output Format - 1

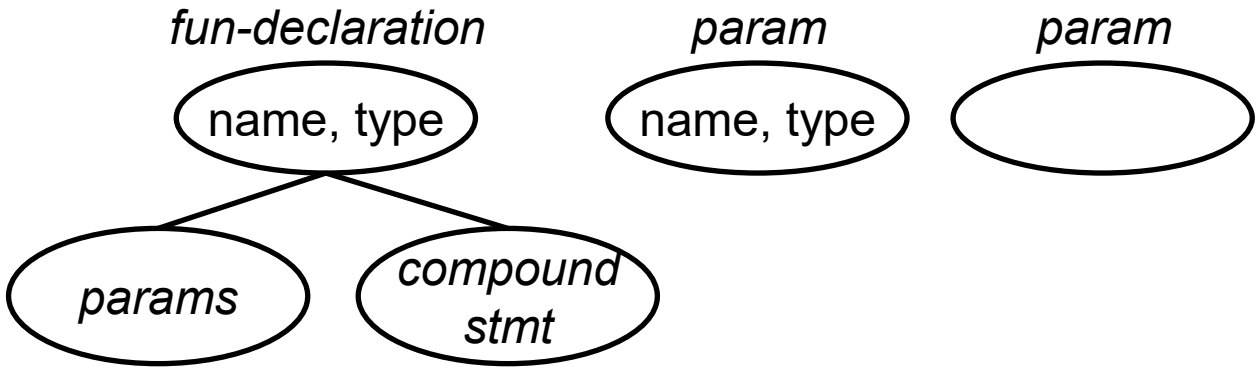
*** Type (*type-specifier, …*)**
<Format: Type>
int
void
int[]
void[]

*** Variable Declaration (*var-declaration*)**
<Format: Variable Declaration>
Variable Declaration: name = %s, type = %s
/* Child Node: Array Size */



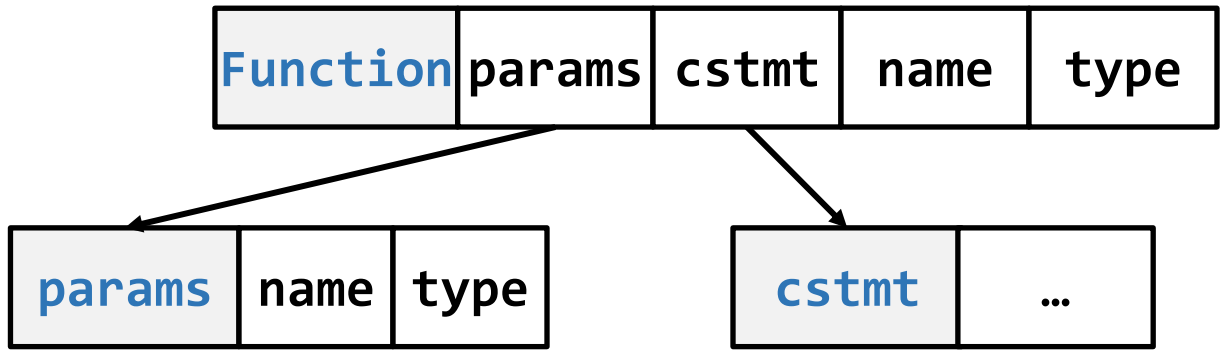
*** Function Declaration (*fun-declaration*)**
<Format: Function Declaration>
Function Declaration: name = %s, return type = %s
/* Child Node: Parameters */
/* Child Node: Compound Statement */

<Format: Parameters>
Parameter: name = %s, type = %s
Void Parameter



AST Data Structure in C-Minus Example

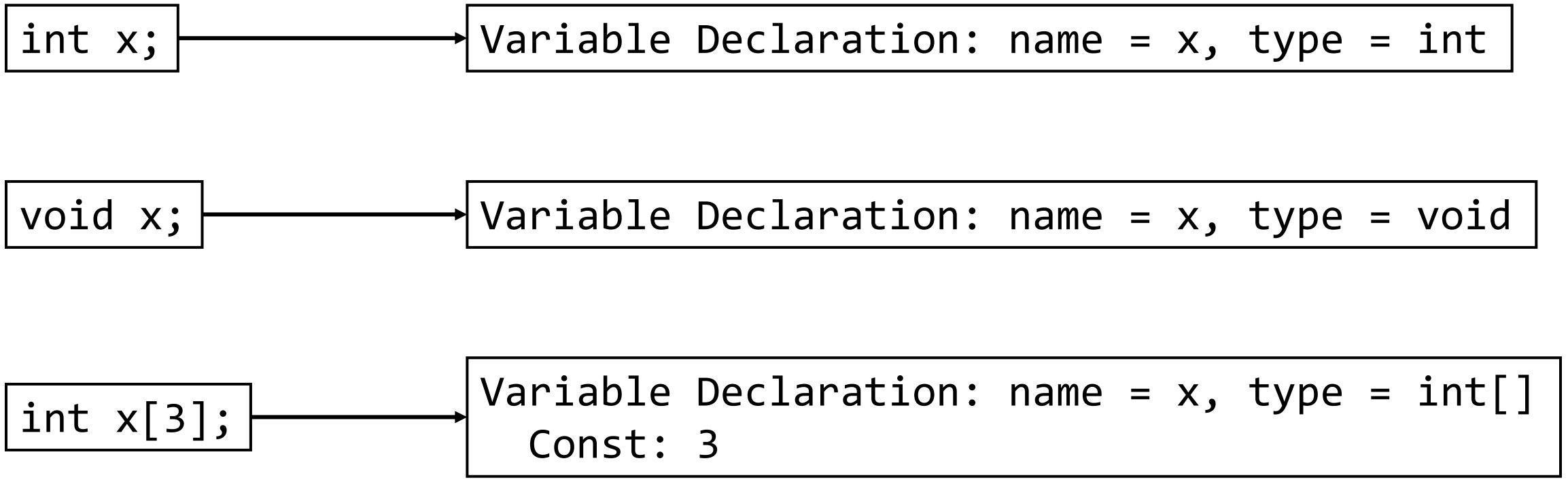
```
abstract class expr {}
class Function extends expr {
        expr params, cstmt;
        string name;
        Type type;
        Function (expr params, expr cstmt, name, type) {
                this->params = params; this-> cstmt = cstmt;
        }
}
…
```



AST Output Format - 1

- **Let's make an example**

Source Code **AST Output**



AST Output Format - 1

- **Let's make an example**

Source Code

```
int func(int x, void y){}
```

AST Output

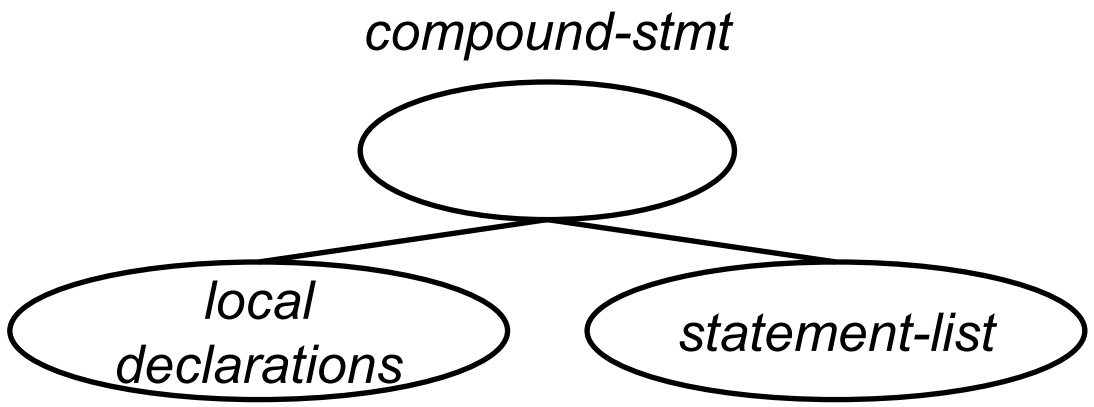
```
Function Declaration: name = func, return type = int
  Parameter: name = x, type = int
  Parameter: name = y, type = void
  Compound Statement:
```

```
int func(void){}
```

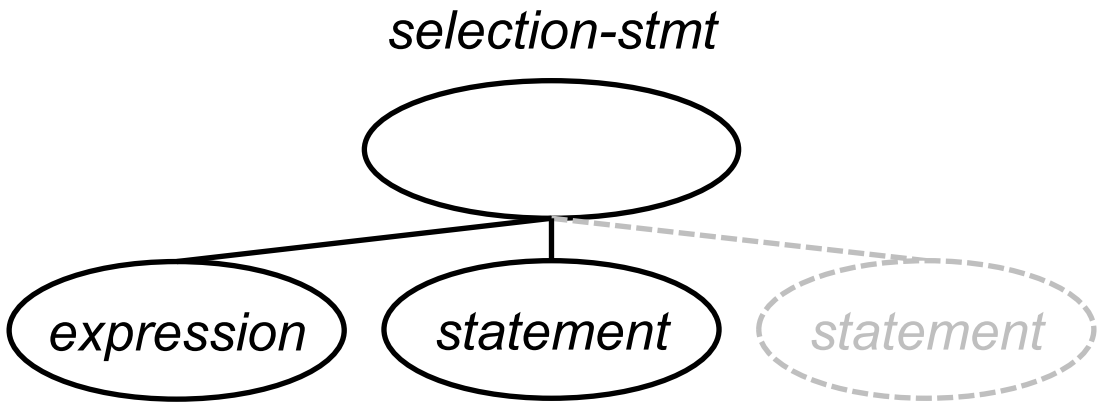
```
Function Declaration: name = func, return type = int
  Void Parameter
  Compound Statement:
```

AST Output Format - 2

*** Compound Statement (*compound-stmt*)**
<Format: Compound Statement>
Compound Statement:
  /* Child Node: Local Declarations */
  /* Child Node: Statement Lists */

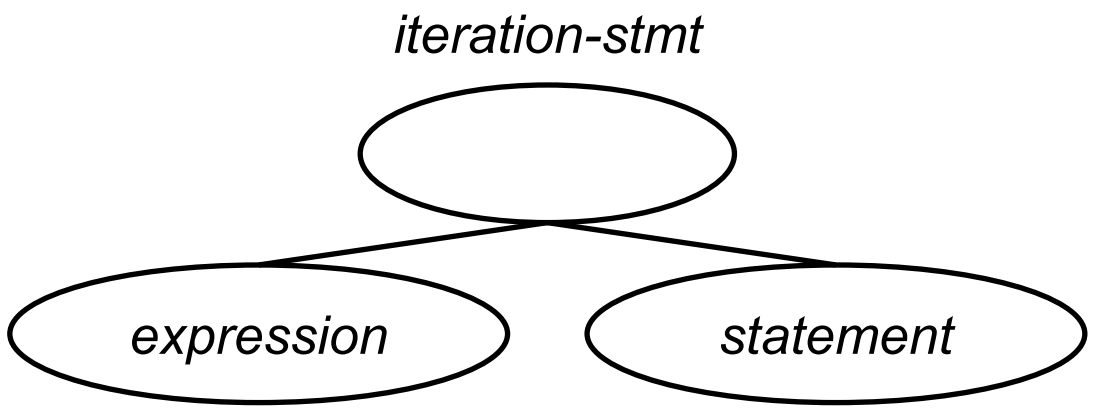


*** If/If-Else Statement (**selection-stmt**)**
<Format: If/If-Else Statement>
If Statement:
  /* Child Node: Condition Expression */
  /* Child Node: Then-Statement */
If-Else Statement:
  /* Child Node: Condition Expression */
  /* Child Node: Then-Statement */
  /* Child Node: Else-Statement */

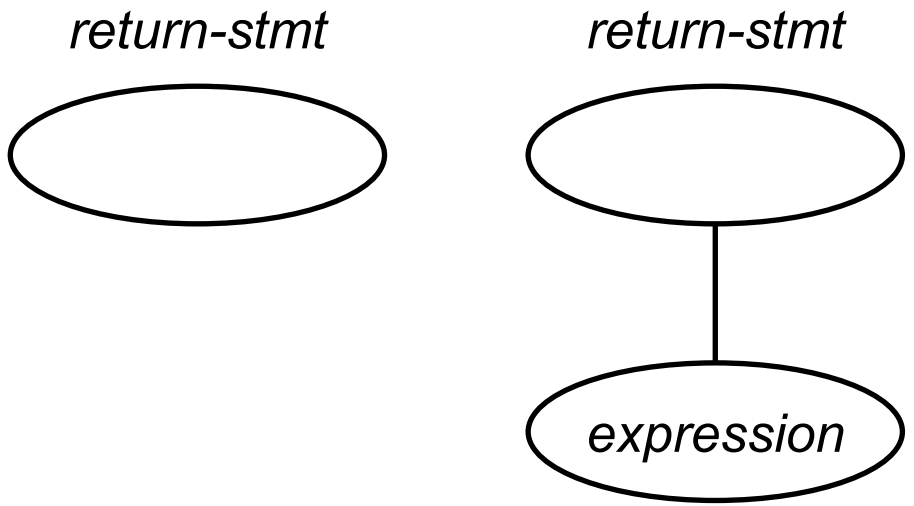


AST Output Format - 2

*** While Statement (*iteration-stmt*)**
<Format: While Statement>
While Statement:
  /* Child Node: Condition Expression */
  /* Child Node: Loop Body Statement */



*** Return Statement (*return-stmt*)**
<Format: Return Statement>
Non-value Return Statement
Return Statement:
  /* Child Node: Return Expression */



AST Output Format - 2

- **Let's make an example**

Source Code

```
…
int func(void){
      int x;
      int y;
      return x;
}
…
```

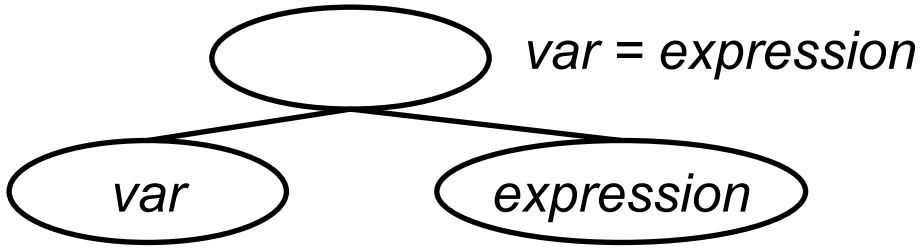
AST Output

```
Function Declaration: name = func, return type = int
  Void Parameter
  Compound Statement:
    Variable Declaration: name = x, return type = int
    Variable Declaration: name = y, return type = int
    Return Statement:
      Variable: name = x
```

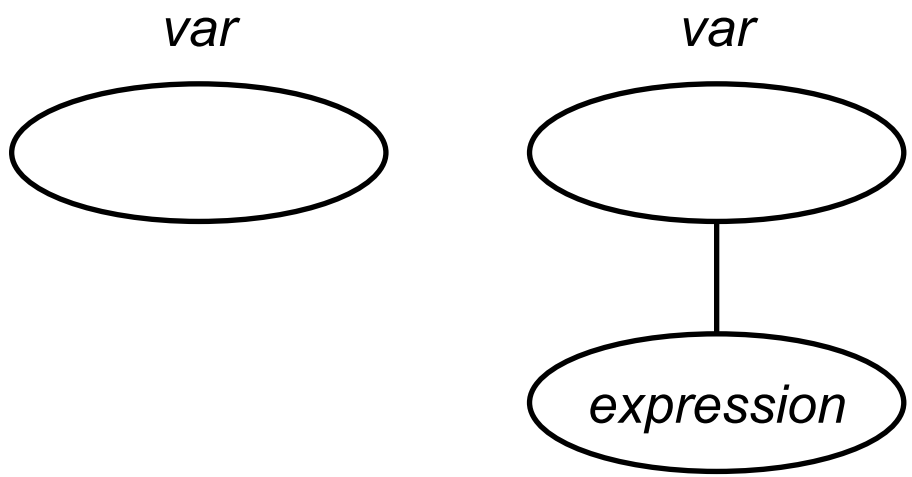
AST Output Format - 3

*** Operator (*relop, addop, mulop*)**
<Format: Operator>
+
*****
<=
…

*** Assignment Expression (*var = expression*)**
<Format: Assignment Expression>
Assign:
/* Child Node: Variable */
/* Child Node: Expression */



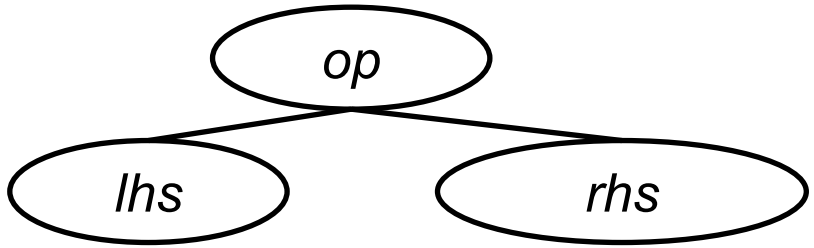
*** Variable Accessing & Array Indexing Expression (*var*)**
<Format: Variable Accessing & Array Indexing>
Variable: name = %s
/* Child Node: Array Index Expression */



AST Output Format - 3

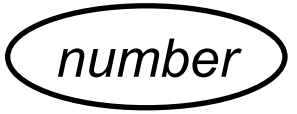
*** Binary Operator Expression**
(*simple-expression, additive-expression, term*)
<Format: Binary Operator Expression>
Op: %s
/* Child Node: Left Hand Side */
/* Child Node: Right Hand Side */

simple-expression
additive-expression
term

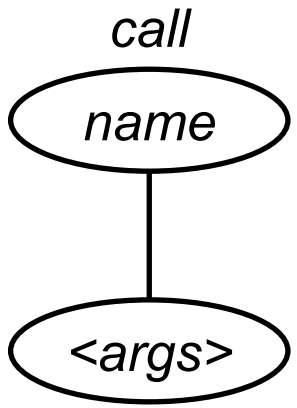


*** Constant Expression (*NUM*)**
<Format: Constant Expression>
Const: %d

NUM



*** Call Expression (*call*)**
<Format: Call Expression>
Call: function name = %s
/* Child Node: Arguments */



AST Output Format - 3

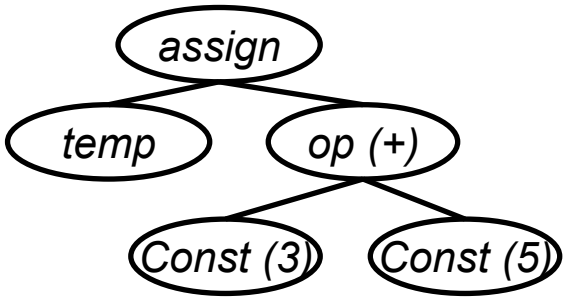
- **Let's make an example**

Source Code

```
…
int temp;
temp = 3 + 5;
func(temp);
…
```

AST Output

```
Variable Declaration: name = temp, type = int
Assign:
  Variable: name = temp
  Op: +
    Const: 3
    Const: 5
Call: function name = func
  Variable: name = temp
```

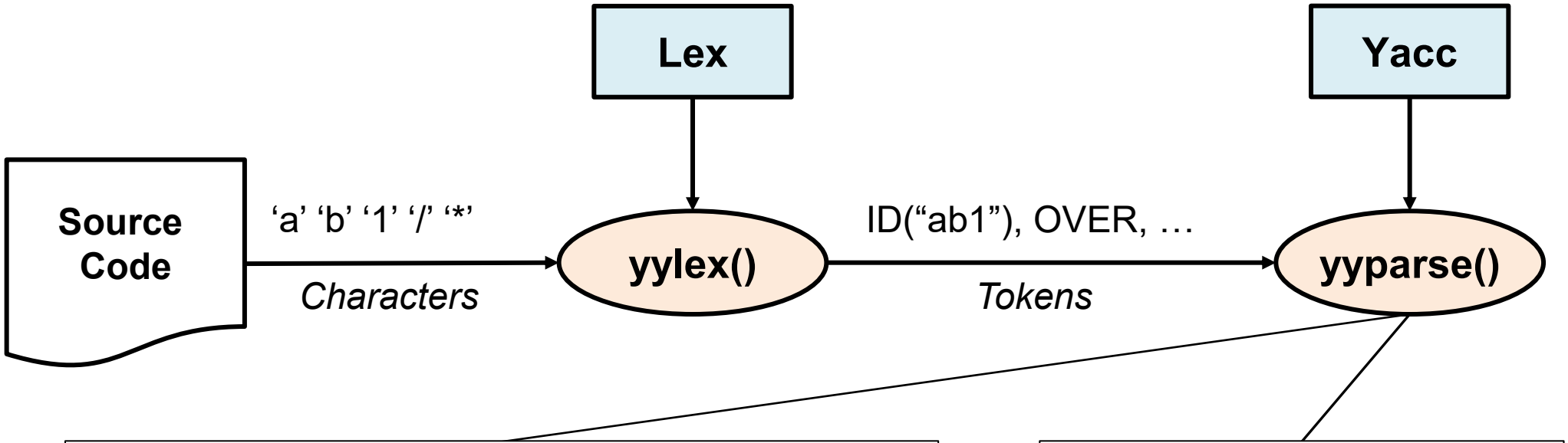


Yacc (Bison)

- **Parser Generator for UNIX**
  - Yacc: Yet Another Compiler Compiler
  - Bison: GNU project parser generator (upward compatible with Yacc)

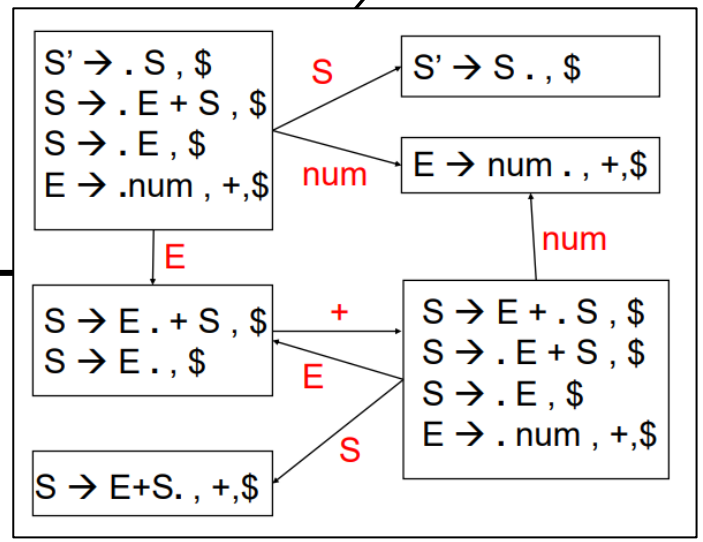
- **Input**
  - LALR(1) grammar specification with declarations of "precedence and associativity"

- **Output**
  - LALR(1) parser program



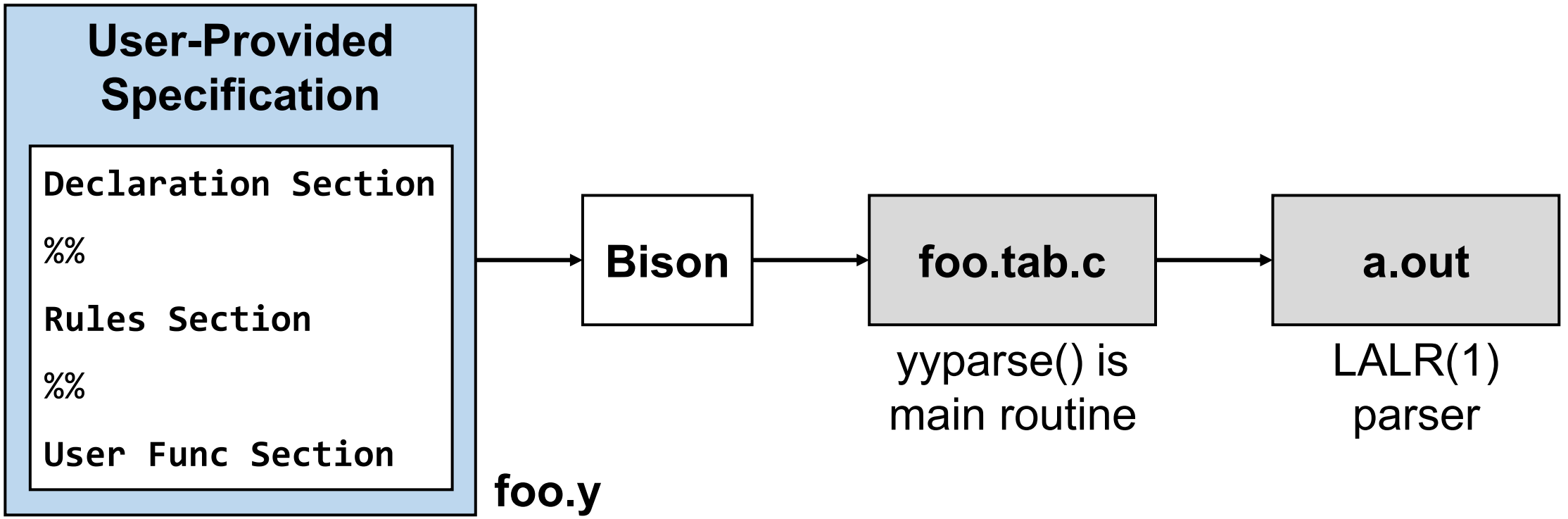
derivation	stack	input stream	action
(1+2+(3+4))+5		(1+2+(3+4))+5	shift
(1+2+(3+4))+5	(	1+2+(3+4))+5	shift
(1+2+(3+4))+5	(1	+2+(3+4))+5	reduce E→ num
(E+2+(3+4))+5	(E	+2+(3+4))+5	reduce S→ E
(S+2+(3+4))+5	(S	+2+(3+4))+5	shift
(S+2+(3+4))+5	(S+	2+(3+4))+5	shift
(S+2+(3+4))+5	(S+2	+(3+4))+5	reduce E→ num
(S+E+(3+4))+5	(S+E	+(3+4))+5	reduce S → S+E
(S+(3+4))+5	(S	+(3+4))+5	shift
(S+(3+4))+5	(S+	(3+4))+5	shift
(S+(3+4))+5	(S+(	3+4))+5	shift
(S+(3+4))+5	(S+(3	+4))+5	reduce E→ num

Shift-Reduce Parsing



Parsing Table

Bison / Yacc Overview



Declarations Section

```
%{
  #include <stdio.h>
  int yylex(void)
  …
%}
```

```
%nonassoc ELSE
%token NUM
%left MINUS PLUS
%right EXPONENT
```

Higher Precedence

- **Users can declare or include variables, enumeration, etc using the code in between "%{" and "%}"**
- **Define terminal symbols (tokens) of the grammar**
  - **General:** %token terminal1 terminal2 …
  - **Left-associative:** %left terminal1 terminal 2 …
  - **Right-associative:** %right terminal1 terminal 2 …
  - **No-associative:** %nonassoc terminal1 terminal 2 …
- **The declaration order determines precedence**

Rules Section - 1

- **Every name in the rules section that has not been declared is a non-terminal**

- **Productions format**
  - non-terminal : first production RHS | second production RHS …;
  - ε production is a blank (i.e., non-terminal : ;)
  - Use braces after RHS to indicate actions to take

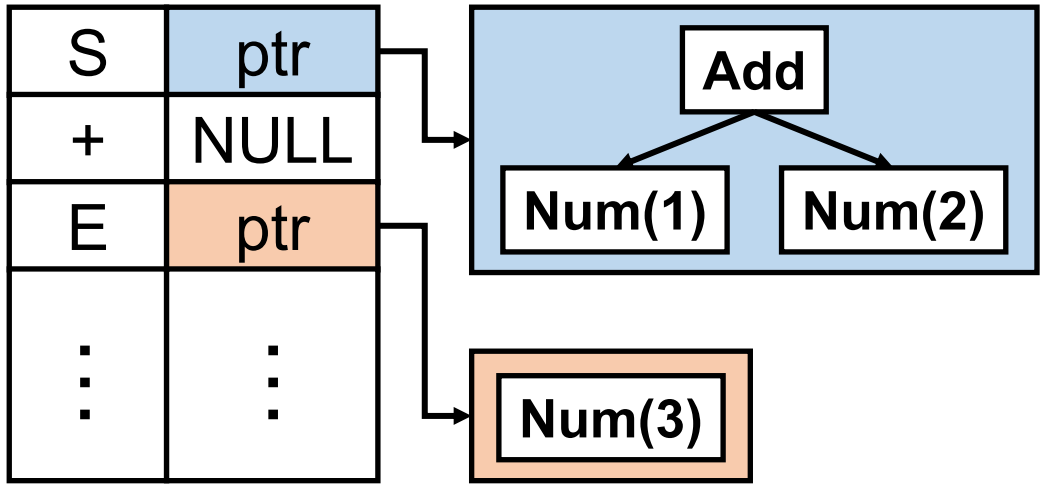
Rules Section - 2

- **We use special format to indicate LHS and n-th term in the action of each production**
  - $$: LHS
  - $n : nth symbol in RHS
- **The precedence is defined in the declaration section**
  - We can also force precedence for a given production using %prec

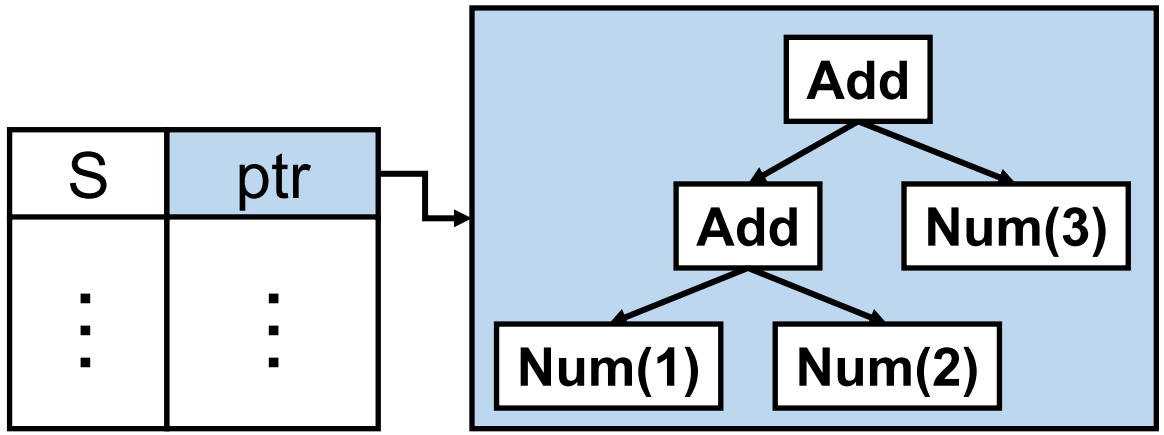
```
%left '+' '-'
%left UMINUS
…
exp : NUM                          {$$ = $1;}
    | exp ‘+’ exp                  {$$ = $1 + $3;}
    | exp ‘-’ exp                  {$$ = $1 - $3;}
    | ‘-’ exp %prec UMINUS         {$$ = -$2;}
```

AST Construction: LR

- **AST construction mechanism**
  - Store parts of the tree on the stack
  - For each nonterminal X on the stack, store the sub-tree for X on the stack
  - After reduce operation for a production X ➔ α, create an AST node for X



Before S ➔ E + S Reduction



After S ➔ E + S Reduction

AST Construction: LR

- **AST construction mechanism**
  - Store parts of the tree on the stack
  - For each nonterminal X on the stack, store the sub-tree for X on the stack
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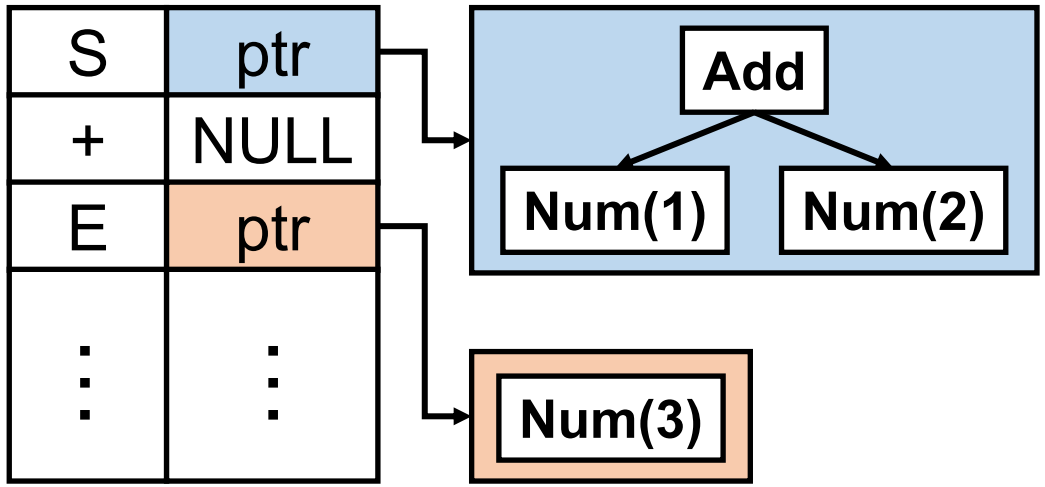


Before S ➔ E + S Reduction

```
// For the reduce action
$3 = pop_stack();
$2 = pop_stack();
$1 = pop_stack();
$$ = new S($1, $3);
push_stack($$);
```

After S ➔ E + S Reduction

Yacc Example: tiny.y

Pointer to *LHS* (non-terminal)

Pointer to YYSTYPE (TreeNode*)

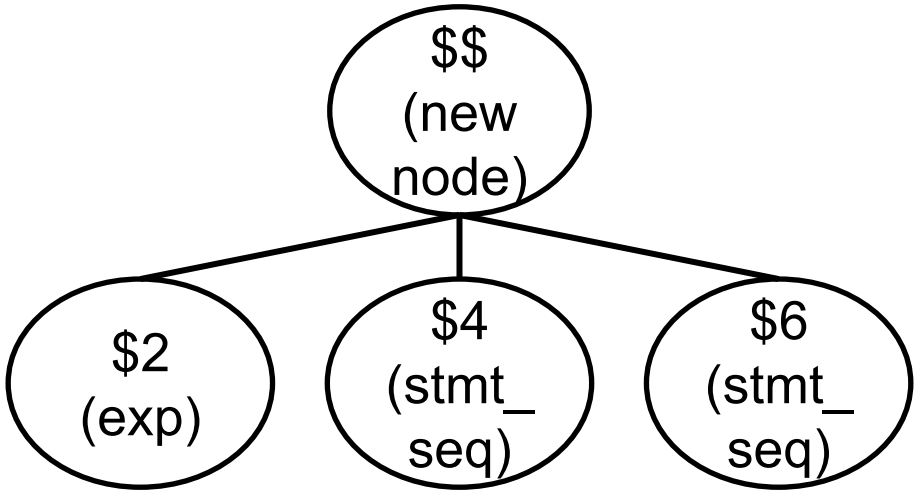
$$ $1 $2 $3 $4 $5

```
if_stmt     : IF exp THEN stmt_seq END
                { $$ = newStmtNode(IfK);
                  $$->child[0] = $2;
                  $$->child[1] = $4;
                }
            | IF exp THEN stmt_seq ELSE stmt_seq END
                { $$ = newStmtNode(IfK);
                  $$->child[0] = $2;
                  $$->child[1] = $4;
                  $$->child[2] = $6;
                }
            ;
```

Executed at REDUCE

```
#define MAXCHILDREN 3

typedef struct treeNode
   { struct treeNode * child[MAXCHILDREN];
     struct treeNode * sibling;
     int lineno;
     NodeKind nodekind;
     union { StmtKind stmt; ExpKind exp;} kind;
     union { TokenType op;
             int val;
             char * name; } attr;
     ExpType type; /* for type checking of exps */
   } TreeNode;
```



Yacc Usages

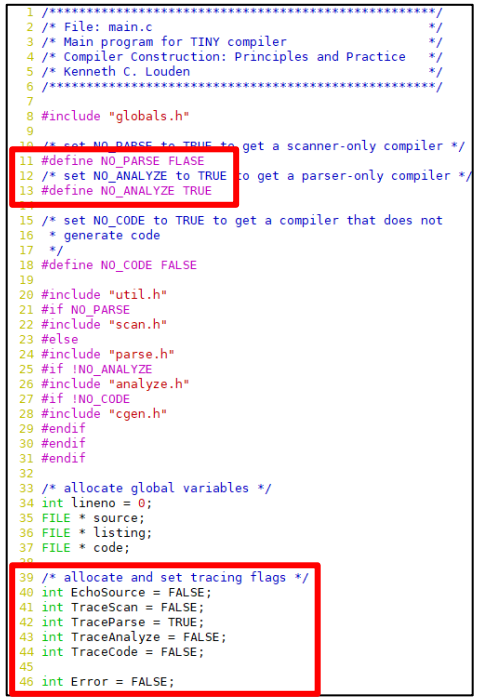
- **Usage**
  - yacc [options] filename

- **Options**
  - d write definitions (y.tab.h)
  - o [output_file] (default: y.tab.c)
  - t add debugging support
  - v write description (y.output)

- **Manual**
  - https://www.gnu.org/software/bison/manual

Modify main.c File

- **main.c**
  - Modify code to print only syntax tree
  - NO_ANALYZE, TraceParse



```
/****************************************************/
/* File: main.c                                     */
/* Main program for TINY compiler                   */
/* Compiler Construction: Principles and Practice   */
/* Kenneth C. Louden                                */
/****************************************************/

#include "globals.h"

/* set NO_PARSE to TRUE to get a scanner-only compiler */
#define NO_PARSE FLASE
/* set NO_ANALYZE to TRUE to get a parser-only compiler */
#define NO_ANALYZE TRUE

/* set NO_CODE to TRUE to get a compiler that does not
 * generate code
 */
#define NO_CODE FALSE

#include "util.h"
#if NO_PARSE
#include "scan.h"
#else
#include "parse.h"
#if !NO_ANALYZE
#include "analyze.h"
#if !NO_CODE
#include "cgen.h"
#endif
#endif
#endif

/* allocate global variables */
int lineno = 0;
FILE * source;
FILE * listing;
FILE * code;

/* allocate and set tracing flags */
int EchoSource = FALSE;
int TraceScan = FALSE;
int TraceParse = TRUE;
int TraceAnalyze = FALSE;
int TraceCode = FALSE;

int Error = FALSE;
```

```
10 /* set NO_PARSE to TRUE to ge
11 #define NO_PARSE FLASE
12 /* set NO_ANALYZE to TRUE to
13 #define NO_ANALYZE TRUE
```

```
39 /* allocate and set tracing flags */
40 int EchoSource = FALSE;
41 int TraceScan = FALSE;
42 int TraceParse = TRUE;
43 int TraceAnalyze = FALSE;
44 int TraceCode = FALSE;
45
46 int Error = FALSE;
```

Modify globals.h File

- **Overwrite your globals.h with yacc/globals.h**
- **Modify the "Sytax tree for parsing" part in the globals.h file**
  - Free to modify/add/remove NodeKind, StmtKind, ExpKind, ExpType, and TreeNode
    → Modify them according to the C-Minus grammar in page 3
  - Free to modify the kind, attr, and type if you want (TreeNode* is used to define YYSTYPE in cminus.y), following the modified NodeKind, StmtKind, ExpKind …

Modify globals.h File

```
/**************************************************/
/***********   Syntax tree for parsing ************/
/**************************************************/

typedef enum {StmtK,ExpK} NodeKind;
typedef enum {IfK,RepeatK,AssignK,ReadK,WriteK} StmtKind;
typedef enum {OpK,ConstK,IdK} ExpKind;

/* ExpType is used for type checking */
typedef enum {Void,Integer,Boolean} ExpType;

#define MAXCHILDREN 3

typedef struct treeNode
   { struct treeNode * child[MAXCHILDREN];
     struct treeNode * sibling;
     int lineno;
     NodeKind nodekind;
     union { StmtKind stmt; ExpKind exp;} kind;
     union { TokenType op;
             int val;
             char * name; } attr;
     ExpType type; /* for type checking of exps */
   } TreeNode;
```

Modify util.c File

- **util.c**
  - printTree() function should be updated to print C-Minus Syntax Tree.
    - Refer to the AST output format to determine what to print (for each node type you defined in global.h)
    - INDENT and UNINDENT macros automatically control the indentation (for the tree structure)
    - printTree() traverses child and sibling fields in TreeNode
  - Update newStmtNode(), newExprNode() or other function to allocate and initialize new Node type (according to the one you defined in global.h file)

Modify cminus.y File

- **cminus.y**
  - Copy yacc/tiny.y to cminus.y.
  - Write C-Minus tokens in the definition section.
    - Consider priority and associativity (and remove ambiguity)
  - Define a C-Minus grammar and reduce actions for each rules.
    - YYSTYPE (the type of $$, $1, …) is defined as TreeNode*.

Example Syntax Tree

```
/* A program to perform Euclid's
   Algorithm to computer gcd */

int gcd (int u, int v)
{
    if (v == 0) return u;
    else return gcd(v,u-u/v*v);
    /* u-u/v*v == u mod v */
}

void main(void)
{
    int x; int y;
    x = input(); y = input();
    output(gcd(x,y));
}
```

```
C-MINUS COMPILATION: ./test.1.txt

Syntax tree:
  Function Declaration: name = gcd, return type = int
    Parameter: name = u, type = int
    Parameter: name = v, type = int
    Compound Statement:
      If-Else Statement:
        Op: ==
          Variable: name = v
          Const: 0
        Return Statement:
          Variable: name = u
        Return Statement:
          Call: function name = gcd
            Variable: name = v
            Op: -
              Variable: name = u
              Op: *
                Op: /
                  Variable: name = u
                  Variable: name = v
                Variable: name = v
  Function Declaration: name = main, return type = void
    Void Parameter
    Compound Statement:
      Variable Declaration: name = x, type = int
      Variable Declaration: name = y, type = int
      Assign:
        Variable: name = x
        Call: function name = input
      Assign:
        Variable: name = y
        Call: function name = input
      Call: function name = output
        Call: function name = gcd
          Variable: name = x
          Variable: name = y
```

Some Hints - 1

- **You should generate the exactly same output as the reference and output format**
- **Remove all YACC conflicts even if it is just a warning**
  - PENALTIES FOR EACH CONFLICT: Shift/Shift, Shift/Reduce, Reduce/Reduce
- **There are some potential errors**
  - *If* without *Else* statement and *If-Else* Statement
  - No Parameter (*void*) and Parameters
  - *Return* statement without value and *return* statement with value

Some Hints - 2

- **How to implement Lists?** (*declaration-list, statement-list, param-list, …*)
  - Hint: see stmt_seq in tiny.y

- **Store attributes of TreeNode such as ID (=name), type and op**
  - Consideration: TokenString may not contain “string of the ID token” when reduce
    - Consider using an intermediate non-terminal (e.g., identifier : ID …)
  - Intra-Rule action (performed at shift) such as [assign_stmt] in tiny is not recommended (This may cause unexpected actions)
  - Do not directly update variables handled by scanner such as TokenString. Use copyString()

Some Hints - 3

- You should properly set the line number (This will be important when doing a semantic analysis)
- In var_declaration, fun_declaration, and … : the lineno is set according to lineno of the identifier

```
fun_declaration     : type_specifier identifier LPAREN params RPAREN compound_stmt
                        {
                            $$ = newTreeNode(FunctionDecl);
                            $$->lineno = $2->lineno;
                            $$->type = $1->type;
```

- Remaining cases: lineno is set using the last symbol lineno

```
compound_stmt       : LCURLY local_declarations statement_list RCURLY
                        {
                            $$ = newTreeNode(CompoundStmt);
                            $$->lineno = lineno;
```

Some Hints - 4

- **You don’t need to care about Semantics, just Syntax analyzer will be okay. (Analyzing semantics is for Project 3.)**

- **For this example, this code will be parsed correctly even though the code has some semantic error.**

```
/* Semantic Error Example */
/* (1) void-type variable a, b
 * (2) uninitialized variable c (and b)
 * (3) undefined variable d */

int main ( void a[] )
{
    void b;
    int c;
    d[1] = b + c;
}
```

```
C-MINUS COMPILATION: ./error_test.cm

Syntax tree:
  Function Declaration: name = main, return type = int
    Parameter: name = a, type = void[]
    Compound Statement:
      Variable Declaration: name = b, type = void
      Variable Declaration: name = c, type = int
      Assign:
        Variable: name = d
          Const: 1
        Op: +
          Variable: name = b
          Variable: name = c
```

Build with Makefile

- **I will upload a proper makefile for you**
  - Execute `make cminus_parser`

Evaluation

- **Evaluation Items**
  - **Compilation** (Success / Fail): **20%**
    - Please describe in the report how to build your project.
  - **Correctness** check for several testcases: **70%**
    - Note: Make sure there are no segmentation fault or infinite loop on any inputs.
  - **Report** : **10%**

Report

- **Guideline ($\leq$ 5 pages)**
  - Compilation environment and method
  - Brief explanations about how to implement and how it operates
  - Examples and corresponding result screenshots

- **Format**
  - Use PDF with the filename as follows

Submission

- **Deadline: 10/28 23:59:00**
- **Submission**
  - Submit all the **source codes** in a single zip file and **report** as a pdf file
  - Format + Name:
    - Report: [Student No]_Project2.pdf
    - Code: do not modify any name and compress all the codes into a single zip file and the name should be
      - [Student No]_Project2.zip
- **Questions**
  - **Upload any questions to the LMS**