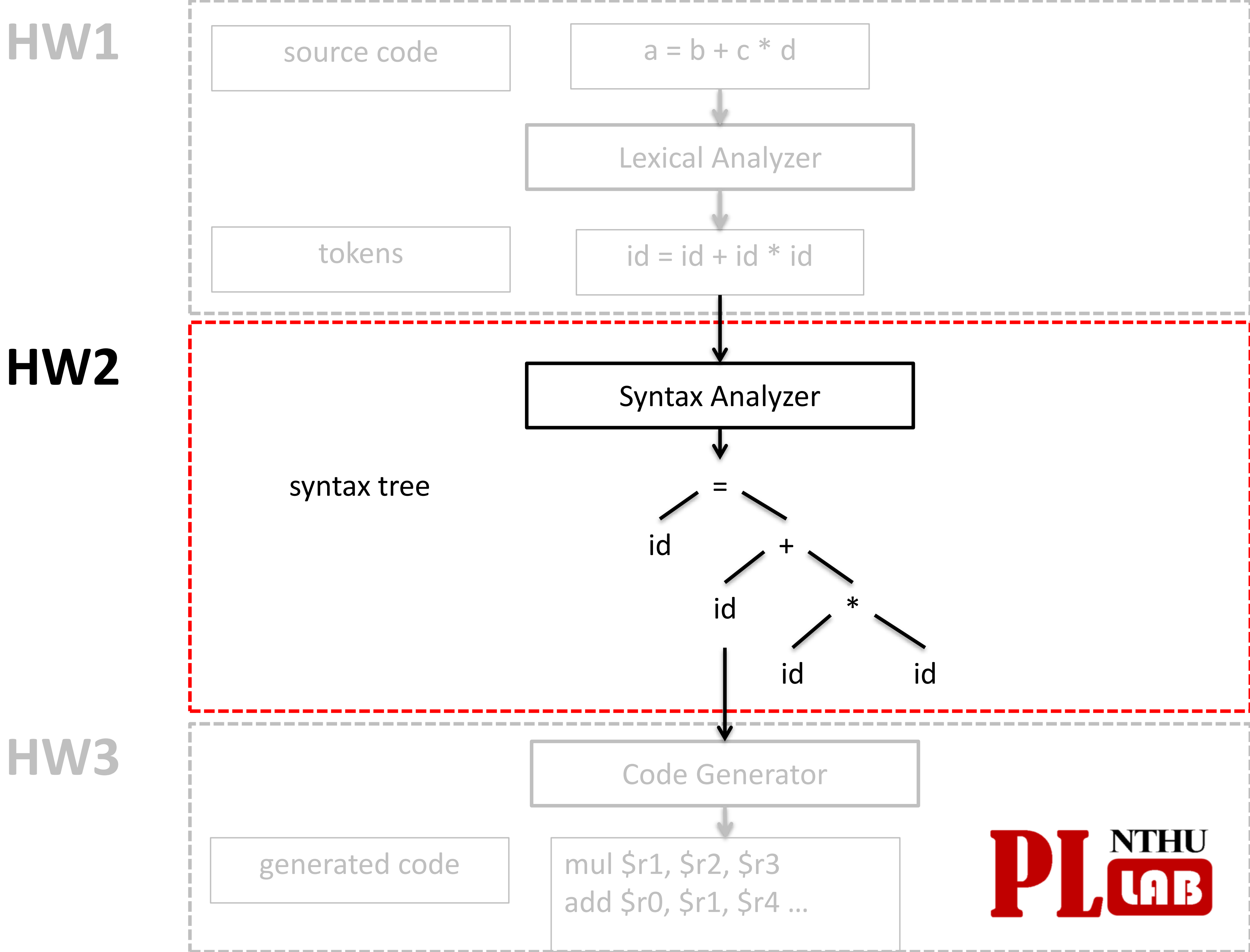
CS340400 Compiler Design Homework 2

Deadline

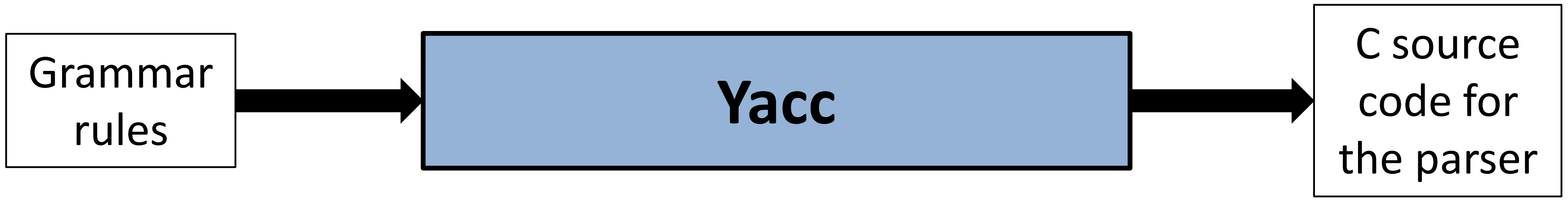
2024/06/02 12:00 pm

Yacc: Yet Another Compiler-Compiler

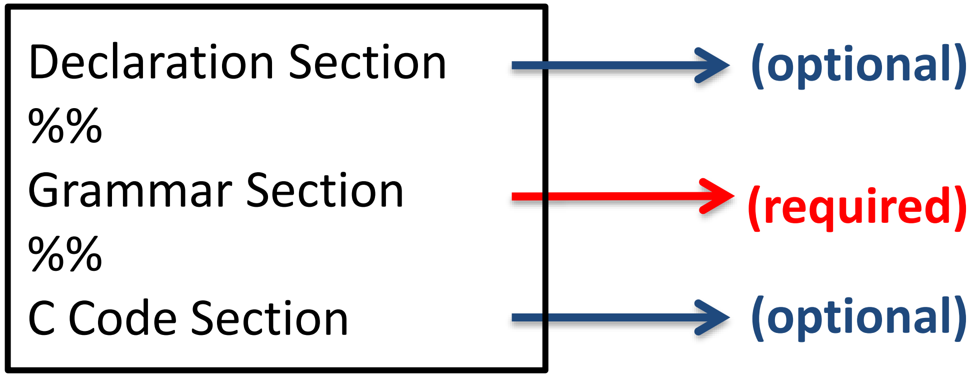

HW1
source code
a = b + c * d
Lexical Analyzer
tokens
id = id + id * id
HW2
Syntax Analyzer
syntax tree
=
id
+
id
*
id
id
HW3
Code Generator
generated code
mul $r1, $r2, $r3
add $r0, $r1, $r4 ...

What is Yacc?

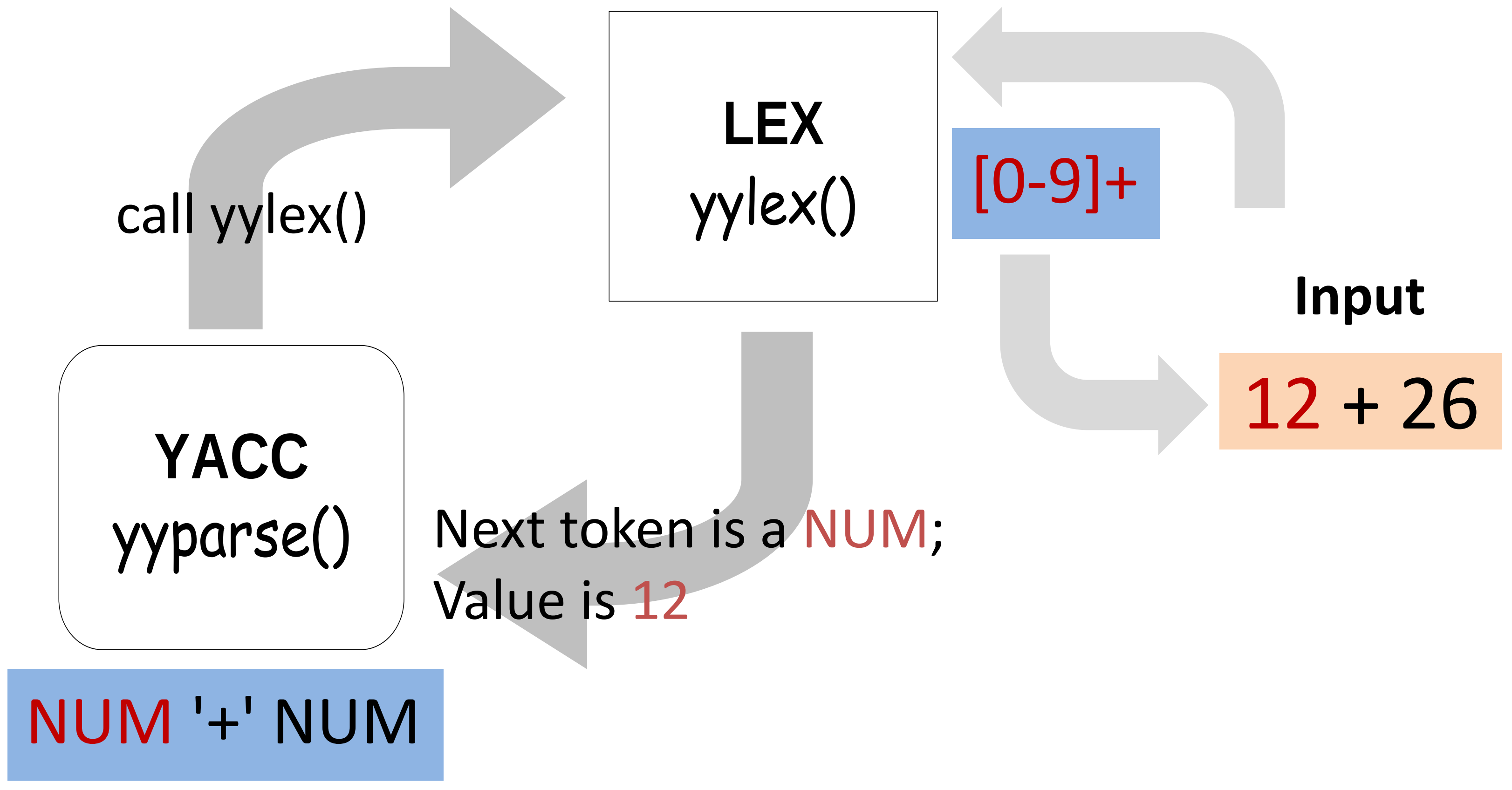
- A tool which can produce a parser with a given grammar
- A program designed to compile a LALR(1) grammar and produce the source code of the syntactic analyzer of the language defined by this grammar



How to Write Yacc?



How YACC Cooperates with LEX?



Interface between Lex and Yacc

- The interface is **`y.tab.h`**, which is produced by Yacc.
- How to create `y.tab.h` and use it?
  - `$ yacc -d parser.y`
    - The command will produce `y.tab.h` and `y.tab.c`.
  - Include `y.tab.h` in the Lex program.

scanner

```
%{
…
#include "y.tab.h"
%}

%%
"+"       { return '+';}
[0-9]+    { return NUM;}
…
%%
```

Terminals

parser

```
…
%token NUM

%%

expression : expression '+' NUM
           ;
…
```

Non-terminals

yylval

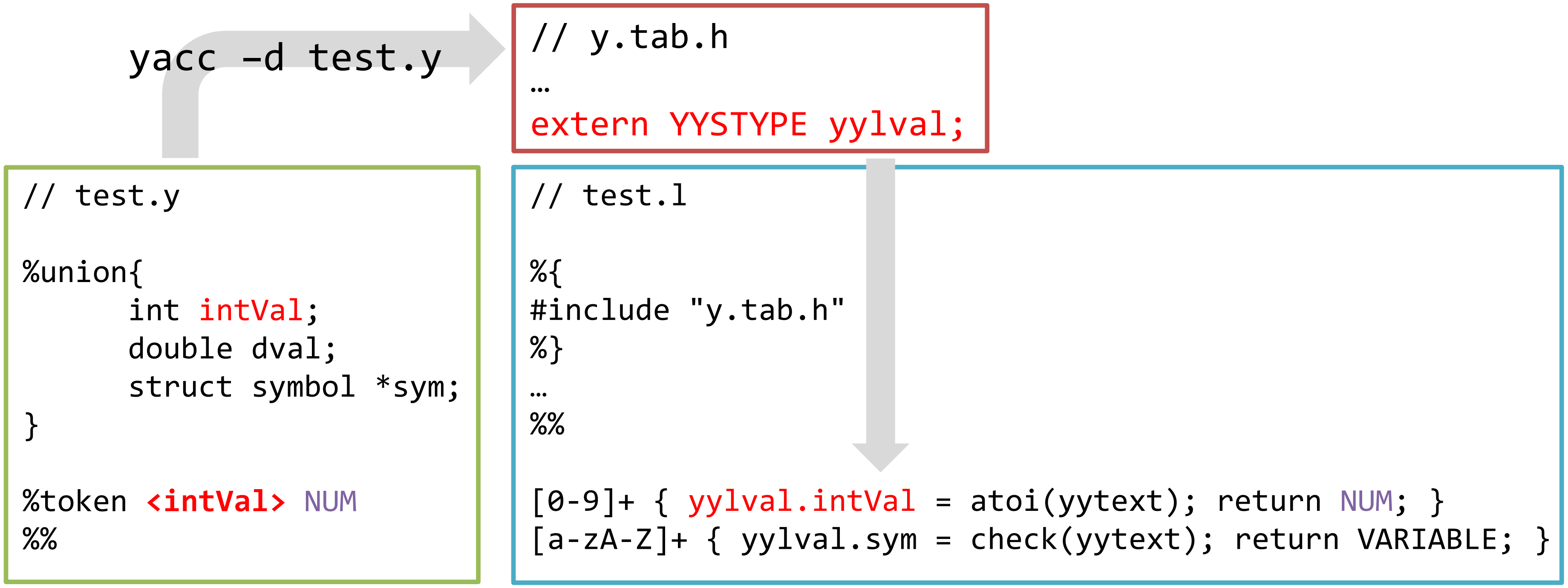
- A symbol in Yacc may carry a value with `yylval`
  - For example, a numeric value 42, or a pointer to a string `"Hello world!"`
- Default type of `yylval` is `int`
  - The type of `yylval` can be overwritten with `%union`
  - E.g.
    - Lex

```
// by default, type of yylval is int
[0-9]+ { yylval = atoi(yytext); return NUM; }
// type of yylval is overwritten with %union
[0-9]+ { yylval.intVal = atoi(yytext); return NUM; }
```

- Yacc: Use `$$, $1, $2,` …… to access values of reduced symbols

%union

- YYSTYPE is the type defined by `%union` in `y.tab.h`.
- All symbols, include terminal and nonterminal symbols are of YYSTYPE.



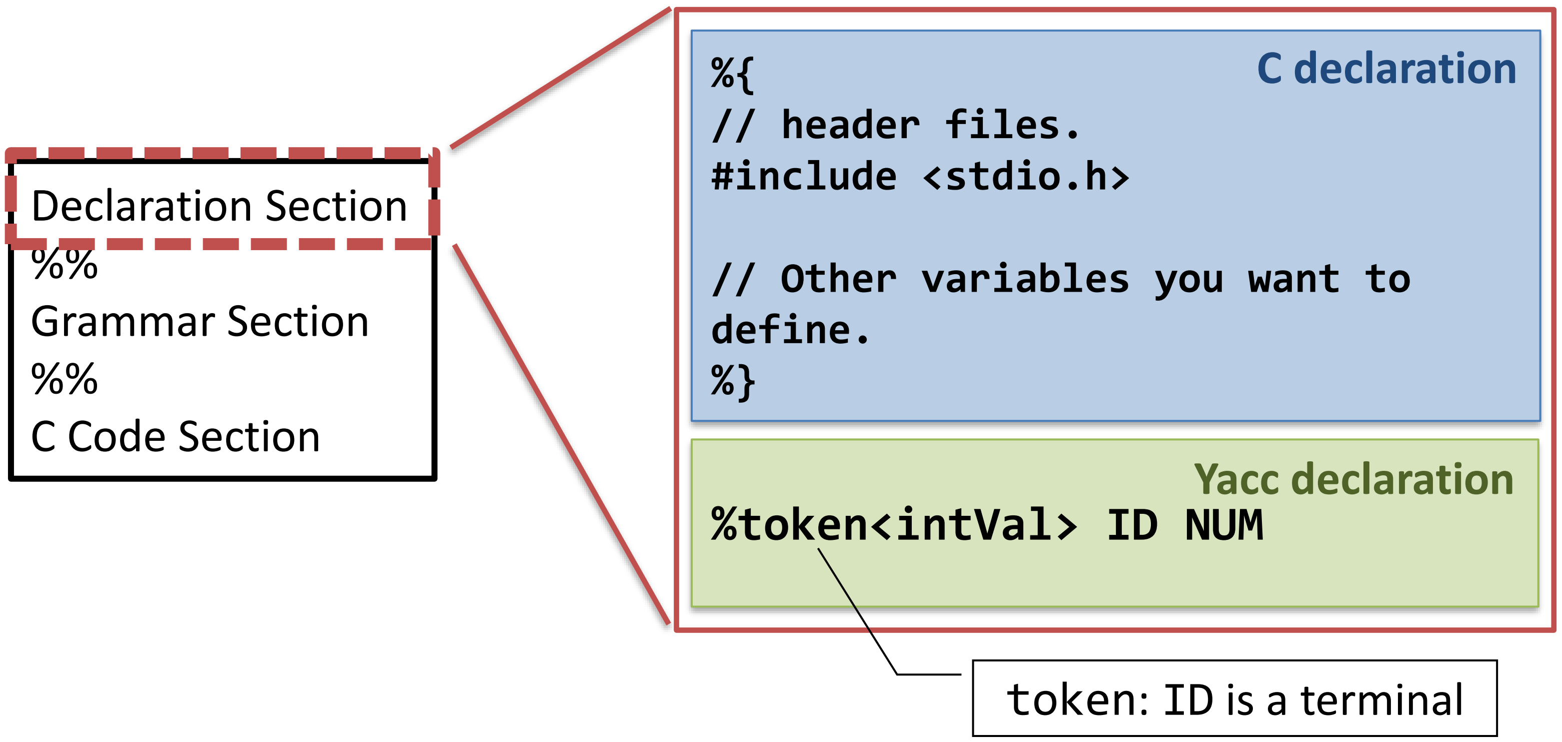
```
yacc –d test.y
```

```
// y.tab.h
…
extern YYSTYPE yylval;
```

```
// test.y

%union{
      int intVal;
      double dval;
      struct symbol *sym;
}

%token <intVal> NUM
%%
```

```
// test.l

%{
#include "y.tab.h"
%}
…
%%

[0-9]+ { yylval.intVal = atoi(yytext); return NUM; }
[a-zA-Z]+ { yylval.sym = check(yytext); return VARIABLE; }
```

How to Write Yacc?



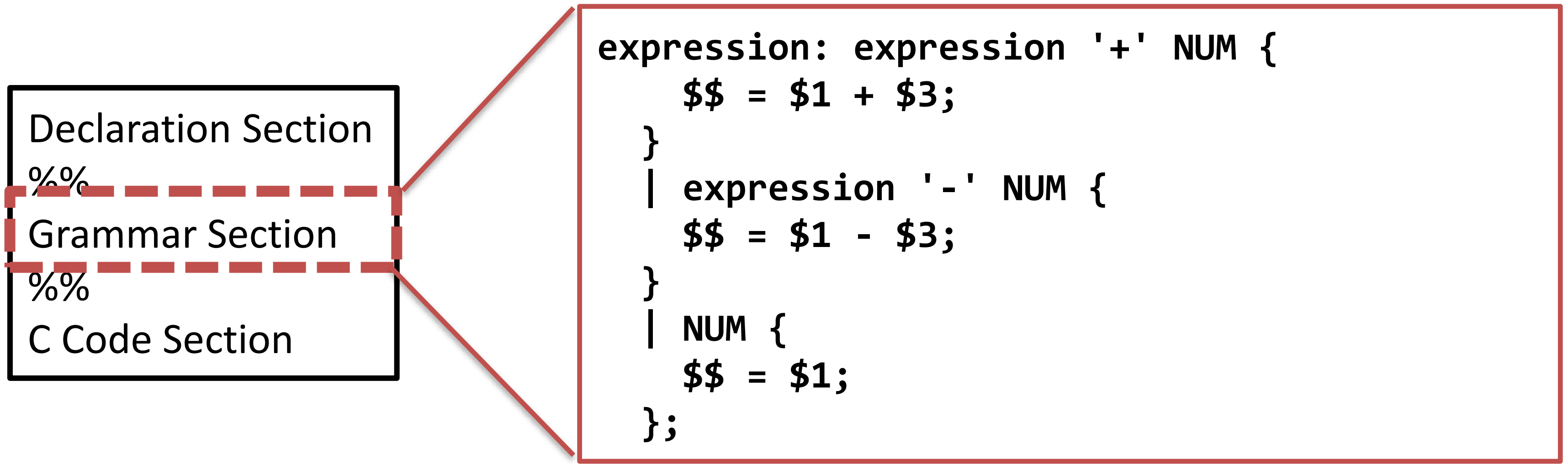
```
Declaration Section
%%
Grammar Section
%%
C Code Section
```

```
%{
// header files.
#include <stdio.h>

// Other variables you want to
define.
%}
```

```
%token<intVal> ID NUM
```

The Definition Section
C code will be copied to the top of generated C program.
Define tokens, start symbol, terminal and non-terminal type, association ……

How to Write Yacc?



```
expression: expression '+' NUM {
      $$ = $1 + $3;
   }
   | expression '-' NUM {
      $$ = $1 - $3;
   }
   | NUM {
      $$ = $1;
   };
```

The grammar section is where to write your own grammar.

```
non-terminal : grammar_rule_1 { actions_1 }
                    ...
                    | grammar_rule_n { actions_n } ;
```

Grammar Section

Grammar

$$
\begin{aligned}
\text{expr} &\rightarrow \text{expr '+' term} \mid \text{term} \\
\text{term} &\rightarrow \text{term '*' factor} \mid \text{factor} \\
\text{factor} &\rightarrow \text{'(' expr ')'} \mid \text{ID} \mid \text{NUM}
\end{aligned}
$$

Grammar Section in Yacc file

```
expr   : expr '+' term
       | term
       ;
term   : term '*' factor
       | factor
       ;
factor : '(' expr ')'
       | ID
       | NUM
       ;
```

Semantic Routines

```
expr : expr '+' term     { C code }
     | term              { C code }
     ;
term : term '*' factor   { C code }
     | factor            { C code }
     ;
factor : '(' expr ')'    { C code }
       | ID
       | NUM
       ;
```

Semantic Routines with yylval

```
expr : expr '+' term    { $$ = $1 + $3; }
     | term             { $$ = $1; }
     ;
term : term '*' factor  { $$ = $1 * $3; }
     | factor           { $$ = $1; }
     ;
factor : '(' expr ')'   { $$ = $2; }
       | ID
       | NUM
       ;
```

Symbol Value Numbering

$1

```
expr : expr '+' term     { $$ = $1 + $3; }
     | term              { $$ = $1; }
     ;
term : term '*' factor   { $$ = $1 * $3; }
     | factor            { $$ = $1; }
     ;
factor : '(' expr ')'    { $$ = $2; }
       | ID
       | NUM
       ;
```

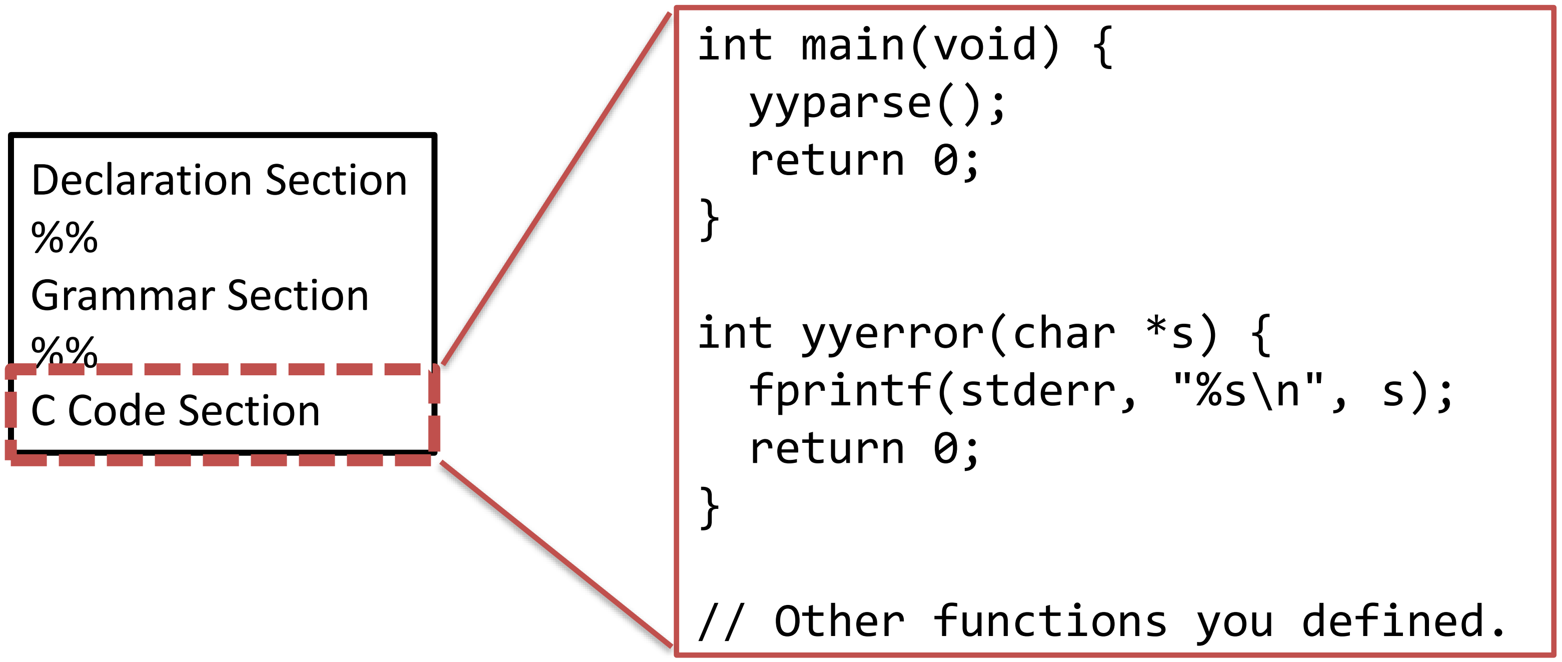
Symbol Value Numbering

```
expr : expr '+' term     { $$ = $1 + $3; }
     | term              { $$ = $1; }
     ;
term : term '*' factor   { $$ = $1 * $3; }
     | factor            { $$ = $1; }
     ;
factor : '(' expr ')'    { $$ = $2; }
       | ID
       | NUM       $2
       ;
```

Symbol Value Numbering

```
expr : expr '+' term       { $$ = $1 + $3; }
     | term                { $$ = $1; }
     ;
term : term '*' factor     { $$ = $1 * $3; }
     | factor              { $$ = $1; }
     ;
factor : '(' expr ')'      { $$ = $2; }
       | ID
       | NUM          $3
       ;
// Default action: { $$ = $1;}
```

How to Write Yacc?



```
Declaration Section
%%
Grammar Section
%%
C Code Section
```

```
int main(void) {
  yyparse();
  return 0;
}

int yyerror(char *s) {
  fprintf(stderr, "%s\n", s);
  return 0;
}

// Other functions you defined.
```

The C Code Section
will be copied to the bottom of generated C program.

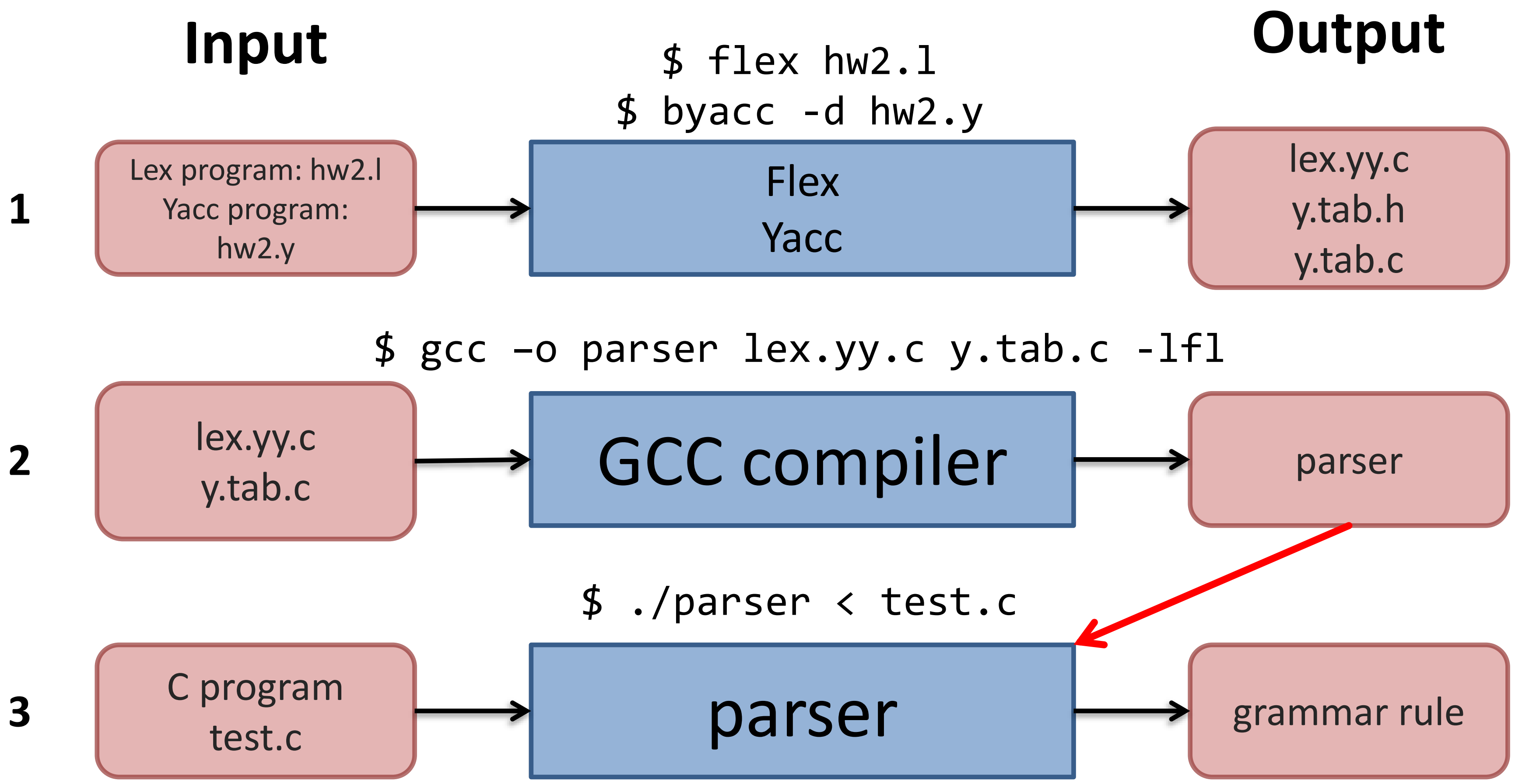
How to Write Yacc?

```
Declaration Section
%%
Grammar Section
%%
C Code Section
```

```
%{
#include <stdio.h>
%}
%union { int intVal; }
%token<intVal> ID NUM '=' '+' '-'
%type<intVal> statement expression

%%
statement: ID '=' expression
   | expression { printf("= %d\n", $1); };

expression: expression '+' NUM { $$ = $1 +
$3; }
   | expression '-' NUM { $$ = $1 - $3; }
   | NUM { $$ = $1; };

%%
int main(void) {
  yyparse();
  return 0;
}

int yyerror(char *s) {
  fprintf(stderr, "%s\n", s);
  return 0;
}
```

A completed Yacc program.

How to Use Yacc?



```
$ flex hw2.l
$ byacc -d hw2.y
```

```
$ gcc –o parser lex.yy.c y.tab.c -lfl
```

```
$ ./parser < test.c
```

Precedence / Association

- Consider two cases
  1. `1 - 2 - 3` (association)
  2. `1 - 2 * 3` (precedence)
- With grammar

```
expr: expr ' - ' expr
    | expr ' * ' expr
    | expr ' < ' expr
    | ' ( ' expr ' ) ';
```

- `1 - 2 - 3` is `(1 - 2) - 3` or `1 - (2 - 3)` ?
  – Define `'-'` operator to be left associated
- `1 - 2 * 3` is `1 - (2 * 3)`
  – Define the ' * ' operator to precede the ' - ' operator

Precedence / Association

- In Yacc definition section:

```
%left '+' '-'        low precedence
%left '*' '/'
%nonassoc UMINUS     high precedence
```

  - `%left` means left-associative
  - `%right` means right-associative
  - `%nonassoc` means non-associative

```
expr: expr '+' expr { $$ = $1 + $3; }
    | expr '-' expr { $$ = $1 - $3; }
    | expr '*' expr { $$ = $1 * $3; }
    | expr '/' expr {
      if ($3 == 0) yyerror("divide 0");
      else $$ = $1 / $3;
    }
    | '-' expr %prec UMINUS { $$ = - $2; };
```

Shift-Reduce Conflicts

- Shift-Reduce Conflicts:
  - Occurs when a grammar is written in a way such that a decision between shifting and reducing cannot be made
  - e.g. Dangling ELSE Ambiguity
- To resolve this conflict, Yacc will choose to shift
- NOT GOOD!! Eliminate them.

Shift-Reduce Conflict Example

- Grammar:
  S: IF '(' expr ')' S
  | IF '(' expr ')' S ELSE S ;
- Input: `if (e1) if (e2) s1 else s2`
- When parser encounters `else`, it can either
  - Shift (-in `else` first): `else` becomes part of the inner if statement
    - `if (e1) { if (e2) s1 else s2 }`
  - Reduce (S first): `else` becomes part of the outer if statement
    - `if (e1) { if (e2) s1 } else s2`

- From: "A brief yacc tutorial", Saumya Debray, *The University of Arizona, Tucson, AZ 85721.*

Reduce-Reduce Conflicts

- Reduce-Reduce Conflicts
  ```
  start: expr | stmt;
  expr: CONSTANT;
  stmt: CONSTANT;
  ```
- Yacc resolves reduce-reduce conflicts by using the rule that occurs earlier in the grammar.
- NOT GOOD!! Eliminate them.

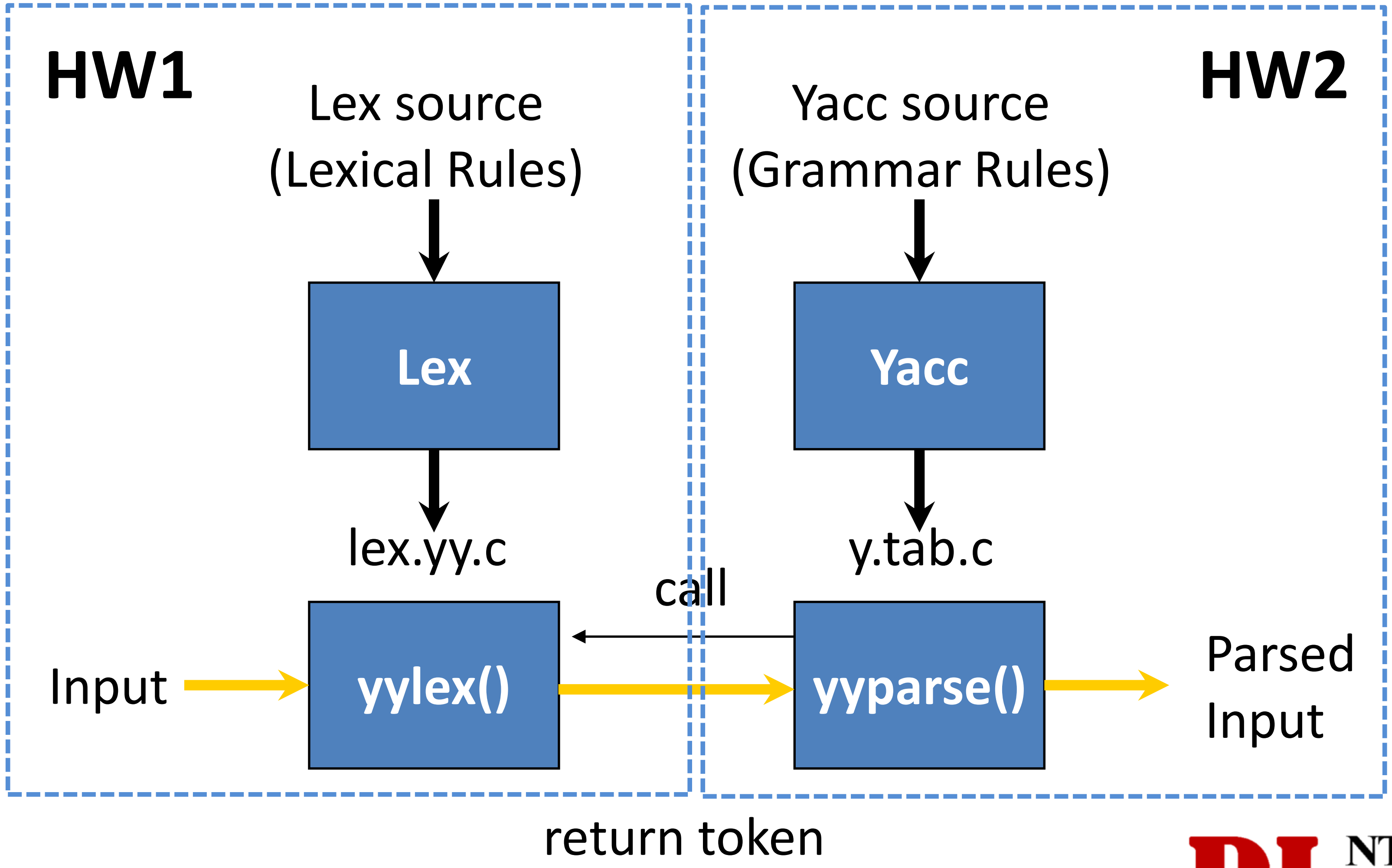
Handling Conflicts

- General approach
  1. Use `yacc -v` to generate the file `y.output`
  2. Examine `y.output` to find reported conflicts
  3. For each conflict, examine your grammar and `y.output` to figure out why there's the conflict
  4. Transform your grammar to eliminate the conflict

Yacc-Predefined Declaration

Name	Function
`%start`	Specify the start symbol of grammar.
`%union`	Declare the collection of data types that semantic values may have.
`%token`	Declare a terminal symbol (token name) with no precedence or associativity specified.
`%type`	Declare the type of semantic values for a nonterminal symbol.
`%right`	Declare a terminal symbol (token name) that is right-associative.
`%left`	Declare a terminal symbol (token name) that is left-associative.
`%nonassoc`	Declare a terminal symbol (token name) that is non-associative. Using it in a way that would be associative is a syntax error, Ex: **x operand y operand z** has a syntactic error.

Lex with Yacc



Lex and Yacc

- Rewrite HW 1 Lex to interface with Yacc
  1. `#include "y.tab.h"`
     - `y.tab.h` defines terminal symbols
  2. Remove main function
     - The only main function is in the Yacc file
  3. Set `yylval` in your lex actions
     - So that you can use `$1`, `$2`, … in your Yacc file
  4. Return token or character in your lex actions
     - So that your Yacc knows what kind of token is extracted by Lex

Homework 2 - Requirements

Top-level Program Ingredients

- Global Variable Declarations
- Function Declarations
- Function Definitions

Implement: Scalar Declaration

- ``type idents;"
  - ``type" can be either
    - ``[const] [signed|unsigned] [long long|long|short] int"
    - ``[const] [signed|unsigned] (long long)|long|short|char"
    - ``[const] signed|unsigned|float|double|void"
    - ``const"
  - ``idents" consists of 1 or more ``ident" separated by commas, and each ``ident" can be either a scalar or a single-level pointer scalar
    - `int a, *b, c;`
  - ``ident" in ``idents" can be initialized with ``ident = expr"
    - `int a = 123;`

Implement: Array Declaration

- ``type arrays;''
  - ``arrays'' consists of one or more ``ident[expr]\[[expr]...\]''
  - ``ident[expr]\[[expr]...\]'' can be initialized with: ``ident[expr]\[[expr]...\] = arr_content''
  - ``arr_content'' format: `{' 1 or more ``expr'' / ``arr_content'' separated by commas `}'
  - E.g.
    - `int a[1][3];`
    - `float a[1], b[1 + 1][3] = {{0, 1, 2}, {3, 4, 5}};`

Implement: Function Declaration

- ``type ident(parameters);" or ``type * ident(parameters);"
- ``parameters" consists of 0 or more parameters in the form of ``type ident" separated by commas
  - Only support scalar/single-level pointer parameters
- Parentheses are required even if there's no parameter

Implement: Function Definition

- ``type ident(parameters) compound_stmt" or ``type * ident(parameters) compound_stmt"
- Functions are global and may not be nested within other functions
- ``compound_stmt" refers to compound statements defined in later pages

Implement: Expression (``expr")

- Parentheses dictate a new precedence sequence for the enclosed ``expr"
- Support ``expr"s constructed by other ``expr"s with the following operators (some of those implemented in HW1)
  - + - * / % ++ -- < <= > >= == != = && || ! ~ ^ & | >> << [ ] ( )
    - Includes (post / pre-fix) (``++" / ``--"), unary (`+' / `-'), function invocation `(params...)`, array subscription, dereference (`*'), address-of (`&'), type-casting (``(type)", including single-level pointer types)
- Also includes
  - ``variable": ``ident" or ``ident[expr]\[[expr]...\]"
  - ``literal": single signless integer / signless floating-point number / char / string literal
  - ``NULL": Equals to integer ``0"
- For precedence and associativity, please refer to <https://en.cppreference.com/w/c/language/operator_precedence>

Implement: Statement (``stmt")

- Expression Statement: ``expr;"
- IF / IF-ELSE Statement
- SWITCH Statement
- WHILE Statement
- FOR Statement
- RETURN, BREAK, CONTINUE Statement
- Compound Statement

IF / IF-ELSE Statement

- ``if (expr) compound_stmt''
- ``if (expr) compound_stmt else compound_stmt''
- No ELSE-IF

SWITCH Statement

- ``switch (expr) { switch_clauses }"
  - ``switch_clauses" consists of 0 or more ``switch_clause" seperated by space / tab / newline / nothing
  - ``switch_clause" is in the form of
    - ``case expr:" 0 or more ``stmt"
    - ``default:" 0 or more ``stmt"

WHILE Statement

- ``while (expr) stmt"
- ``do stmt while (expr);"

FOR Statement

- ``for (\[expr\] ; \[expr\] ; \[expr\]) stmt"

RETURN, BREAK, CONTINUE Statement

- ``return expr;'' or ``return;''
- ``break;''
- ``continue;''

Compound Statement

- `{' 0 or more ``stmt"s / ``var_declaration"s `}'
- ``var_declaration" refers to variable declarations requiring implementations in the previous pages

Output Format

- Print the syntax tree to stdout
  - <scalar_decl>``scalar_declaration"</scalar_decl>
  - <array_decl>``array_declaration"</array_decl>
  - <func_decl>``function_declaration"</func_decl>
  - <func_def>``function_definition"</func_def>
  - <expr>``expr"</expr>
  - <stmt>``stmt"</stmt>
- In each tag, strip away all whitespaces ([\t\n]), except those in char / string literals
- Literals are canonicalized
  - Integer Literals: `atoi` then printf with `"%d"`
  - Double Literals: `atof` then printf with `"%f"`
  - Char Literals: No Change from Input. Keep the quotes.
  - String Literals: No Change from Input. Keep the quotes.
- There should be no raw newline in the output
- Follow `golden_parser` in the case of ambiguity

Formatting Output for Debug Purpose

- Our output follows the XML Format
- One can format it using an arbitrary XML formatter for debugging
  - $ tidy –xml –i –q input.txt
  - (p.s. This one looks good: https://jsonformatter.org/xml-formatter
- Use formatter only when you know there are something wrong in your output

yyerror()

- Called whenever an error is encountered during parsing
  - It must be supplied by the Yacc user
- Though there would be no syntax error in the input, one can supply the following:

```c
void yyerror(char * msg) {
  fprintf(stderr, "Error at line %d: %s\n", lineNo, curLine)
  exit(1);
}
```

Report

- For students who **cannot finish** the homework
  - Explain the Lex-Yacc interaction
  - Describe your understanding on the difficulties you faced
  - Describe how you tried to overcome those difficulties

Grading Policies

- Any Yacc Conflict or Compiler Warning: -20 points
- Late Submission: -10 points/day
- Executable, but not complying to specifications: 20% off your original score if you apply for a manual review (Reviews are not guaranteed to be accepted.)
- Non-executable: A flat grade of 40 points if you turn in your codes and report (late submission penalty applies)
- **Cheating: You will receive zero credit!**

Grading Policies

- Scalar Declarations without initialization: +10 pts
- Array Declarations without initialization: +10 pts
- Function Declarations: +10 pts
- Expressions (arithematics, ++/--, unary +/-, (expr), function invocation, array subscription, dereference, address-of, type-casting): +10 pts
- Expressions (arithematics, comparisons, logical operations): +10 pts
- Expressions (all operations): +10 pts
- Full Implementation of Variable Declarations: +10 pts
  - Scalar / Array Declarations with initialization
- Statements: +20 pts
- Function Definitions: +10 pts
- Note: There's dependency between these items, so exact grading is not possible.

Submission

- Source code
  - Upload to eeclass
    - The revised Lex source code of your lex scanner named \`scanner.l\`
    - Your Yacc parser source code named \`parser.y’\`
    - A \`makefile\` for TAs to compile your code
      - We'll \`make\` in a directory, so make sure you use relative paths in your makefile
  - The compiled output must be named \`parser\` and marked as an executable
- Report (if you can’t turn in a working executable)
  - Upload your code and report in PDF format to eeclass

How we run and test your program

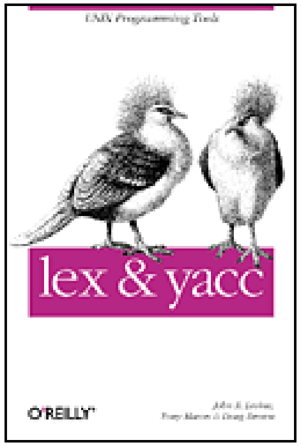
- How we compile
  - Copy your ‘scanner.l’, ‘parser.y’, ‘makefile’ in to a folder
  - Execute command ‘make’ to compile an executable ‘parser’
  - $ ./parser < input.txt > output.txt
- How we test
  - $ diff output.txt golden_answer.txt

Before you submit

- Make sure your makefile work well on the server
- Compare your output with golden_parser output
- Use ‘diff’ command to compare outputs
  - $ diff my_parser.txt golden_parser.txt

Reference

- **lex & yacc**
  - by John R.Levine, Tony Mason & Doug Brown
  - O′ Reilly
  - ISBN: 1-56592-000-7



- **Mastering Regular Expressions**
  - by Jeffrey E.F. Friedl
  - O′ Reilly
  - ISBN: 1-56592-257-3