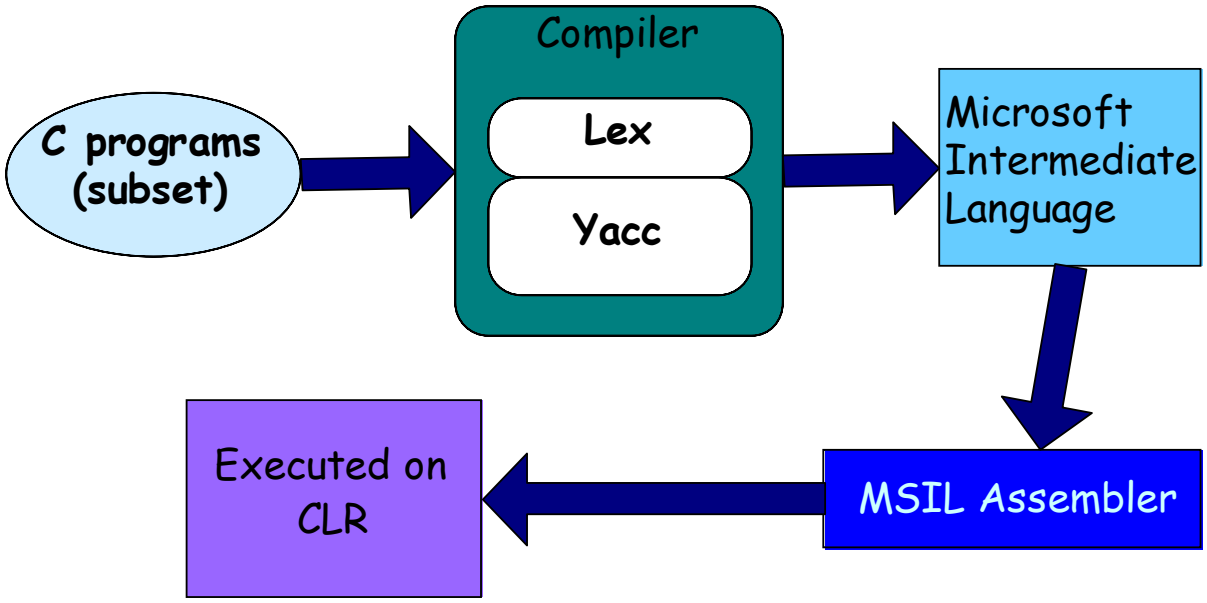
The Goal

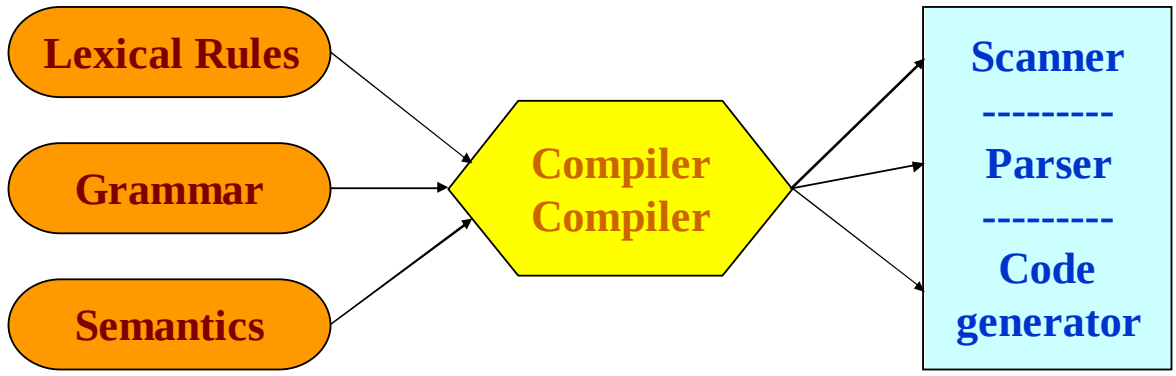


YACC
(Yet Another Compiler-Compiler)

Chung-Ju Wu
E-mail: jasonwu@pllab.cs.nthu.edu.tw

Why use Lex & Yacc ?

- Writing a compiler is difficult requiring lots of time and effort.
- Construction of the scanner and parser is routine enough that the process may be automated.



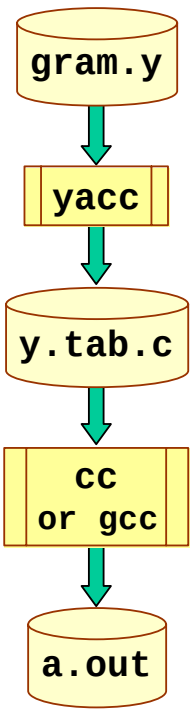
Introduction

- What is **YACC** ?
  - **Tool which will produce a parser for a given grammar.**
  - YACC (Yet Another Compiler Compiler) is a program designed to compile a LALR(1) grammar and to produce the source code of the syntactic analyzer of the language produced by this grammar.

History

- Original written by *Stephen C. Johnson*, 1975.
- Variants:
  - lex, yacc (AT&T)
  - bison: a yacc replacement (GNU)
  - flex: *f*ast *lex*ical analyzer (GNU)
  - BSD yacc
  - PCLEX, PCYACC (Abraxas Software)

How YACC Works



File containing desired grammar in yacc format

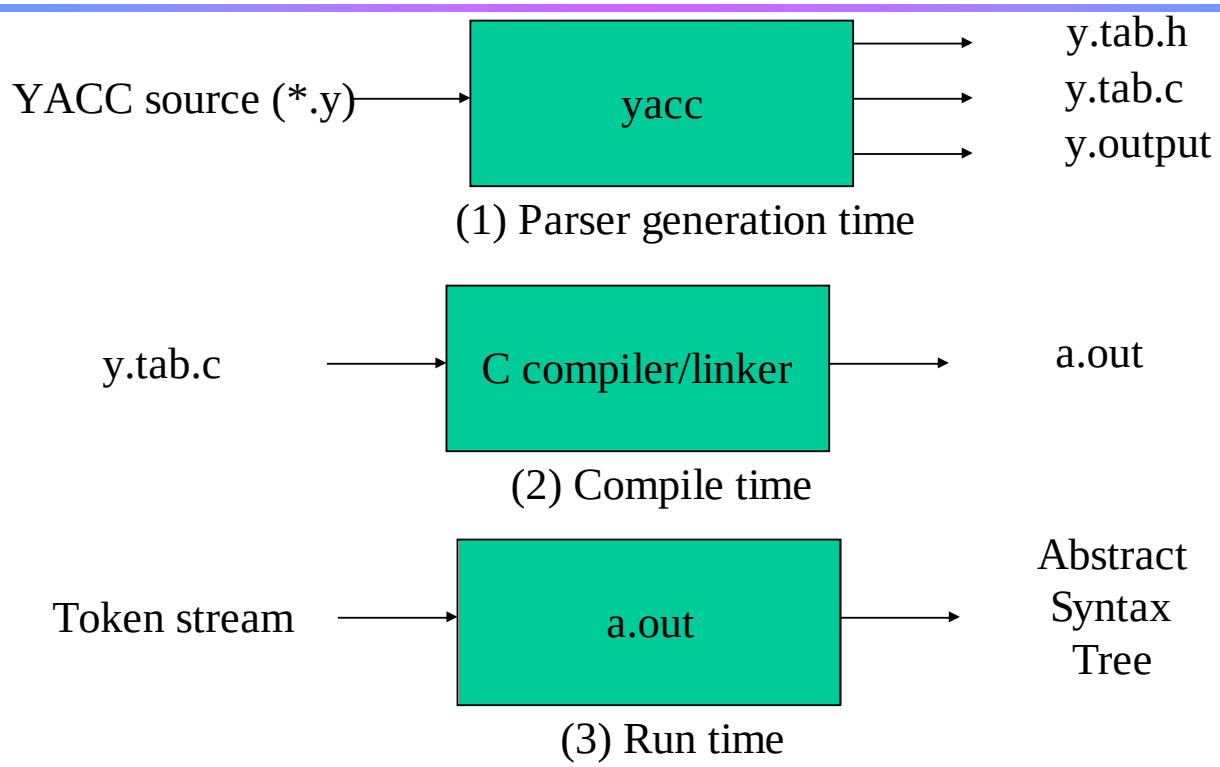
yacc program

C source program created by yacc

C compiler

Executable program that will parse grammar given in gram.y

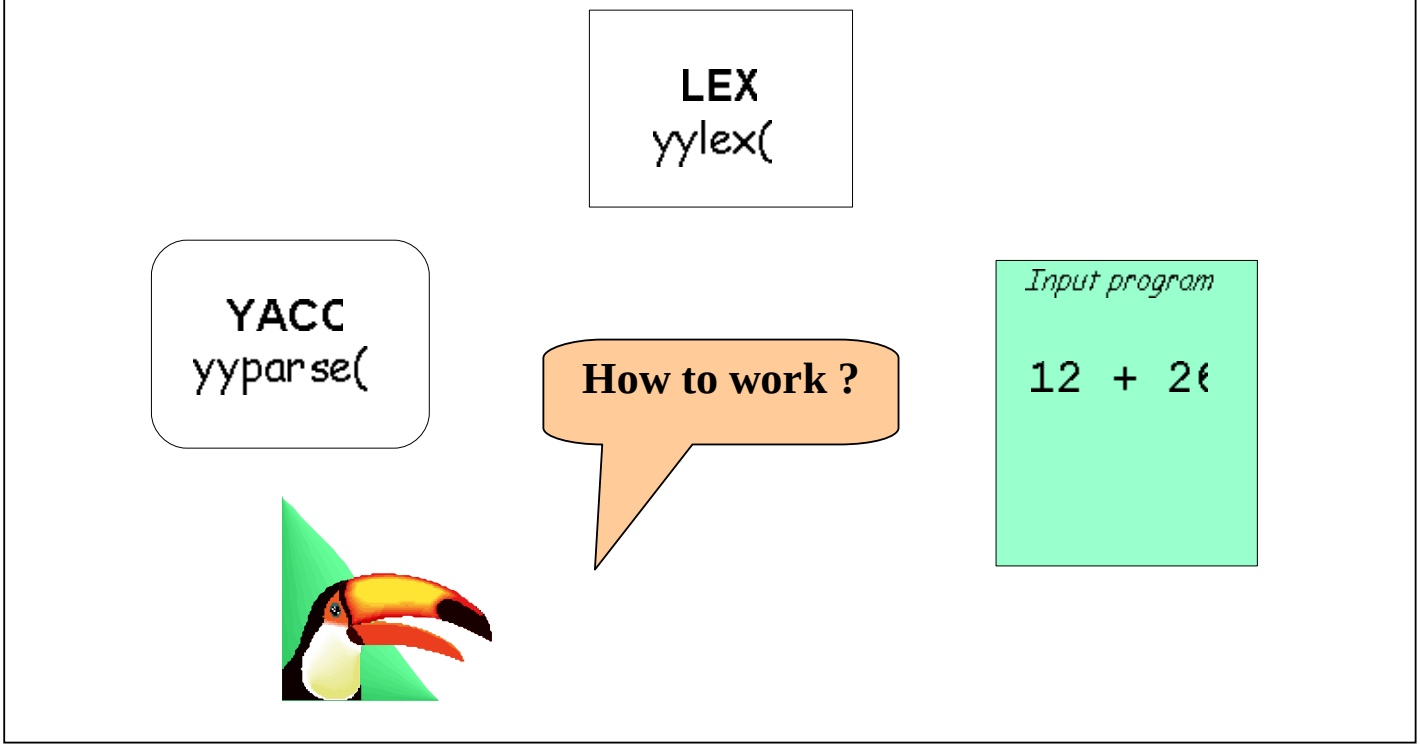
How YACC Works



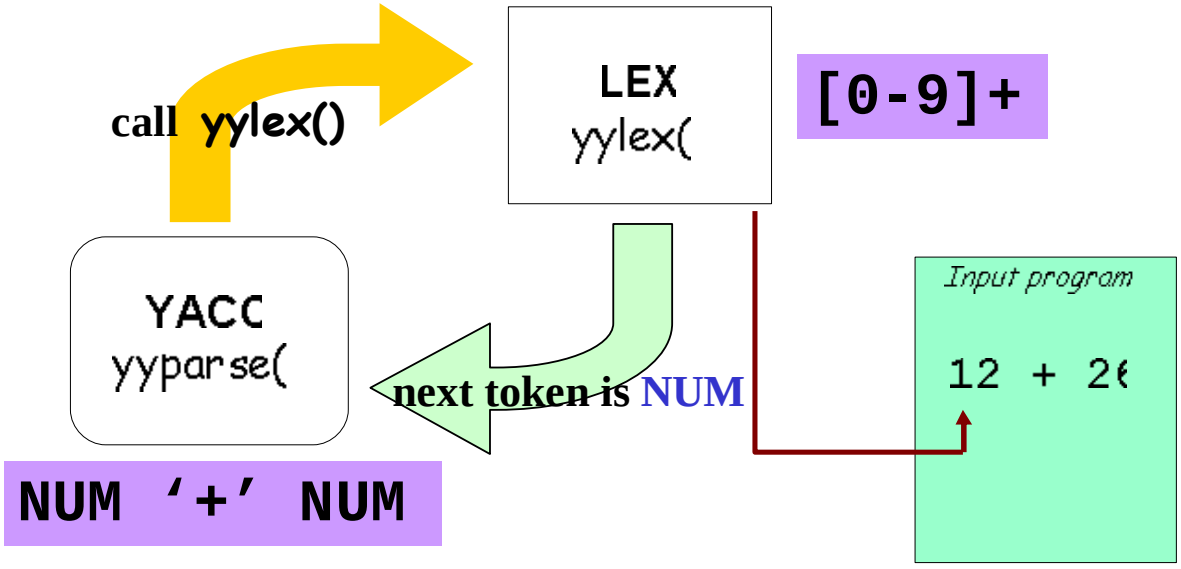
An YACC File Example

```
%{
#include <stdio.h>
%}

%token NAME NUMBER
%%

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

expression: expression '+' NUMBER { $$ = $1 + $3; }
        |   expression '-' NUMBER { $$ = $1 - $3; }
        |   NUMBER                { $$ = $1; }
        ;
%%
int yyerror(char *s)
{
   fprintf(stderr, "%s\n", s);
   return 0;
}

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

Works with Lex



Works with Lex



YACC File Format

%{

C declarations

%}

yacc declarations

%%

Grammar rules

%%

Additional C code

– **Comments enclosed in /* ... */ may appear in any of the sections.**

Definitions Section

```
%{
#include <stdio.h>
#include <stdlib.h>
%}
%token ID NUM
%start expr
```

It is a terminal

由 expr 開始parse

Start Symbol

- The first non-terminal specified in the grammar specification section.
- To overwrite it with %start declaraction.

```
%start  non-terminal
```

Rules Section

- Is a grammar
- Example

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

Rules Section

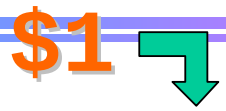
- Normally written like this
- Example:

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

The Position of Rules

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

The Position of Rules




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

The Position of Rules

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

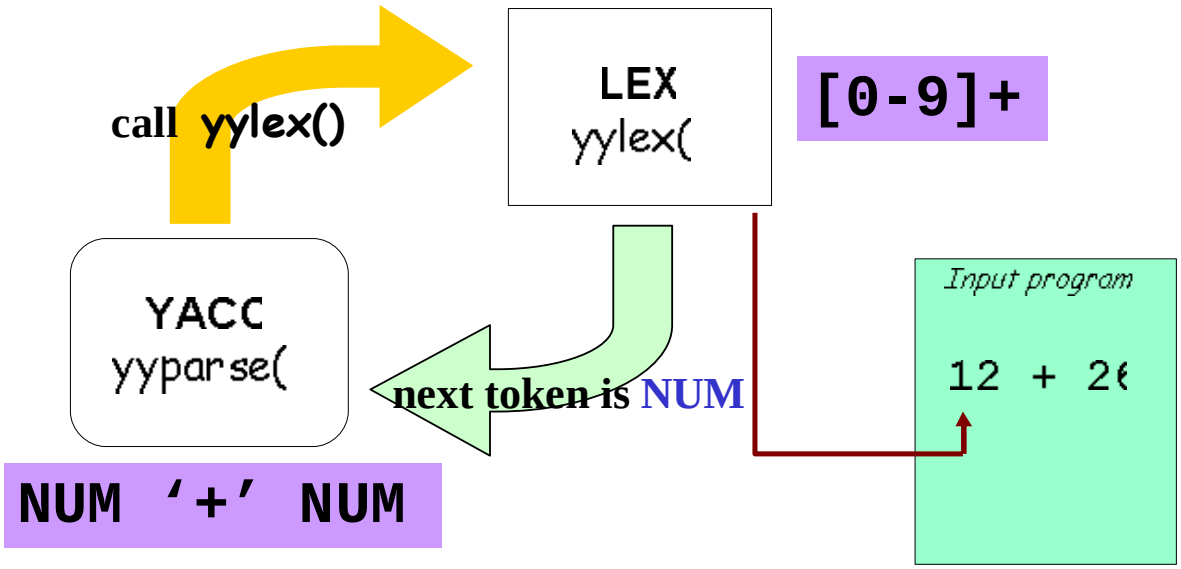
The Position of Rules

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

$3

Default: $$ = $1;

Communication between LEX and YACC



LEX and YACC需要一套方法確認token的身份

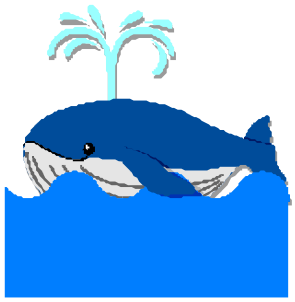
Communication between LEX and YACC

- **Use enumeration（列舉）/ define**
- **由一方產生，另一方 include**
  - **YACC 產生 y.tab.h**
  - **LEX include y.tab.h**

yacc -d gram.y

Will produce:

y.tab.h



Communication between LEX and YACC

scanner.l

```
%{
#include <stdio.h>
#include "y.tab.h"
%}
id          [_a-zA-Z][_a-zA-Z0-9]*
%%
int         { return INT; }
char        { return CHAR; }
float       { return FLOAT; }
{id}        { return ID;}
```

parser.y

```
%{
#include <stdio.h>
#include <stdlib.h>
%}
%token  CHAR, FLOAT, ID, INT
%%
```

```
yacc -d xxx.y
•  Produced
y.tab.h

# define CHAR 258
# define FLOAT 259
# define ID 260
# define INT 261
```

YACC

- Rules may be recursive
- Rules may be ambiguous*
- Uses bottom up Shift/Reduce parsing
  - Get a token
  - Push onto stack
  - Can it reduced (How do we know?)
    - If yes: Reduce using a rule
    - If no: Get another token
- Yacc cannot look ahead more than one token

Another Problem?

- Every terminal-token (symbol) may represent a value or data type
  - May be a numeric quantity in case of a number (42)
  - May be a pointer to a string ("Hello, World!")
- When using lex we put the value into **yylval**
  - In complex situations **yylval** is a union
- Typical lex code:

```
[0-9]+    {yylval = atoi(yytext); return NUM}
```

Another Problem?

- Yacc allows symbols to have multiple types of value symbols

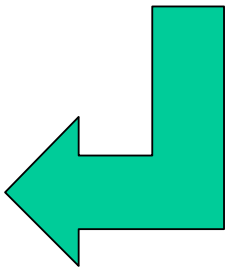
```
%union {
        double dval;
        int    vblno;
        char*  strval;
}
```

Another Problem?

```
%union {
        double  dval;
        int     vblno;
        char*   strval;
}
```

yacc -d

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



```
[0-9]+      { yylval.vblno = atoi(yytext);
              return NUM;}
[A-z]+      { yylval.strval = strdup(yytext);
              return STRING;}
```

Lex file
include “y.tab.h”

Yacc Example

- Taken from Lex & Yacc
- Simple calculator

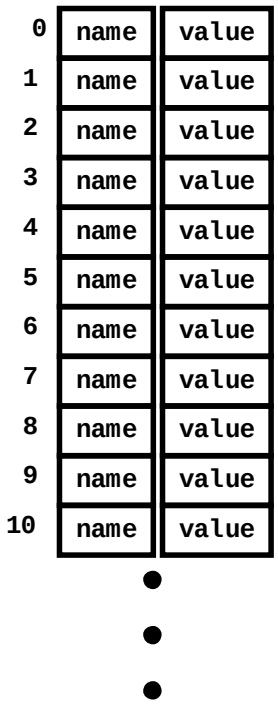
```
a = 4 + 6
a
a=10
b = 7
c = a + b
c
c = 17
$
```

Grammar

```
expression ::= expression '+' term |
               expression '-' term |
               term

term       ::= term '*' factor |
               term '/' factor |
               factor

factor     ::= '(' expression ')' |
               '-' factor  |
               NUMBER |
               NAME
```

Symbol Table

```
#define NSYMS 20  /* maximum number
                     of symbols */

struct symtab {
  char *name;
  double value;
} symtab[NSYMS];

struct symtab *symlook();
```



parser.h

Parser

```
%{
#include "parser.h"
#include <string.h>
%}

%union {
   double dval;
   struct symtab *symp;
}
%token <symp> NAME
%token <dval> NUMBER

%type <dval> expression
%type <dval> term
%type <dval> factor
%%
```

Terminal token **NAME** 與<**symp**>有相同的data type.

Nonterminal token **expression** 與<**dval**>有相同的data type.

parser.y

Parser (cont'd)

```
statement_list:     statement '\n'
              |     statement_list statement '\n'
              ;

statement:    NAME '=' expression { $1->value = $3; }
         |    expression          { printf("= %g\n", $1); }
         ;

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

parser.y

Parser (cont'd)

```
term:       term '*' factor { $$ = $1 * $3; }
    |       term '/' factor { if ($3 == 0.0)
                                 yyerror("divide by zero");
                              else
                                 $$ = $1 / $3;
                            }
    | factor
    ;

factor: '(' expression ')' { $$ = $2; }
      | '-' factor         { $$ = -$2; }
      | NUMBER             { $$ = $1; }
      | NAME               { $$ = $1->value; }
      ;
%%
```

parser.y

Scanner

```
%{
#include "y.tab.h"
#include "parser.h"
#include <math.h>
%}
%%
([0-9]+|([0-9]*\.[0-9]+)([eE][-+]?[0-9]+)?) {
    yylval.dval = atof(yytext);
  return NUMBER;
  }

[ \t] ;            /* ignore white space */
```

scanner.l

Scanner (cont'd)

```
[A-Za-z][A-Za-z0-9]*  { /* return symbol pointer */
                        yylval.symp = symlook(yytext);
                        return NAME;
                      }

"$"   { return 0; /* end of input */ }

\n|"="|"+"|"-"|"*"|"/"  return yytext[0];
%%
```

scanner.l

YACC Command

- Yacc (AT&T)
  - yacc –d *xxx.y*
- Bison (GNU)
  - bison –d **–y** *xxx.y*

產生y.tab.c, 與yacc相同
不然會產生xxx.tab.c

Precedence / Association

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

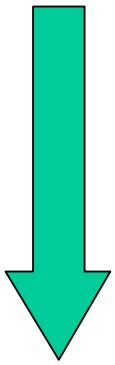
(1) 1 – 2 - 3

(2) 1 – 2 * 3

1. 1-2-3 = **(1-2)-3**? **or** 1-(2-3)?
   Define '-' operator is left-association.
2. 1-2*3 = 1-(2*3)
   Define "*" operator is precedent to "-" operator

Precedence / Association

```
%right ‘=‘
%left  '<' '>' NE LE GE
%left  '+' '-‘
%left  '*' '/'
```



highest precedence

Precedence / Association

```
%left  '+' '-'
%left  '*' '/'
%noassoc UMINUS
```

```
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; }
```

IF-ELSE Ambiguity

- Consider following rule:

```
stmt:
   IF expr stmt
   | IF expr stmt ELSE stmt
   ...
```

Following state : `IF expr stmt IF expr stmt . ELSE stmt`

```
IF expr stmt IF expr stmt . ELSE stmt
IF expr stmt IF expr stmt ELSE . stmt
IF expr stmt IF expr stmt ELSE stmt .
IF expr stmt stmt .
```

```
IF expr stmt IF expr stmt . ELSE stmt
IF expr stmt stmt . ELSE stmt
IF expr stmt . ELSE stmt
IF expr stmt ELSE . stmt
IF expr stmt ELSE stmt .
```

IF-ELSE Ambiguity

- It is a shift/reduce conflict.
- Yacc will always do shift first.
- Solution1 :re-write grammar

```
stmt    : matched
        | unmatched
        ;
matched: other_stmt
        | IF expr THEN matched ELSE matched
        ;
unmatched: IF expr THEN stmt
         | IF expr THEN matched ELSE unmatched
         ;
```

IF-ELSE Ambiguity

- Solution2:

```
%nonassoc IFX
%nonassoc ELSE

stmt:
    IF expr stmt %prec IFX
    | IF expr stmt ELSE stmt
```

the rule has the same precedence as token IFX

Shift/Reduce Conflicts

- **shift/reduce conflict**
  - occurs when a grammar is written in such a way that a decision between shifting and reducing can not be made.
  - ex: IF-ELSE ambigious.
- To resolve this conflict, yacc will choose to shift.

Reduce/Reduce Conflicts

- ***Reduce/Reduce Conflicts:***

```
start : expr | stmt
        ;
expr : CONSTANT;
stmt : CONSTANT;
```

- Yacc(Bison) resolves the conflict by reducing using the rule that occurs earlier in the grammar. **NOT GOOD!!**
- So, modify grammar to eliminate them.

Error Messages

- Bad error message:
  - Syntax error.
  - Compiler needs to give programmer a good advice.
- It is better to track the line number in lex:

```
void yyerror(char *s)
{
   fprintf(stderr, "line %d: %s\n:", yylineno, s);
}
```

Debug Your Parser

1. Use –t option **or** define YYDEBUG to 1.
2. Set variable *yydebug* to 1 when you want to trace parsing status.
3. If you want to trace the semantic values
   - Define your **YYPRINT** function

```
#define YYPRINT(file, type, value  yyprint(file, type, value

static voi(
yyprint (FILE *file, int type, YYSTYPE value

  if (type == VAR
    fprintf (file, " %s", value.tptr->name)
  else if (type == NUM)
    fprintf (file, " %d", value.val);
```

Shift and reducing

```
stmt: stmt ';' stmt
    | NAME '=' exp

exp: exp '+' exp
   | exp '-' exp
   | NAME
   | NUMBER
```

```
stack:

<empty>
```

```
input:
a = 7; b = 3 + a + 2
```

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

NAME

input:
= 7; b = 3 + a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

NAME ‘=‘

input:
7; b = 3 + a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

NAME ‘=‘ 7

input:
; b = 3 + a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

REDUCE!

stack:

NAME ‘=‘ exp

input:
; b = 3 + a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

REDUCE!

stack:

stmt

input:
; b = 3 + a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

stmt ‘;’

input:
b = 3 + a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

stmt ‘;’ NAME

input:
= 3 + a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

stmt ‘;’ NAME ‘=‘

input:
3 + a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

stmt ‘;’ NAME ‘=‘ NUMBER

input:
+ a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

REDUCE!

stack:

stmt ‘;’ NAME ‘=‘ exp

input:
+ a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

stmt ‘;’ NAME ‘=‘ exp ‘+’

input:
a + 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

stmt ‘;’ NAME ‘=‘ exp ‘+’ NAME

input:
+ 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

REDUCE!

stack:

stmt ‘;’ NAME ‘=‘ exp ‘+’ exp

input:
+ 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

REDUCE!

stack:

stmt ‘;’ NAME ‘=‘ exp

input:
+ 2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

stmt ‘;’ NAME ‘=‘ exp ‘+’

input:
2

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

SHIFT!

stack:

stmt ‘;’ NAME ‘=‘ exp ‘+’ NUMBER

input:
<empty>

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

REDUCE!

stack:

stmt ‘;’ NAME ‘=‘ exp ‘+’ exp

input:
<empty>

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

REDUCE!

stack:

stmt ‘;’ NAME ‘=‘ exp

input:
<empty>

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

REDUCE!

stack:

stmt ‘;’ stmt

input:
<empty>

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

REDUCE!

stack:

stmt

input:
<empty>

Shift and reducing

```
stmt: stmt ‘;’ stmt
    | NAME ‘=‘ exp

exp: exp ‘+’ exp
   | exp ‘-’ exp
   | NAME
   | NUMBER
```

DONE!

stack:

stmt

input:
<empty>

Recursive Grammar

- Left recursion

```
list:
     item
   | list ',' item
   ;
```

- Right recursion

```
list:
     item
   | item ',' list
   ;
```

- LR parser prefer left recursion.
- LL parser prefer right recursion.

YACC Declaration Summary

`%start'

Specify the grammar's start symbol

`%union'

Declare the collection of data types that semantic values may have

`%token'

Declare a terminal symbol (token type name) with no precedence or associativity specified

`%type'

Declare the type of semantic values for a nonterminal symbol

YACC Declaration Summary

`%right'

Declare a terminal symbol (token type name) that is right-associative

`%left'

Declare a terminal symbol (token type name) that is left-associative

`%nonassoc'

Declare a terminal symbol (token type name) that is nonassociative (using it in a way that would be associative is a syntax error, ex: x *op*. y *op*. z is syntax error)