Language processing: introduction to compiler construction

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YACC

- 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
  - Input is a grammar (rules) and actions to take upon recognizing a rule
  - Output is a C program and optionally a header file of tokens

LEX

- Lex is a scanner generator
  - Input is description of patterns and actions
  - Output is a C program which contains a function yylex() which, when called, matches patterns and performs actions per input
  - Typically, the generated scanner performs lexical analysis and produces tokens for the (YACC-generated) parser

LEX and YACC: a team

LEX
yylex()

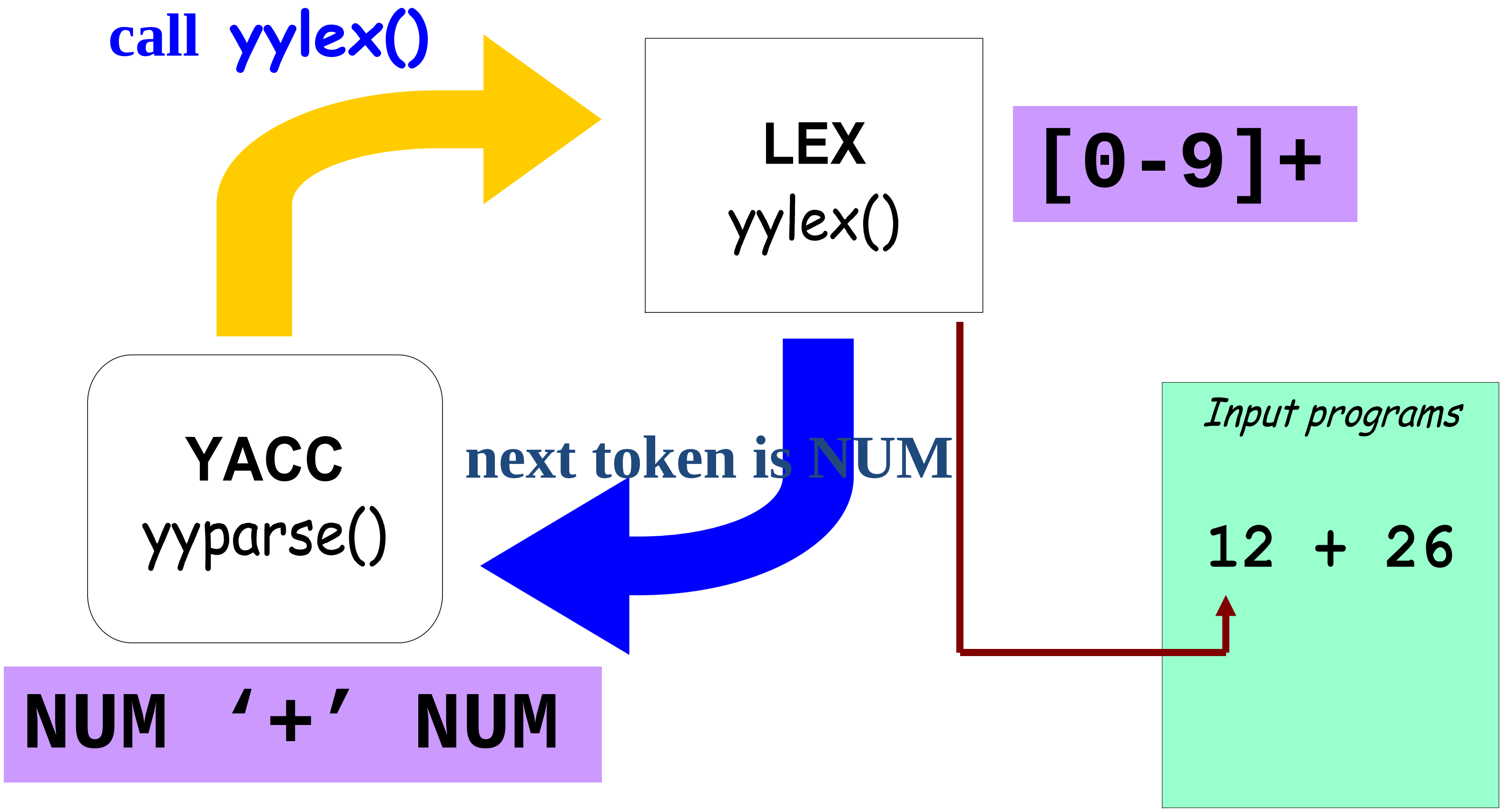
YACC
yyparse()

How to work ?

Input programs

12 + 26

LEX and YACC: a team

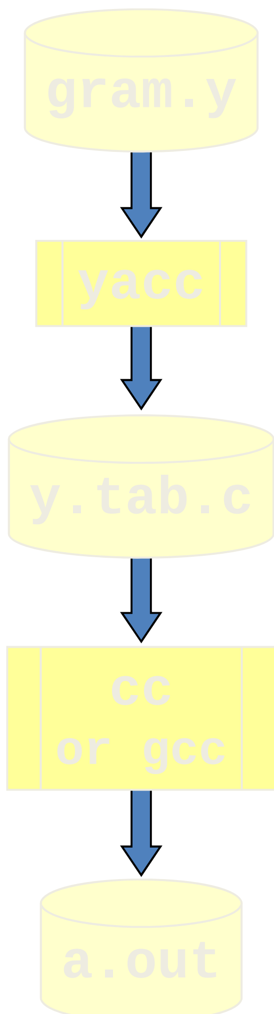


Availability

- lex, yacc on most UNIX systems
- bison: a yacc replacement from GNU
- flex: *f*ast *lex*ical analyzer
- BSD yacc
- Windows/MS-DOS versions exist

YACC

Basic Operational Sequence



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

YACC File Format

```
Definitions

%%

Rules

%%

Supplementary Code
```

The identical LEX format was actually taken from this...

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
       ;
```

Definitions Section

Example

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

This is called a terminal

The start symbol (non-terminal)

Sidebar

- LEX produces a function called yylex()
- YACC produces a function called yyparse()
- yyparse() expects to be able to call yylex()

- How to get yylex()?
- Write your own!

- If you don't want to write your own: Use LEX!!!

Semantic actions

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

Semantic actions (cont’d)

$1

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

Semantic actions (cont'd)

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

$2

Semantic actions (cont'd)

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

$3

Default: $$ = $1;

Bored, lonely? Try this!

`yacc -d gram.y`

- Will produce:

`y.tab.h`

Look at this and you'll never be unhappy again!

`yacc -v gram.y`

- Will produce:

`y.output`

Shows "State Machine"®

scanner.l

Example: LEX

```
%{
#include <stdio.h>
#include "y.tab.h"
%}
id          [_a-zA-Z][_a-zA-Z0-9]*
wspc        [ \t\n]+
semi        [;]
comma       [,]
%%
int         { return INT; }
char        { return CHAR; }
float       { return FLOAT; }
{comma}     { return COMMA; }        /* Necessary? */
{semi}      { return SEMI; }
{id}        { return ID;}
{wspc}      {;}
```

decl.y

Example: Definitions

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

decl.y

Example: Rules

```
/* This production is not part of the "official"
 * grammar. It's primary purpose is to recover from
 * parser errors, so it's probably best if you leave
 * it here. */

line :  /* lambda */
     | line decl
     | line error {
                printf("Failure :-(\n");
                yyerrok;
                yyclearin;
              }
     ;
```

decl.y

Example: Rules

```
decl :  type ID list { printf("Success!\n"); } ;

list :  COMMA ID list
     | SEMI
     ;
type :   INT | CHAR | FLOAT
     ;

%%
```

decl.y

Example: Supplementary Code

```
extern FILE *yyin;
main()
{
    do {
        yyparse();
    } while(!feof(yyin));
}
yyerror(char *s)
{
   /* Don't have to do anything! */
}
```

Bored, lonely? Try this!

yacc -d decl.y

- Produced

y.tab.h

```
# define CHAR 257
# define COMMA 258
# define FLOAT 259
# define ID 260
# define INT 261
# define SEMI 262
```

Symbol attributes

- Back to attribute grammars...
- Every symbol can have a value
  - Might be a numeric quantity in case of a number (42)
  - Might be a pointer to a string ("Hello, World!")
  - Might be a pointer to a symbol table entry in case of a variable
- 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}
```

Symbol attributes (cont'd)

- YACC allows symbols to have multiple types of value symbols

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

Symbol attributes (cont'd)

```
%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"

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

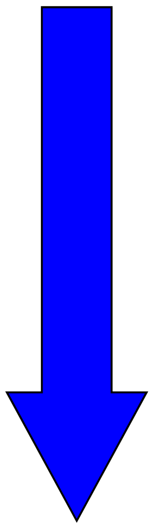
Precedence / Association

```
%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; }
```

Precedence / Association

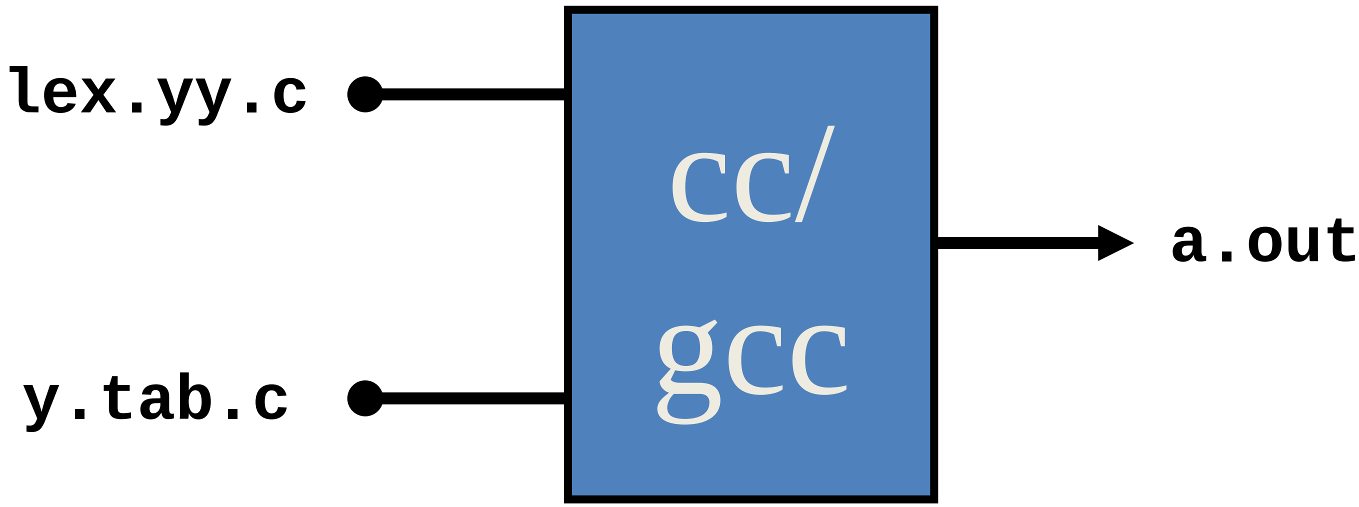
```
%right ‘=‘
%left  '<' '>' NE LE GE
%left  '+' '-‘
%left  '*' '/'
```



Big trick

Getting YACC & LEX to work together!

LEX & YACC



Building Example

- Suppose you have a lex file called **`scanner.l`** and a yacc file called **`decl.y`** and want **`parser`**
- Steps to build...

```
lex scanner.l
yacc -d decl.y
gcc -c lex.yy.c y.tab.c
gcc -o parser lex.yy.o y.tab.o -ll
```

Note: scanner should include in the definitions section: **`#include "y.tab.h"`**

YACC

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

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>
```

IF-ELSE Ambiguity

- Consider following rule:

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

Following state : IF expr IF expr stmt . ELSE stmt

- Two possible derivations:

IF expr IF expr stmt . ELSE stmt IF expr IF expr stmt ELSE . stmt IF expr IF expr stmt ELSE stmt . IF expr stmt	IF expr IF expr 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
- Solution 1 : 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

- Solution 2:

```
%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.
  - e.g.: IF-ELSE ambiguity
- 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

y.output

- Contains a log file: use ‘-v’ to generate a log file.

  State 1

  e: ID . (2)

  . (reduce 2

  State 2

  e: ‘(‘ .e ‘)’ (3)

  ID shift 1

  ‘(‘ shift 2

  . Error

  e goto 5
- Shift Reduce error
  - 9: shift/reduce conflict (shift 7, reduce 4) on ‘+’

  State 9

  e: e . ‘+’ e (4)

  e: e ‘+’ e. (4)

  ‘+’ shift 7

  ‘;’ reduce 4

  ‘)’ reduce 4

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);
}
```

Recursive Grammar

- Left recursion

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

- Right recursion

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

- LR parser prefers left recursion
- LL parser prefers 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, e.g.:
x *op*. y *op*. z is syntax error)