Lex & Yacc

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A compiler or an interpreter performs its task in 3 stages:

1) **Lexical Analysis:**

   Lexical analyzer: scans the input stream and converts sequences of characters into tokens.

   Token: a classification of groups of characters.

   Examples:

Lexeme	Token
Sum	ID
for	FOR
=	ASSIGN_OP
==	EQUAL_OP
57	INTEGER_CONST
"Abcd"	STRING_CONST
*	MULT_OP
,	COMMA
:	SEMICOLUMN
(	LEFT_PAREN

   Lex is a tool for writing lexical analyzers.

2) **Syntactic Analysis (Parsing):**

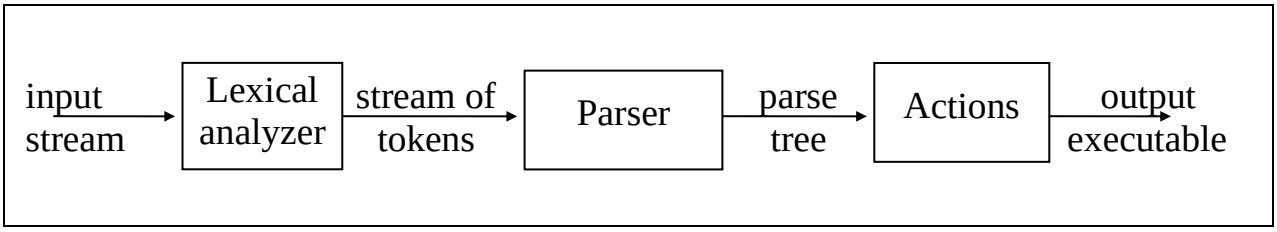
   Parser: reads tokens and assembles them into language constructs using the grammar rules of the language.

   Yacc (Yet Another Compiler Compiler) is a tool for constructing parsers.

3) **Actions:**

   Acting upon input is done by code supplied by the compiler writer.

Basic model of parsing for interpreters and compilers:

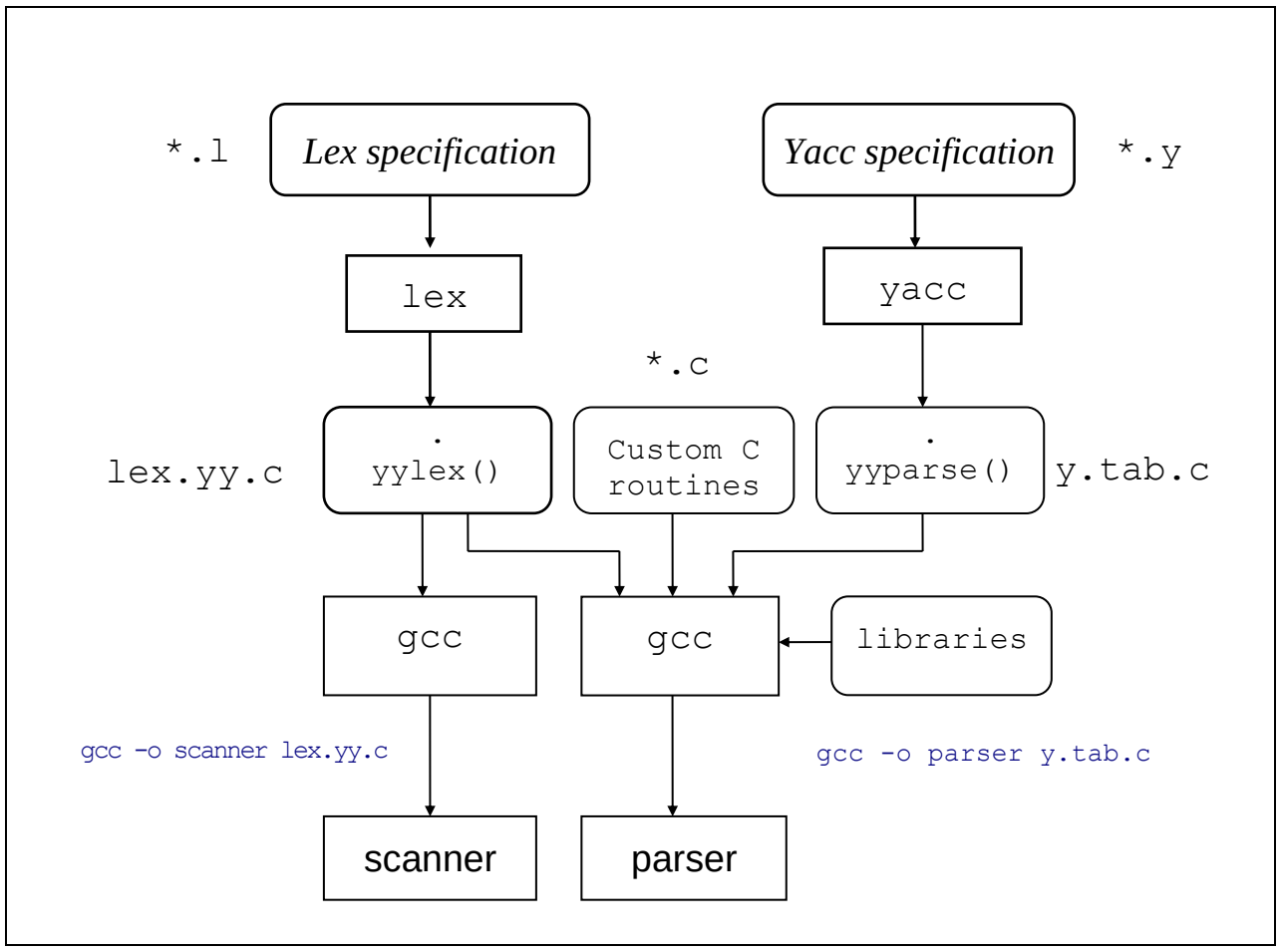


Lex: reads a specification file containing regular expressions and generates a C routine that performs lexical analysis.

Matches sequences that identify tokens.

Yacc: reads a specification file that codifies the grammar of a language and generates a parsing routine.

Using lex and yacc tools:



Lex

Regular Expressions in lex:

`a`	matches `a`
`abc`	matches `abc`
`[abc]`	matches `a`, `b` or `c`
`[a-f]`	matches `a`, `b`, `c`, `d`, `e`, or `f`
`[0-9]`	matches any digit
`X+`	matches one or more of X
`X*`	matches zero or more of X
`[0-9]+`	matches any natural number
`(…)`	grouping an expression into a single unit
`|`	alternation (or)
`(a|b|c)*`	is equivalent to `[a-c]*`
`X?`	X is optional (0 or 1 occurrence)
`if(def)?`	matches `if` or `ifdef` (equivalent to `if|ifdef`)
`[A-Za-z]`	matches any alphabetical character
`.`	matches any character except newline character
`\.`	matches the dot character
`\n`	matches the newline character
`\t`	matches the tab character
`\\`	matches the `\` character
`[ \t]`	matches either a space or tab character
`[^a-d]`	matches any character other than a,b,c and d

Examples:

Real numbers, e.g., 0, 27, 2.10, .17

```
[0-9]+|[0-9]+\.[0-9]+|\.[0-9]+
[0-9]+(\.[0-9]+)?|\.[0-9]+
[0-9]*(\.)?[0-9]+
```

To include an optional preceding sign: `[+-]?[0-9]*(\.)?[0-9]+`

Contents of a lex specification file:

```
definitions
%%
regular expressions and associated actions (rules)
%%
user routines
```

Example ($ is the unix prompt):

```
$emacs ex1.l
$ls
ex1.l
$cat ex1.l
%option main
%%
funny  printf("I recognized FUNNY");
$lex ex1.l
$ls
ex1.l   lex.yy.c
$gcc -o ex1 lex.yy.c
$ls
ex1     ex1.l   lex.yy.c
$emacs test
$cat test
fun
funny
ali is funny
and the course is fun

$cat test | ./ex1                or $./ex1 < test
fun
I recognized FUNNY
Ali is I recognized FUNNY
this course is fun
```

During pattern matching, lex searches the set of patterns for the single longest possible match.

```
$cat ex2.l
%option main
%%
fun    printf("FUN");
funny  printf("FUNNY");
```

```
$cat test | ex2
FUN
FUNNY
Ali is FUNNY
this course is FUN
```

Lex declares an external variable called `yytext` which contains the matched string

```
$cat ex3.l
%option main
%%
tom|jerry   printf(">%s<", yytext);
$cat test3
Did tom chase jerry?
$cat test3 | ex3
Did >tom< chase >jerry<?
```

Definitions:

```
/* float0.l */
%option main
%%
[+-]?[0-9]*(\.)?[0-9]+     printf("FLOAT");
```

input: `ab7.3c--5.4.3+d++5-`
output: `abFLOATc-FLOATFLOAT+d+FLOAT-`

The same lex specification can be written as:

```
/* float1.l */
%option main
digit    [0-9]
%%
[+-]?{digit}*(\.)?{digit}+    printf("FLOAT");
```

Local variables can be defined:

```
/* float2.l */
%option main
digit    [0-9]
sign     [+-]
%%
{sign}?{digit}*(\.)?{digit}+  {   float val;
                                  sscanf(yytext, "%f", &val);
                                  printf(">%f<", val);
                              }
```

Input	Output
ali-7.8veli	ali>-7.800000<veli
ali--07.8veli	ali->-7.800000<veli
+3.7.5	>3.700000<>0.500000<

Other examples

```
/* echo-upcase-wrods.l */
%option main
%%
[A-Z]+[ \t\n\.\,]   printf("%s",yytext);
.    ;    /* no action specified */
```

The scanner with the specification above echoes all strings of capital letters, followed by a space, tab (`\t`), newline (`\n`), dot (`\.`), or comma (`\,`) to stdout, and all other characters will be ignored.

Input	Output
Ali VELI → A7, X. 12	VELI → X.
HAMI BEY a	HAMI BEY

Definitions can be used in definitions

```
/* def-in-def.l */
%option main
alphabetic      [A-Za-z_$]
digit           [0-9]
alphanumeric    ({alphabetic}|{digit})
%%
{alphabetic}{alphanumeric}*  printf("Java identifier");
\,                           printf("Comma");
\{                           printf("Left brace");
\=                           printf("Assignment op");
\=\=                         printf("Equality op");
```

Among all of the rules that match the same number of characters, the rule given first in the file will be chosen.

Example,

```
/* rule-order.l */
%option main
%%
for      printf("FOR");
[a-z]+   printf("IDENTIFIER");
```

for input

```
for count = 1 to 10
```

the output would be

```
FOR IDENTIFIER = 1 IDENTIFIER 10
```

However, if we swap the two lines in the specification file:

```
%option main
%%
[a-z]+  printf("IDENTIFIER");
for     printf("FOR");
```

for the same input

the output would be

```
IDENTIFIER IDENTIFIER = 1 IDENTIFIER 10
```

Note that we get a warning from lex, about this problem!

Important Lex Rules:

1) At any point in the input stream, the rule that matches the longest string is used.
2) If two or more rules march the same input string, the one given the earliest in the specification file is used

Important note:

Do not leave extra spaces and/or empty lines at the end of a lex specification file.

Yacc

Yacc specification describes a CFG, that can be used to generate a parser.

Elements of a CFG:

1. Terminals: tokens and literal characters,
2. Variables (nonterminals): syntactical elements,
3. Production rules, and
4. Start rule.

Format of a production rule:

```
symbol:    definition
           {action}
           ;
```

Example:

`<a> ::= <b>c` in BNF is written as

`a: b 'c';` in yacc

Format of a yacc specification file:

```
declarations
%%
grammar rules and associated actions
%%
C programs
```

Declarations: To define tokens and their characteristics

`%token:`	declare names of tokens
`%left:`	define left-associative operators
`%right:`	define right-associative operators
`%nonassoc:`	define operators that may not associate with themselves
`%type:`	declare the type of variables
`%union:`	declare multiple data types for semantic values
`%start:`	declare the start symbol (default is the first variable in rules)
`%prec:`	assign precedence to a rule

```
%{
   C declarations
%}
```

directly copied to the resulting C program (E.g., variables, types, macros…)

Example: A yacc specification to accept $L = \{a^n b^n \mid n>0\}$.

```
/* anbn0.l */
%%
a   return (A);
b   return (B);
.   return (yytext[0]);
\n  return ('\n');
%%
int yywrap() { return 1; }
```

Function **`yywrap()`** is called by lex when input is exhausted.

Return 1 if you are done or 0 if more processing is required.

```
/*anbn0.y */
%token A B
%%
anbn:  s '\n' {return 0;}
s: A B
 | A s B
;
%%
#include "lex.yy.c"
int main() {
  return yyparse();
}
int yyerror( char *s ) { fprintf(stderr, "%s\n", s); }
```

If the input stream cannot be derived from the `start` variable, the default message of "`syntax error`" is printed and program terminates.

However, customized error messages can be generated.

```
/*anbn1.y */
%token A B
%%
anbn:   s '\n' { printf("  is in anbn\n");
                 return 0;}
s:   A B
 |   A s B
 ;
%%
#include "lex.yy.c"
void yyerror(char *s) { printf("%s, it is not in anbn\n", s); }
int main() {
  return yyparse();
}
```

```
$./anbn
aabb
  is in anbn
$./anbn
acadbefbg
Syntax error, it is not in anbn
$
```

A grammar to accept $L = \{a^n b^n \mid n \geq 0\}$.

```
/*anbn_0.y */
%token A B
%%
anbn:   s '\n' { printf("  is in anbn_0\n");
                 return 0;}
s:   empty
 |   A s B
 ;
empty: ;
%%
#include "lex.yy.c"
void yyerror(char *s){ printf("%s, it is not in anbn_0\n", s); }
int main() {
  return yyparse();
}
```

Positional assignment of values for items.

- $$: left-hand side
- $1: first item in the right-hand side
- $*n*: *n*th item in the right-hand side

Example: Simple adder

```
/* add.l */
digit  [0-9]
%%
{digit}+ {sscanf(yytext, "%d", &yylval);
          return(INT);
         }
\+       return(PLUS);
\n       return(NL);
.        ;
%%
int yywrap() { return 1; }
```

```
/* add.y */
/* L = {INT PLUS INT NL} */
%token INT PLUS NL
%%
add: INT PLUS INT NL { printf(" = %d\n", $1 + $3);}
%%
#include "lex.yy.c"
void yyerror(char *s) { printf("%s\n", s); }
int main() {
  return yyparse();
}
```

```
$ ./add
003 + 05
 = 8
1+2
syntax error
```

Example: printing integers in a loop

```
/* print-int.l */
%%
[0-9]+    {sscanf(yytext, "%d", &yylval);
           return(INTEGER);
          }
\n        return(NEWLINE);
.         return(yytext[0]);
%%
int yywrap() { return 1; }
```

```
/* print-int.y */
%token INTEGER NEWLINE
%%
lines: /* empty */
     | lines NEWLINE
     | lines value NEWLINE {printf(" =%d\n", $2);}
     | error NEWLINE {yyerror("! Reenter: "); yyerrok;}
     ;
value: INTEGER {$$ = $1;}
    ;
%%
#include "lex.yy.c"
void yyerror(char *s) { printf("%s", s); }
int main() {
  return yyparse();
}
```

`error` is a token provided by yacc. The macro **yyerrok** says, ‘‘the old error is finished.’’

Execution:

```
$./print-int
7
 =7
007
 =7
funny
syntax error! Reenter: 0007
 =7
^D
```

Keeping track of line numbers in the source:

```
/* print-int-wln.l */
/* printing integers with line numbers */
%%
[0-9]+  { sscanf(yytext, "%d", &yylval);
          return(INTEGER);
        }
\n      { extern int lineno; lineno++;
          return(NEWLINE);
        }
.       return(yytext[0]);
%%
int yywrap() { return 1; }
```

```
/* print-int-wln.y */
/* prints integers with line numbers */
%token INTEGER NEWLINE
%%
lines: /* empty */
     | lines NEWLINE
     | lines line NEWLINE {printf("%d) %d\n", lineno, $2);}
     | error NEWLINE { printf(" in line %d!\nReenter: ",lineno);
                       yyerrok;
                     }
;
line: INTEGER {$$ = $1;}
%%
#include "lex.yy.c"
int lineno=0;
void yyerror(char *s) { printf("%s", s); }
int main() {
  return yyparse();
}
```

Execution:

```
$./print-int-wln
007
1) 7
jhg
syntax error in line 2!
Reenter: 66
3) 66

_
```

Although right-recursive rules can be used in yacc, left-recursive rules are preferred, and, in general, generate more efficient parsers.

The type of `yylval` is `int` by default. To change the type of `yylval` use macro `YYSTYPE` in the declarations section of a yacc specifications file.

```
%{
#define YYSTYPE double
%}
```

If there are more than one data types for token values, `yylval` is declared as a `union`.

Example with three possible types for yylval:

```
%union{
    double  real;    /* real value */
    int     integer; /* integer value */
    char    str[30]; /* string value */
}
```

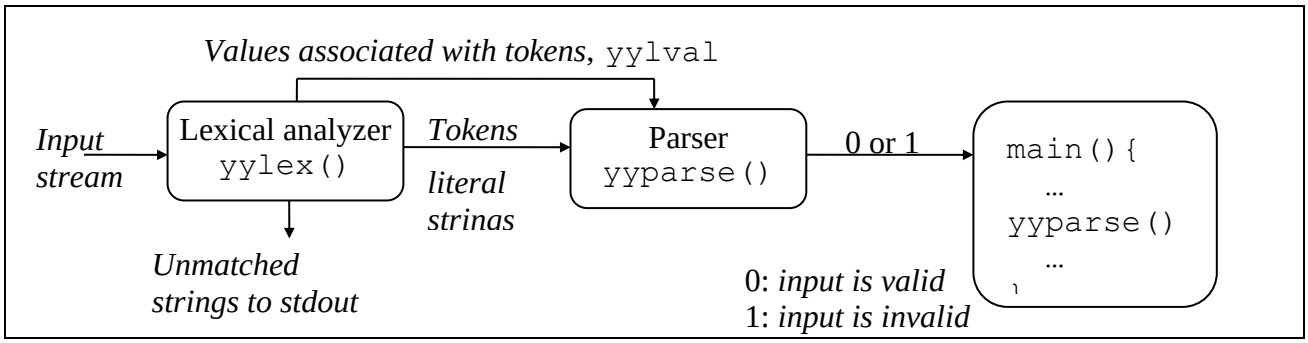
Example:

`yytext = "0012",` type of `yylval: int`, value of `yylval.integer: 12`

`yytext = "+1.70",` type of `yylval: double`, value of `yylval.real: 1.7`

The type of associated values of tokens can be specified by `%token` as

```
%token <real> REAL
%token <integer> INTEGER
%token <str> IDENTIFIER STRING
```



To return values, associated with tokens, from a lexical analyzer:

```
/* types.l */
alphabetic    [A-Za-z]
digit         [0-9]
alphanumeric  ({alphabetic}|{digit})
%%
[+-]?{digit}*(\.)?{digit}+      {sscanf(yytext, "%lf", &yylval.real);
                                 return REAL;
                                }
{alphabetic}{alphanumeric}*     {strcpy(yylval.str, yytext);
                                 return IDENTIFIER;
                                }
\<\-                            return ASSIGNOP;
\n                              return NL;
%%
int yywrap() { return 1; }
```

Type of variables can be defined by `%type` as

```
%type <real> real-expr
%type <integer> integer-expr
```

```
/* types.y */
%union{
  double  real;    /* real value */
  int     integer; /* integer value */
  char    str[30]; /* string value */
}
%token <real> REAL
%token <str>  IDENTIFIER
%token ASSIGNOP NL
%type <real> assignment_stmt
%%
assignment_stmt: IDENTIFIER ASSIGNOP REAL NL {
                          $$ = $3;
                          printf("%s is assigned to %g\n", $1, $$);
                 }
%%
#include "lex.yy.c"
void yyerror(char *s) { printf("%s, it is not an assignment!\n", s); }
int main() {
  return yyparse();
}
```

```
[guvenir@dijkstra types]$ ./types
total <- -01.57
total is assigned to -1.57
^D
```

Example: yacc specification of a calculator is given the web page of the course.
(http://www.cs.bilkent.edu.tr/~guvenir/courses/CS315/lex-yacc/calculator/)

Actions between rule elements:

```
/* actions.l */
%%
a return A;
b return B;
\n return NL;
. ;
%%
int yywrap() { return 1; }
```

```
/* actions.y */
%{
#include <stdio.h>
%}
%token A B NL
%%
s: {printf("1");}
   a
   {printf("2");}
   b
   {printf("3");}
   NL
   {return 0;}
   ;
a: {printf("4");}
   A
   {printf("5");}
   ;
b: {printf("6");}
   B
   {printf("7");}
   ;
%%
#include "lex.yy.c"
int yyerror(char *s) {
  printf ("%s\n", s);
}
int main(void){ yyparse(); }
```

actions:	14ab 52673
actions	14aa 526syntax error
actions	14ba syntax error
actions	14xyz**a**fgh**b**nm 52673

Conflicts

Pointer model: A pointer moves (right) on the RHS of a rule while input tokens and variables are processed.

```
%token A B C
%%
start: A B C ;    /* after reading A: start: A B C */
```

When all elements on the right-hand side are processed (the pointer reaches the end of a rule), the rule is *reduced*.

If a rule reduces, the pointer then returns to the rule where it was called.

Conflict: There is a *conflict* if a rule is reduced when there is more than one pointer. yacc looks one-token-ahead to see if the number of pointers reduces to one before declaring a conflict.

Example:

```
%token A B C D E F
%%
start: x | y;
x: A B C D;
y: A B E F;
```

After tokens `A` and `B`, either one of the tokens, or both will disappear. For example, if the next token is `E`, the first, if the next token is `C` the second token will disappear. If the next token is anything other than `C` or `E` both pointers will disappear. Therefore, there is no conflict.

The other way for pointers to disappear is to merge in a common subrule.

Example:

```
%token A B C D E F
%%
start: x | y;
x: A B z D E;
y: A B z D F;
z: C;
```

Initially, there are two pointers, one in `x`, the other in `y` rules. After reading tokens `A`, and `B`, these two pointers shift. Then, these two pointers merge in the `z` rule. The state after reading token C is shown below.

```
%token A B C D E F
%%
start: x | y ;
x: A B z D E ;
y: A B z D F ;
z: C↑;
```

However, after reading A B C, the `z` rule reduces. There is only one pointer when `z` reduces. Then, this pointer splits again into two pointers in `x` and `y` rules.

```
%token A B C D E F
%%
start: x | y ;
x: A B z↑D E ;
y: A B z↑D F ;
z: C;                          No conflicts
```

Conflict example:

```
%token A B
%%
start: x B | y B ;
x: A↑;        reduce
y: A↑;        reduce           reduce/reduce conflict on B.
```

After `A`, there are two pointers. Both rules (`x` and `y`) want to reduce at the same time. If the next token is `B`, there will be still two pointers. Such conflicts are called **reduce/reduce** conflict.

Note that yacc looks **one-token-ahead** before declaring any conflict.

```
%token A B C D E
%%
start: A x C D | A y C E ;
x: B↑ ;
y: B↑ ;                        reduce/reduce conflict on C.
```

The pointers in `x` and `y` rules will reduce on `C`, resulting in reduced/reduce conflict on `C`, although the grammar is not ambiguous. If yacc has looked two tokens ahead, it would have realized that only one pointer would remain on tokens `D` or `E`, and no pointer otherwise, so it would not declare any conflict.

Another type of conflict occurs when one rule reduces while the other shifts. Such conflicts are called **shift/reduce** conflicts.

Example:

```
%token A R
%%
start: x | y R;
x: A R ;      shift
y: A ;        reduce          shift/reduce conflict on R
```

After `A`, `y` rule reduces, `x` rule shifts. The next token for both cases is `R`.

Example:

```
%token A
%%
start: x | y;
x: A;         reduce
y: A;         reduce          reduce/reduce conflict on $end.
```

At the end of each string there is a `$end` token. Therefore, yacc declares reduce/reduce conflict on `$end` for the grammar above.

Debugging:

`$yacc -v` *filename*`.y`

produces a file named `y.output` for debugging purposes.

Example:

```
%token A P
%%
s: x | y P;
x: A P; /* shifts on P */
y: A;   /* reduces on P */
```

Execution starts with state=0 and 0 is the only item on the stack.
Current state is the top state of the stack.
Actions:

`shift` ***s*** : consume the token, push ***s*** onto the stack, go to state ***s***

`reduce` ***r*** : rule ***r*** is reduced, pop as many states from the stack as there are items on the RHS of rule ***r***. Go to the state on top of the stack

`goto` ***s*** : push state ***s*** onto the stack, go to the state ***s***.

`accept` : accept the input and halt

`error` call *yyerror*(), and halt

The `y.output` file for the grammar above is shown below:

```
  0  $accept : s $end

  1  s : x
  2    | y P
  3  x : A P
  4  y : A


state 0
        $accept : . s $end
        A  shift 1
        .  error

        s  goto 2
        x  goto 3
        y  goto 4

1: shift/reduce conflict (shift 5, reduce 4) on P
state 1
        x : A . P  (3)
        y : A .  (4)

        P  shift 5

state 2
        $accept : s . $end  (0)

        $end  accept


state 3
        s : x .  (1)

        .  reduce 1


state 4
        s : y . P  (2)

        P  shift 6
        .  error
```

`s: x` is called rule number 1

Each state corresponds to a unique combination of possible pointers in the yacc specifications file.

In state 0, if the lookahead token is A, then push the current state (0) onto the stack, shift the pointer, go to state 1.

Otherwise, call yyerror()

When s rule is reduced, push 2, state becomes 2

Reduce rule (4)

Shift and goto state 5

Shift/reduce conflict on P

One pointer is in rule (3) between tokens A and P

The other pointer is in rule (4) after token A

If the next token is P, the system will choose to shift and push 5 to the stack to go to state 5.

state 2: input matched the start variable

if this is the end of string, accept it.

State 3: rule (1) s: x is to reduce on any text token

Default action

Pop as many states as the number of items on the RHS or rule (1), in this case it is 1. The top of the stack becomes the next state.

State 4: pointer is in rule 2. After y rule is processed

If the look-ahead token is P, shift the pointer, go to state 6

If the look-ahead token is anything else, call *yyerror*()

```
state 5
        x : A P .  (3)

        .  reduce 3
state 6
        s : y P .  (2)

        .  reduce 2

Rules never reduced:
        y : A  (4)


State 1 contains 1 shift/reduce conflict.


4 terminals, 4 nonterminals
5 grammar rules, 7 states
```

State 5: Token A and then token P are seen.

Reduce rule (3) Pop 2 states since RHS of rule (3) has 2 items

Reduce rule (2). Pop 2 states since RHS of rule (2) has 2 items

{$end, A, P, .}

{$accept, s, x, y}

Recursive Rules:

Consider the following grammar:

```
/* recursive.y */
%token A
%%
s: A                // L ={A, AAA, AAAAA, …}, Not ambiguous !
 | A s A
;
```

y.output file:

```
   0  $accept : s $end

   1  s : A
   2    | A s A
^L
state 0
        $accept : . s $end  (0)

        A  shift 1
        .  error

        s  goto 2       if the state machine pops back to this state,
                        the lookahead symbol is s, the parser will go to state 2

1: shift/reduce conflict (shift 1, reduce 1) on A
state 1
        s : A .  (1)              reduce rule (1)
        s : A . s A  (2)          shift in rule (2)

        A  shift 1        if A, shift to state 1, that is, stay in the same state
        $end  reduce 1    if $end, reduce rule 1

        s  goto 3
...
```

However, the same language can also be represented by the following grammar, which does not have any conflict.

```
/* recursive.y */
%token A
%%
s: A                  // L ={A, AAA, AAAAA, …}, Not ambiguous !
 | s A A
;
```

The `y.output` file for this grammar

```
   0  $accept : s $end

   1  s : A
   2    | s A A
^L
state 0
        $accept : . s $end  (0)

        A  shift 1
        .  error

        s  goto 2


state 1
        s : A .  (1)

        .  reduce 1


state 2
        $accept : s . $end  (0)
        s : s . A A  (2)

        $end  accept
        A  shift 3
        .  error


state 3
        s : s A . A  (2)

        A  shift 4
        .  error


state 4
        s : s A A .  (2)

        .  reduce 2


3 terminals, 2 nonterminals
3 grammar rules, 5 states
```

Execution of this Push Down Automata for 3 input cases:

1) input: **`A $end`**
stack: case, action

```
[0]: token A, shift 1
[1,0]: default, reduce rule (1). |RHS(1)|=1
[0]: s rule (1) reduced, goto 2
[2,0]: token $end, accept.
```

2) input **`A A A $end`**
stack: case, action

```
[0]: token A, shift 1
[1,0]: default, reduce (1). |RHS(1)|=1
[0]: s rule (1) reduced, goto 2
[2,0]: token A, shift 3
[3,2,0]: token A, shift 4
[4,3,2,0]: default, reduce rule (2). |RHS(2)|=3
[0]: s rule(2) reduced, goto 2
[2,0]: token $end, accept.
```

3) input: **`A A $end`**
stack: case, action

```
[0]: token A, shift 1
[1,0]: default, reduce (1). |RHS(1)|=1
[0]: s rule (1) reduced, goto 2
[2,0]: token A, shift 3
[3,2,0]: token $end, error.
```

Actions on a Rule:

Actions can appear anywhere in the RHS of a rule.

However, for technical reasons, it is convenient for yacc to transform the grammar so that actions always appear at the very end.

For this reason, yacc introduces new variables, called *marker variables* (non-terminals), so that all actions are at the end of the rules.

Example,

Rule

```
a: {action1} b {action2} c {action3};
```

is replaced by

```
a: $$1 b $$2 c {action3};
$$1: {action1};  // Empty rules
$$2: {action2};
```

Example:

```
%token A B NL
%%
start: x | y;
x:  A A NL ;
y:  A B NL ;
```

Internally:

```
0  $accept : start $end
   1  start : x
   2        | y
   3  x : A A NL
   4  y : A B NL
```

No Conflict.

However, the equivalent following grammar

```
%token A B NL
%%
start: x | y;
x: {printf("using x");} A A NL ;
y: {printf("using y");} A B NL ;
```

Converted into:

```
0  $accept : start $end
   1  start : x
   2        | y
   3  $$1 :
   4  x : $$1 A A NL
   5  $$2 :
   6  y : $$2 A B NL
```

Conflict:

```
reduce/reduce conflict (reduce 3, reduce 5) on A
```

Make utility

Using the make utility on linux systems:
Contents of the file named `Makefile`:

```
parser: lex.yy.c y.tab.c
    gcc -o parser y.tab.c
y.tab.c: parser.y
    yacc parser.y
lex.yy.c: scanner.l
    lex scanner.l
```

On the command prompt, just type

`make`

It automatically determines which source files (in this example, `y.tab.c`, `parser.y`, `lex.yy.c`, `scanner.l`) of a program (`parser` in this example) need to be recompiled and/or linked.

Bibliography

Saumya Debray “A Quick Introduction to Handling Conflicts in Yacc Parsers”
https://www2.cs.arizona.edu/~debray/Teaching/CSc453/DOCS/conflicts.pdf

Tom Niemann, “LEX & YACC TUTORIAL”,
https://www.epaperpress.com/lexandyacc/

Programming Utilities Guide, Chapter 3 yacc -- A Compiler Compiler
https://docs.oracle.com/cd/E19504-01/802-5880/6i9k05dgt/index.html