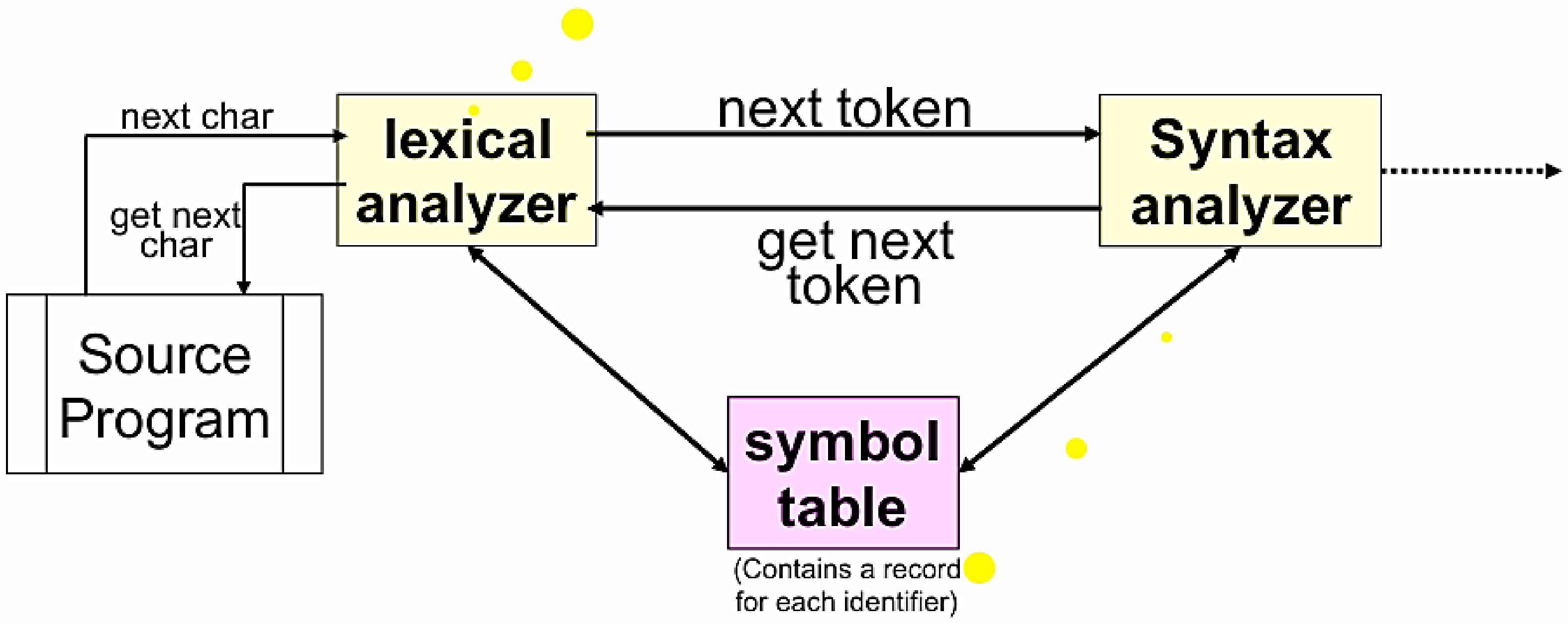
Compiler Design

Yacc

Yet another compiler compiler

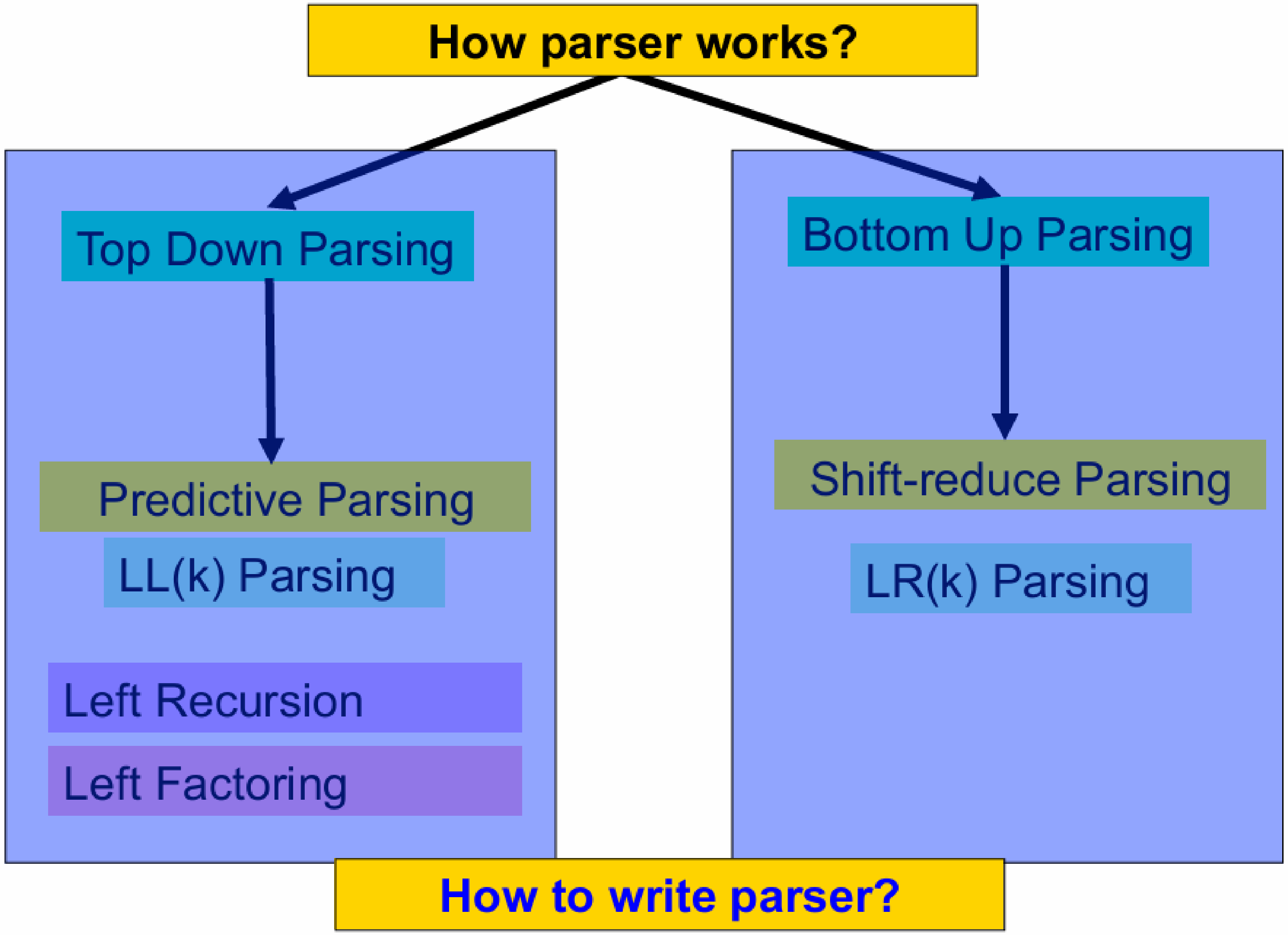
1. Uses Regular Expressions to define tokens
2. Uses Finite Automata to recognize tokens



Uses Top-down parsing or Bottom-up parsing

To construct a Parse tree

Parsing


How parser works?
Top Down Parsing
Predictive Parsing
LL(k) Parsing
Left Recursion
Left Factoring
Bottom Up Parsing
Shift-reduce Parsing
LR(k) Parsing
How to write parser?

UNIX Programming Tools

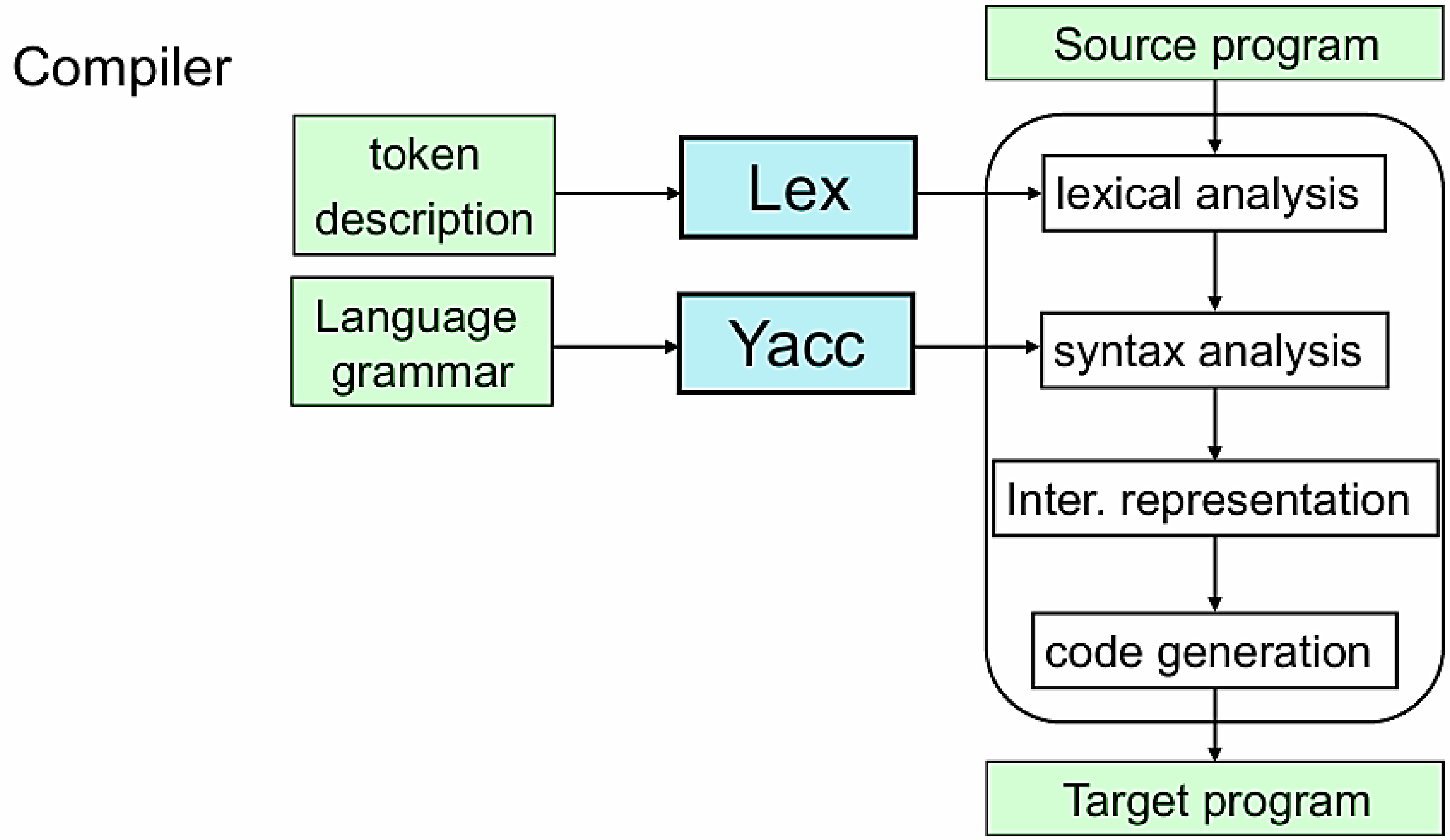
2nd Edition

lex & yacc

O'REILLY®

John R. Levine,
Tony Mason & Doug Brown

Yacc



Compiler
token description
Lex
Language grammar
Yacc
Source program
lexical analysis
syntax analysis
Inter. representation
code generation
Target program

How to write an LR parser?

General approach:

The construction is done automatically by a tool such as the *Unix* program ***yacc***.

Using the source program language grammar to write a simple yacc program and save it in a file named name.y

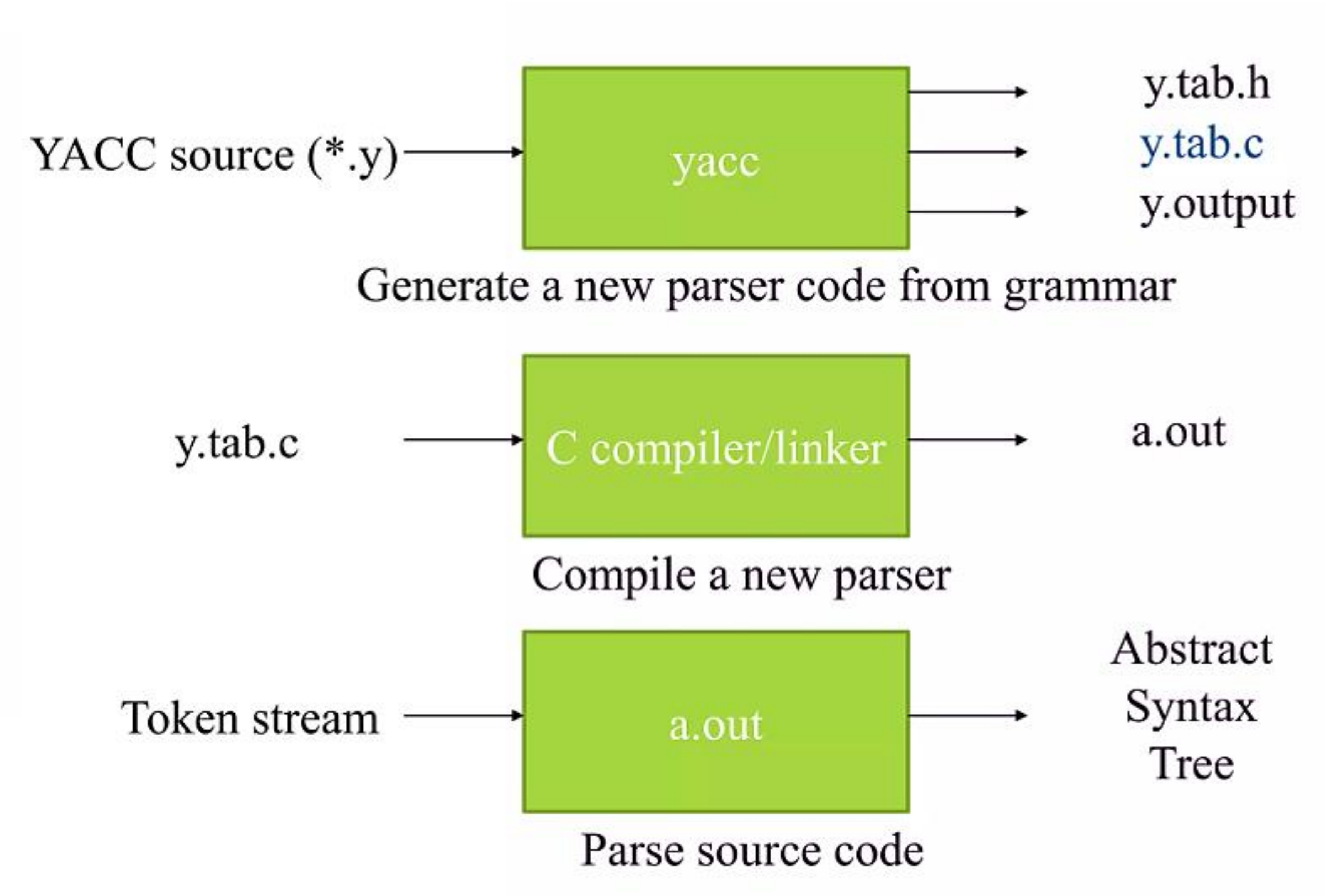
Using the unix program yacc to compile name.y resulting in a C (parser) program named y.tab.c

Compiling and linking the C program y.tab.c in a normal way resulting the required parser.

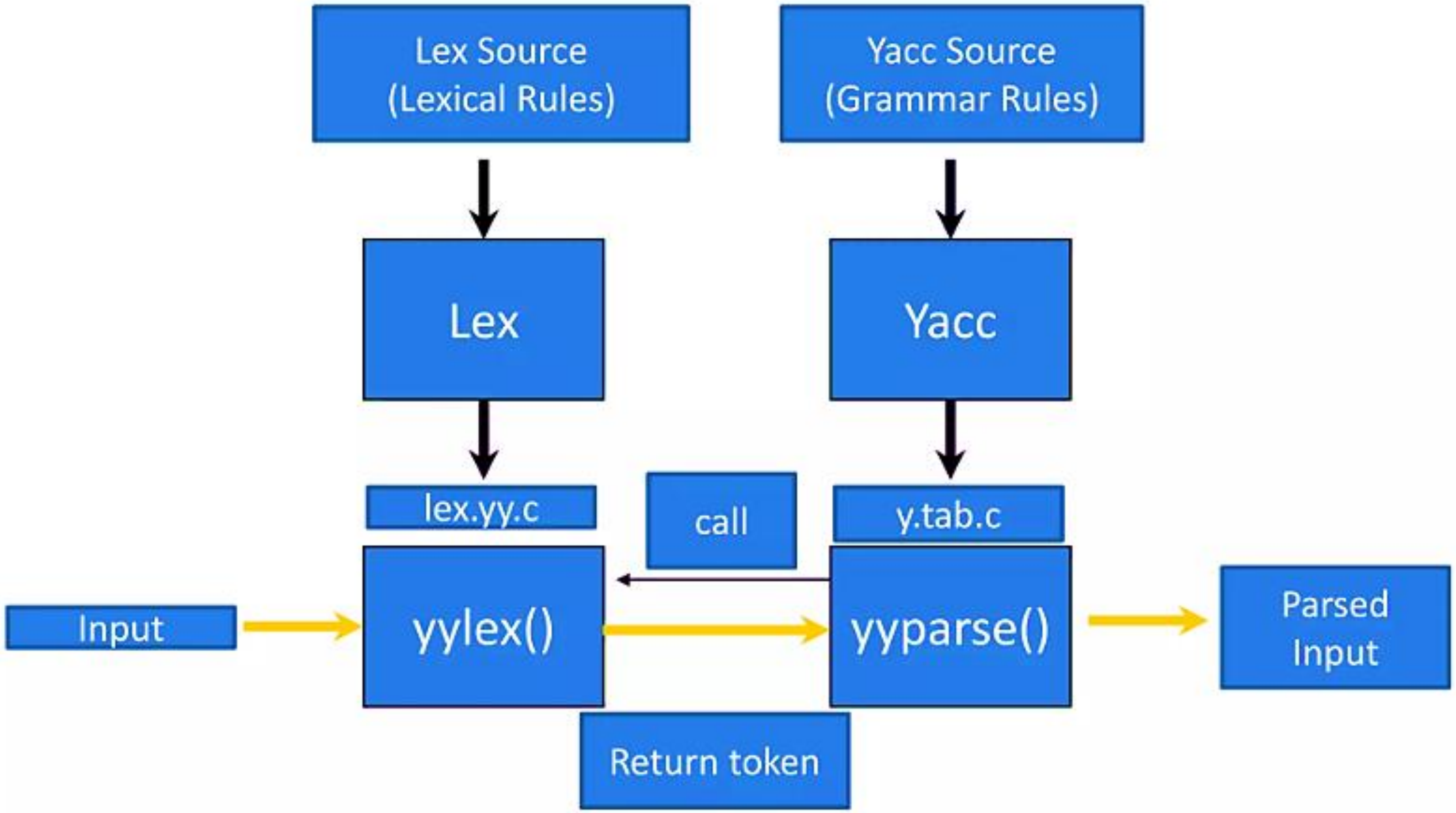
LR parser generators

- Yacc: Yet another compiler compiler
- Automatically generate LALR parsers
- Created by S.C. Johnson in 1970’s

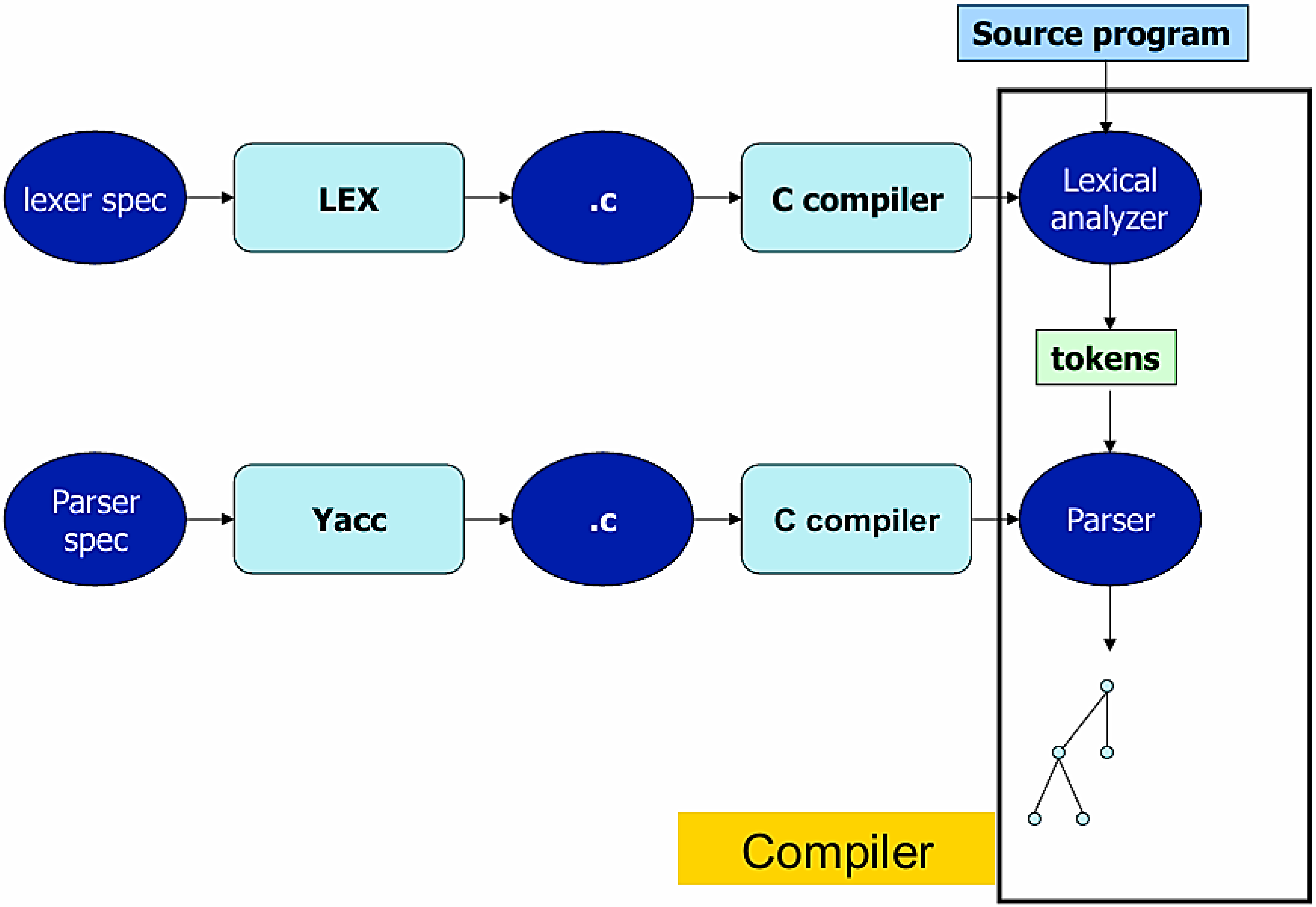
How Does Yacc Work?



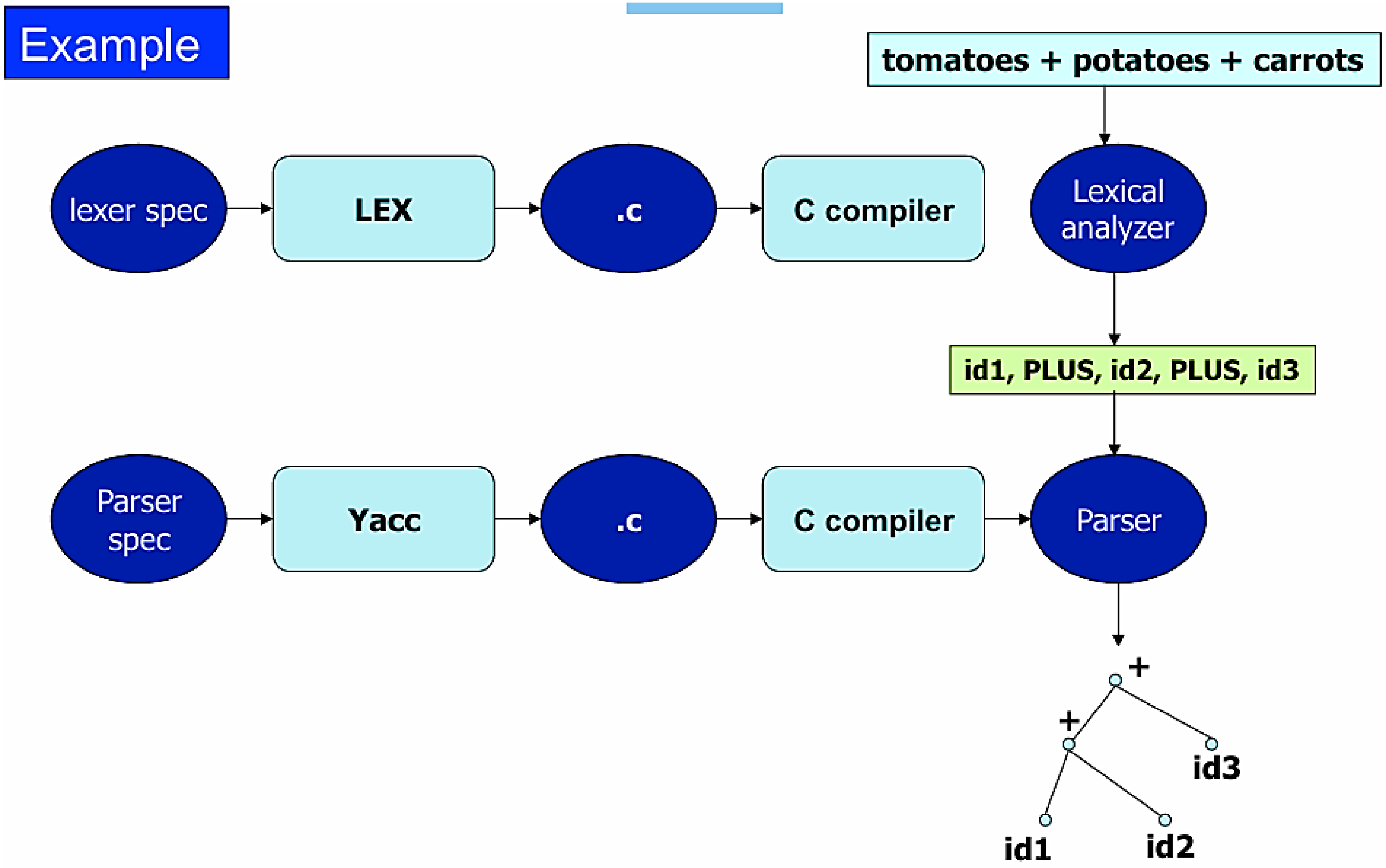
Lex with Yacc (1)



Lex with Yacc (2)

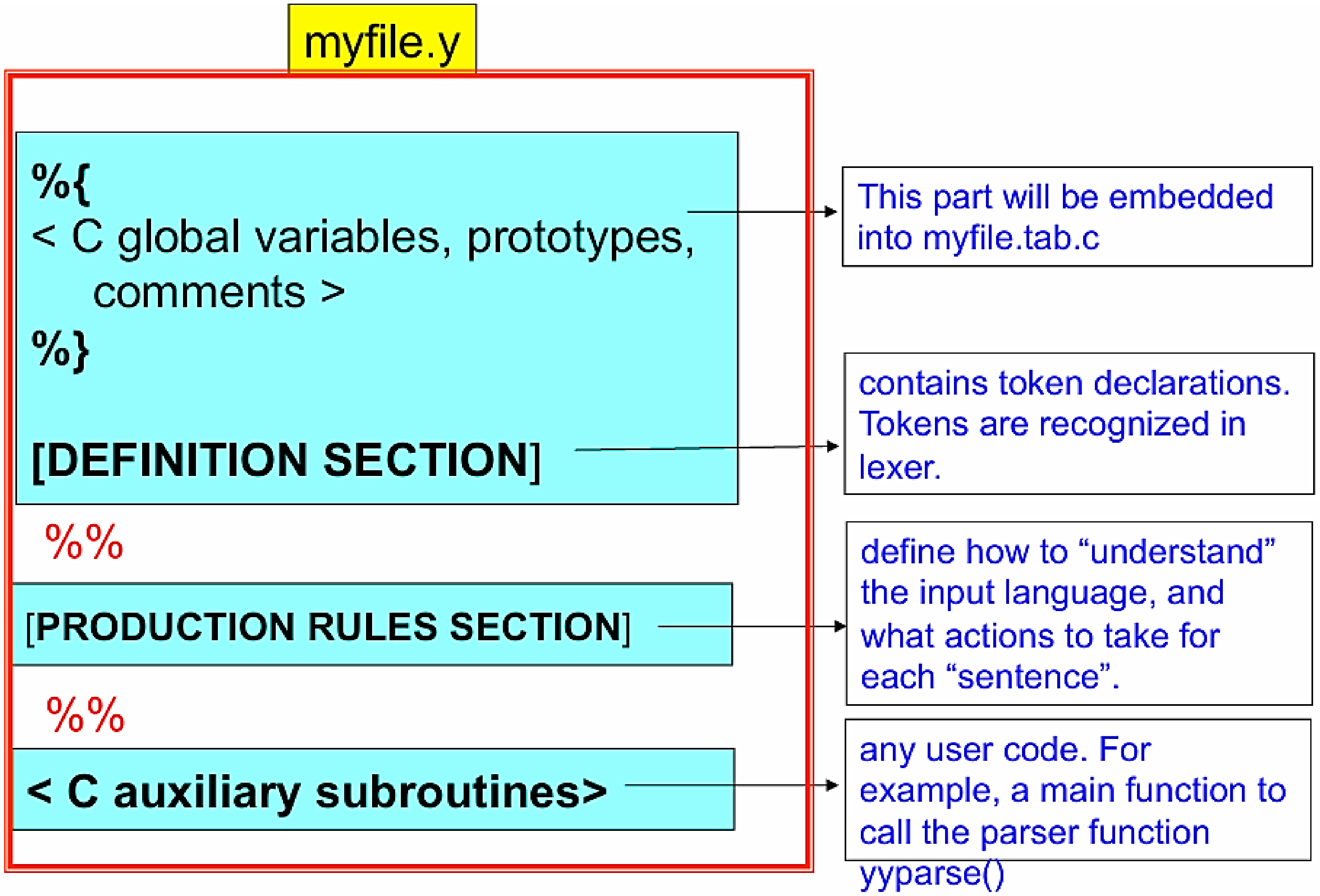


Lex with Yacc (3)



How to write a Yacc program

- **Declarations/definition Section** – defines tokens and data types
- **Grammar Rules Section** – defines production rules with actions
- **Auxiliary Code Section** – contains C helper functions (optional)



Running Yacc programs

```
% yacc -d -v my_prog.y
% gcc -o y.tab.c -ly
```

The `-d` option creates a file "`y.tab.h`", which contains a `#define` statement for each terminal declared.
Place `#include "y.tab.h"` in between the `%{` and `%}` to use the tokens in the functions section.

The `-v` option creates a file "`y.output`", which contains useful information on debugging.

We can use Lex to create the lexical analyser. If so, we should also place `#include "y.tab.h"` in Lex's definitions section, and we must link the parser and lexer together with both libraries (`-ly` and `-ll`).

Running Yacc programs

- Yacc:
  - produce C file y.tab.c contains the C code to apply the grammar
  - y.tab.h contains the data structures to be used by lex to pass data to yacc

Definition Section

Any terminal symbols which will be used in the grammar must be declared in this section as a token. For example

```
%token VERB
%token NOUN
```

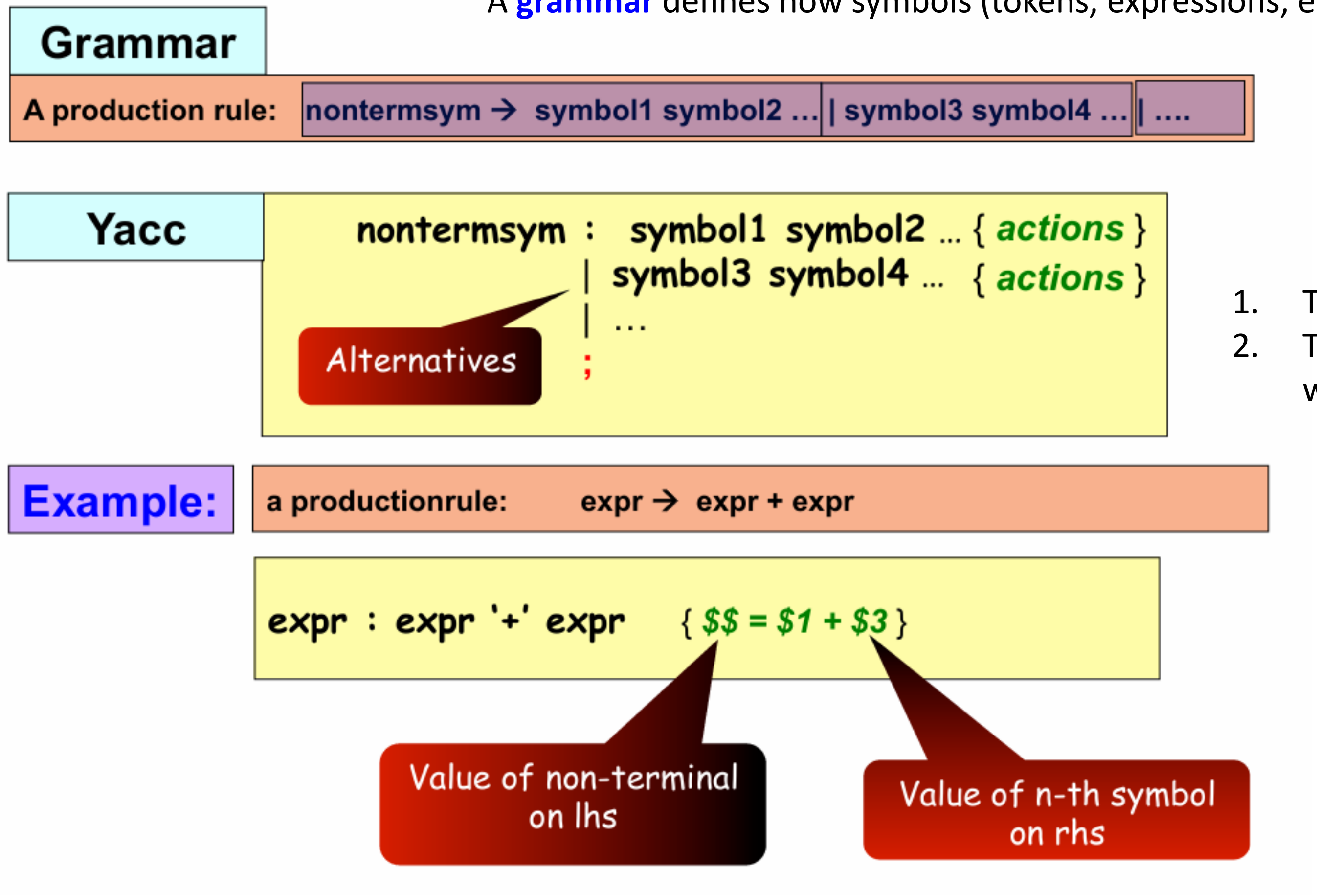
Non-terminals do not need to be pre-declared.

Anything enclosed between %{ ... %} in this section will be copied straight into y.tab.c (the C source for the parser).

All `#include` and `#define` statements, all variable declarations, all function declarations and any comments should be placed here.

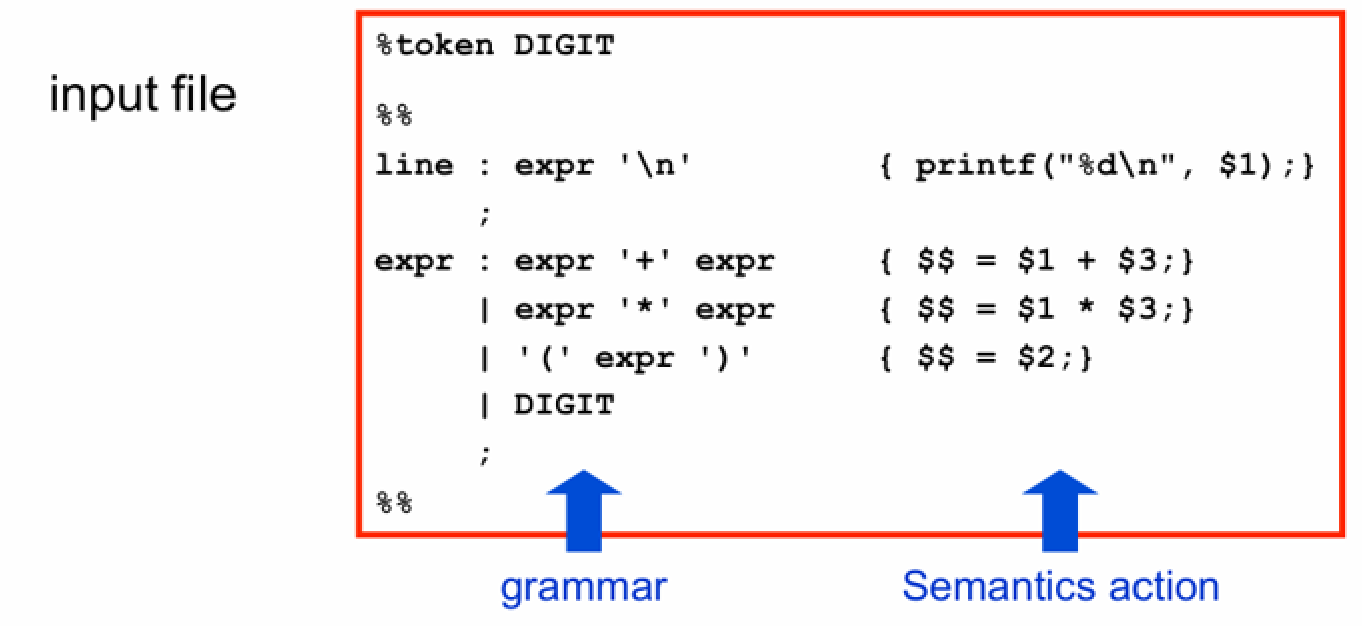
Production Rules Section

A **grammar** defines how symbols (tokens, expressions, etc.) combine to form valid structures in a language



1. The semicolon (;) ends the set of alternatives.
2. The part inside { … } is an action — a snippet of C code that runs when the rule is applied.

Production Rules Section



1. **line** is a **non-terminal**.
2. **expr '\n'** is the **right-hand side (RHS)** — it says a line is an expression followed by a newline.
3. **{ printf("%d\n", $1); }** is the **semantic action** in C that executes when this rule is matched.
   - $1 → value of the first symbol (expr) on the RHS.

- Ends with another %%, followed by any **C helper code** (optional), like main() or error handling.

Role of the Semantic Stack

- Yacc automatically maintains a stack of values corresponding to grammar symbols.
- When a rule is applied (reduced), its semantic action uses these stack values ($i) and stores the result in $$.

Production Rules Section

Semantic Actions in Yacc

- Semantic actions are small pieces of C code that are executed when a grammar rule (production) is recognized by Yacc.
- They are used to perform operations like:
  - Building syntax trees
  - Performing calculations
  - Installing identifiers in symbol tables
  - Type checking
  - Generating intermediate code

- Semantic actions are written inside curly braces { ... } at the end (or middle) of a production rule.
- They are placed on the right-hand side (RHS) of grammar rules.

- *Examples*:

```
ident_decl : ID     { symtbl_install( id_name ); }

type_decl : type  { tval = ... } id_list;
```

- When the rule ident_decl : ID is recognized,
- The action { symtbl_install(id_name); } is executed.
- It installs the identifier into the symbol table.

Production Rules Section

Each nonterminal can return a value.

- The value returned by the i^{th} symbol on the RHS is denoted by **$i**.
- An action that occurs in the middle of a rule counts as a “symbol” for this.
- To set the value to be returned by a rule, assign to **$$**.

  *By default, the value returned by a rule is the value of the first RHS symbol, i.e., **$1**.*

PRODUCTION RULES SECTION

Example:

```
statement → expression
expression → expression + expression |  expression - expression
           |  expression * expression |  expression / expression
           |  NUMBER
```

```
statement : expression  { printf (" = %g\n", $1); }
expression : expression '+' expression { $$ = $1 + $3; }
           |  expression '-' expression { $$ = $1 - $3; }
           |  expression '*' expression { $$ = $1 * $3; }
           |  expression '/' expression  { $$ = $1 / $3 ; }
           |  NUMBER  { $$ = $1; }
           ;
```

C auxiliary subroutines

This section contains the user-defined main() routine, plus any other required functions. It is usual to include:

`lexerr()` - to be called if the lexical analyser finds an undefined token. The default case in the lexical analyser must therefore call this function.

`yyerror(char*)` - to be called if the parser cannot recognise the syntax of part of the input. The parser will pass a string describing the type of error.

The line number of the input when the error occurs is held in `yylineno`.

The last token read is held in `yytext`.

C Auxiliary Subroutines and Yacc Interface to Lexical Analyzer

C auxiliary subroutines

Yacc interface to lexical analyzer

yylex() is **lexical analyzer function** (*lexer*), used by **Yacc** to get the **next token** from the input stream.

Example

```
%%
yylex()
{
        int c;
        c = getchar();
        if (isdigit(c)) {
                yylval = c - '0';
                return DIGIT;
        }
        return c;
}
```

- Reads one character at a time.
- If it's a digit (e.g., '3'), converts it to integer (3) and returns the token DIGIT.
- For other characters (like +, *, (,)), returns them as single-character tokens.

- Every token can carry a **value**, e.g., the numeric value of a digit.
- This value is stored in the **global variable yylval** before returning the token.
- Yacc uses this yylval to compute results in **semantic actions**.

Note: `yylex()` acts as the **bridge between lexical analysis and syntax parsing** — it tells Yacc *what* symbol was read (token type) and *what its value is* (in `yylval`).

- After Yacc parses input, it must **interact with C functions** to control program execution.
- This is called the **Yacc interface to the back-end**. Two parts (1) yyparse, (2) yyerror

C auxiliary subroutines

Yacc interface to back-end

Example

```
%%
yylex()
{
     ...
}
main()
{
     yyparse();
}

yyerror()
{
     printf("syntax error\n");
     exit(1);
}
```

- **(1) yyparse: Generated automatically** by Yacc when you run it on your **.y file**.
- It drives the entire parsing process:
    - Calls yylex() repeatedly to get tokens.
    - Matches tokens against grammar rules.
    - Executes **semantic actions** when rules are reduced.
- Essentially, yyparse() is the **heart of the Yacc parser**.

(2) Yyerror: It's called automatically when Yacc encounters an invalid token or grammar mismatch.

Yacc Errors

Yacc can not accept ambiguous grammars, nor can it accept grammars requiring two or more symbols of lookahead.

The two most common error messages are:

```
shift-reduce conflict
reduce-reduce conflict
```

The first case is where the parser would have a choice as to whether it shifts the next symbol from the input, or reduces the current symbols on the top of the stack.

The second case is where the parser has a choice of rules to reduce the stack.

Yacc Errors

Do not let errors go uncorrected. A parser will be generated, but it may produce unexpected results.

Study the file "y.output" to find out when the errors occur.

The SUN C compiler and the Berkeley PASCAL compiler are both written in Yacc.

You should be able to change your grammar rules to get an unambiguous grammar.

Yacc Errors

- Example 1

Yacc

```
Expr    :   INT_T
        |   Expr + Expr
        ;
```

Causes a shift-reduce error, because

`INT_T + INT_T + INT_T`

can be parsed in two ways.

Yacc cannot decide whether to:

- **Shift** the next token (+), or
- **Reduce** the previous tokens into Expr

Yacc

```
Animal    :   Dog
          |   Cat
          ;

Dog       :   FRED_T;

Cat       :   FRED_T;
```

Causes a reduce-reduce error, because

`FRED_T`

can be parsed in two ways.

Both `Dog` and `Cat` can be reduced to **`Animal`**.

Yacc Errors

Example 2

Yacc

1. input file (desk0.y)

```
%token DIGIT
%%
line : expr '\n'          { printf("%d\n", $1);}
     ;
expr : expr '+' expr      { $$ = $1 + $3;}
     | expr '*' expr      { $$ = $1 * $3;}
     | '(' expr ')'       { $$ = $2;}
     | DIGIT
     ;
%%
yylex()
{
    int c;

    c = getchar();

    if (isdigit(c)) {
        yylval = c - '0';
        return DIGIT;
    }
    return c;
}
```

2. run yacc

```
> yacc -v desk0.y
```

Conflicts: 4 shift/reduce

Ex: 3 + 4 * 5

This can be parsed as:
(3 + 4) * 5 → if + has higher precedence, or
3 + (4 * 5) → if * has higher precedence.

Conflict resolution in Yacc

Correcting errors

- **shift-reduce**: prefer shift
- **reduce-reduce**: prefer the rule that comes first

How to Fix the Conflicts: Add **operator precedence and associativity** declarations

```
%left '+'
%left '*'
%token DIGIT
%%
line : expr '\n'   { printf("%d\n", $1); }
     ;
expr : expr '+' expr  { $$ = $1 + $3; }
     | expr '*' expr  { $$ = $1 * $3; }
     | '(' expr ')'   { $$ = $2; }
     | DIGIT
     ;
```

Now, Yacc knows:

- * has higher precedence than +
- Both are left-associative

Result: **No shift/reduce conflicts**

Conflict resolution in Yacc

Correcting errors

- shift-reduce: prefer shift
- reduce-reduce: prefer the rule that comes first

```
>cat y.output
State 11 conflicts: 2 shift/reduce
State 12 conflicts: 2 shift/reduce.

Grammar

    0 $accept: line $end

    1 line: expr '\n'

    2 expr: expr '+' expr
    3     | expr '*' expr
    4     | '(' expr ')'
    5     | DIGIT
```

Conflict resolution in Yacc

Correcting errors

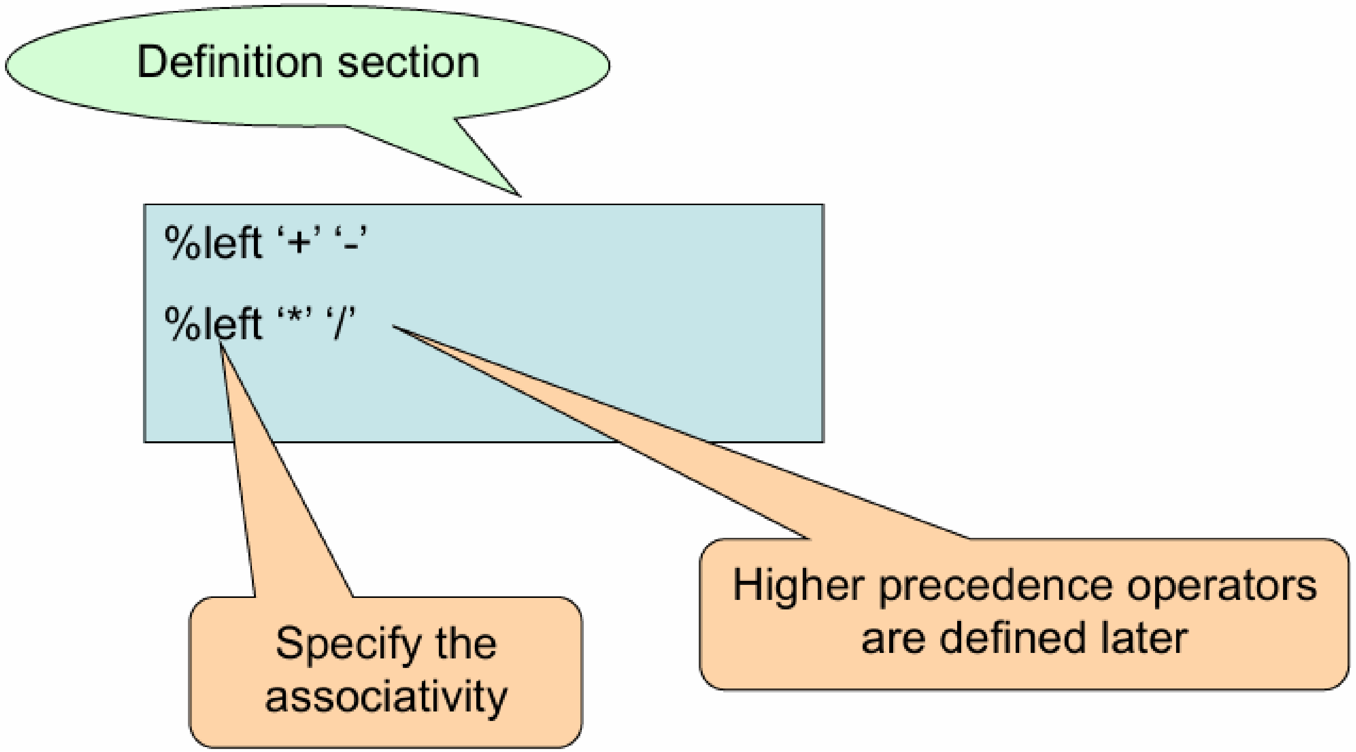
- shift-reduce: prefer shift
- reduce-reduce: prefer the rule that comes first

```
state 11

    2 expr: expr . '+' expr
    2     | expr '+' expr .
    3     | expr . '*' expr

    '+'  shift, and go to state 8
    '*'  shift, and go to state 9

    '+'       [reduce using rule 2 (expr)]
    '*'       [reduce using rule 2 (expr)]
    $default  reduce using rule 2 (expr)
```

```
state 12

    2 expr: expr . '+' expr
    3     | expr . '*' expr
    3     | expr '*' expr .

    '+'  shift, and go to state 8
    '*'  shift, and go to state 9

    '+'       [reduce using rule 3 (expr)]
    '*'       [reduce using rule 3 (expr)]
    $default  reduce using rule 3 (expr)
```

Conflict resolution in Yacc

Define operator's precedence and associativity
resolve shift/reduce conflict in Example 2



Example 2 Correct

Operator precedence in Yacc

priority from top (low) to bottom (high)

```
> yacc -v desk0.y
```

```
> gcc -o desk0 y.tab.c
```

```
%token DIGIT
%left '+'
%left '*'
%%
line : expr '\n'          { printf("%d\n", $1);}
     ;
expr : expr '+' expr      { $$ = $1 + $3;}
     | expr '*' expr      { $$ = $1 * $3;}
     | '(' expr ')'       { $$ = $2;}
     | DIGIT
     ;
%%
yylex()
{
    int c;

    c = getchar();

    if (isdigit(c)) {
        yylval = c - '0';
        return DIGIT;
    }
    return c;
}
```

The **order** of declaration gives **precedence**:

- The **top** operator (+) → **lower precedence**
- The **bottom** operator (*) → **higher precedence**

Exercise

multiple lines:

```
%%
lines: line
     | lines line
     ;
line : expr '\n'          { printf("%d\n", $1);}
     ;
expr : expr '+' expr      { $$ = $1 + $3;}
     | expr '*' expr      { $$ = $1 * $3;}
     | '(' expr ')'       { $$ = $2;}
     | DIGIT
     ;
%%
```

Extend the interpreter to a desk calculator with registers named a – z. Example input: v=3*(w+4)

Answer

```
%{
int reg[26];
%}
%token DIGIT
%token REG
%right '='
%left '+'
%left '*'
%%
expr : REG '=' expr          { $$ = reg[$1] = $3;}
     | expr '+' expr         { $$ = $1 + $3;}
     | expr '*' expr         { $$ = $1 * $3;}
     | '(' expr ')'          { $$ = $2;}
     | REG                   { $$ = reg[$1];}
     | DIGIT
     ;
%%
```

Answer

```
%%

yylex()
{   int c = getchar();
    if (isdigit(c)) {
        yylval = c - '0';
        return DIGIT;
    } else if ('a' <= c && c <= 'z') {
        yylval = c - 'a';
        return REG;
    }
    return c;
}
```

Example Yacc Script

A case study 1

S → NP VP
NP → Det NP1 | PN
NP1 → Adj NP1| N
Det → a | the
PN → peter | paul | mary
Adj → large | grey
N → dog | cat | male | female
VP → V NP
V → is | likes | hates

We want to write a Yacc script which will handle files with multiple sentences from this grammar. Each sentence will be delimited by a "."

Change the first production to
S → NP VP .

and add

D → S D | S

Valid sentences

the grey cat likes a dog.
paul hates mary.
a large dog is a male.

We must write a **Yacc program** that:

- Recognizes such sentences.
- Allows **multiple sentences** (each ending with .).
- Uses this grammar for parsing.

The Lex Script

```
%{
/* simple part of speech lexer */

#include "y.tab.h"
%}

L [a-zA-Z]

%%

[ \t\n]+            /* ignore space */
is|likes|hates      return VERB_T;
a|the               return DET_T;
dog |
cat |
male |
female              return NOUN_T;
peter|paul|mary     return PROPER_T;
large|grey          return ADJ_T;
\.                  return PERIOD_T;
{L}+                lexerr();
.                   lexerr();

%%
```

Yacc Definitions

```
%{
/* simple natural language grammar */

#include <stdio.h>
#include "y.tab.h"

extern in yyleng;
extern char yytext[];
extern int yylineno;
extern int yyval;

extern int yyparse();
%}

%token DET_T
%token NOUN_T
%token PROPER_T
%token VERB_T
%token ADJ_T
%token PERIOD_T

%%
```

Yacc rules

```
/* a document is a sentence followed
   by a document, or is empty */

Doc     :    Sent Doc
            |    /* empty */
            ;

Sent    :    NounPhrase VerbPhrase PERIOD_T
            ;

NounPhrase   :   DET_T NounPhraseUn
                     |   PROPER_T
                     ;

NounPhraseUn   :   ADJ_T NounPhraseUn
                         |   NOUN_T
                         ;

VerbPhrase   :   VERB_T NounPhrase
                      ;

%%
```

User-defined functions

```
void lexerr()
{
   printf("Invalid input '%s' at line%i\n",
             yytext,yylineno);
   exit(1);
}

void yyerror(s)
char *s;
{
   (void)fprintf(stderr,
      "%s at line %i, last token: %s\n",
             s, yylineno, yytext);
}

void main()
{
   if (yyparse() == 0)
      printf("Parse OK\n");
   else printf("Parse Failed\n");
}
```

Running the example

```
% yacc -d -v parser.y
% cc -c y.tab.c
% lex parser.l
% cc -c lex.yy.c
% cc y.tab.o lex.yy.o -o parser -ly -ll
```

```
peter is a large grey cat.
the dog is a female.
paul is peter.
```

file1

```
the cat is mary.
a dogcat is a male.
```

file2

```
peter is male.
mary is a female.
```

file3

```
% parser < file1
Parse OK
% parser < file2
Invalid input 'dogcat' at line 2
% parser < file3
syntax error at line 1, last token: male
```

A case study 2 – The Calculator

zcalc.l

```
%{
#include “zcalc.tab.h”
%}
%%
([0-9]+|([0-9]*\.[0-9]+)([eE][-+]?[0-9]+)?)
                { yylval.dval = atof(yytext);
                  return NUMBER; }
[ \t]           ;
[a-zA-Z][a-zA-Z0-(]*
                { struct symtab *sp = symlook(yytext);
                  yylval.symp = sp;
                  return NAME;
                }

%%
```

zcalc.y

```
%{
#include “zcalc.h”
%}
%union { double dval; struct symtab *symp; }
%token <symp> NAME
%token <dval> NUMBER
%left ‘+’ ‘-’
%type <dval> expression
%%
statement_list :  statement ‘\n’ | statement_list statement ‘\n’
statement : NAME ‘=‘ expression  {$1->value = $3;}
                | expression { printf (“ = %g\n”, $1); }

expression : expression ‘+’ expression { $$ = $1 + $3; }
                  | expression ‘-’ expression { $$ = $1 - $3; }
                  | NUMBER  { $$ = $1; }
                  | NAME { $$ = $1->value; }
%%
struct symtab * symlook( char *s )
{ /* this function looks up the symbol table and check whether
the symbol s is already there. If not, add s into symbol table. */
}
int main() {
    yyparse();
    return 0;
}
```