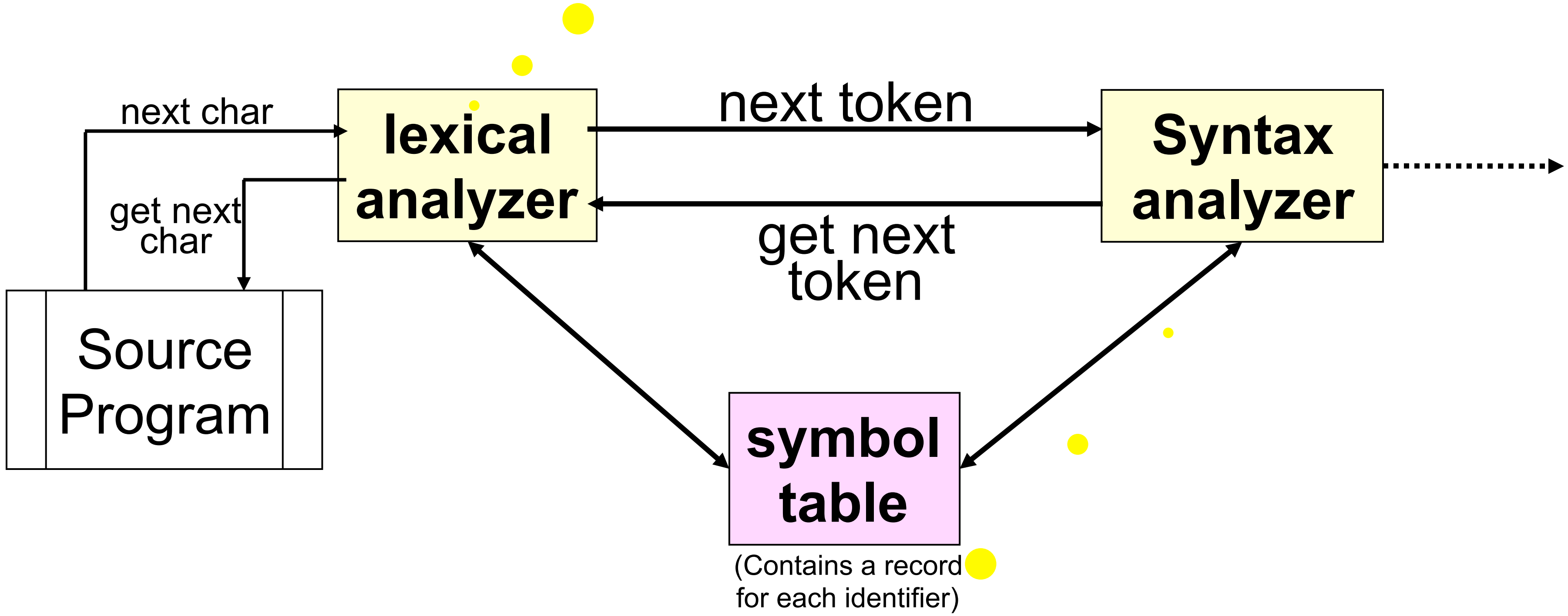
Language Processing Systems

Prof. Mohamed Hamada

Software Engineering Lab.
The University of Aizu
Japan

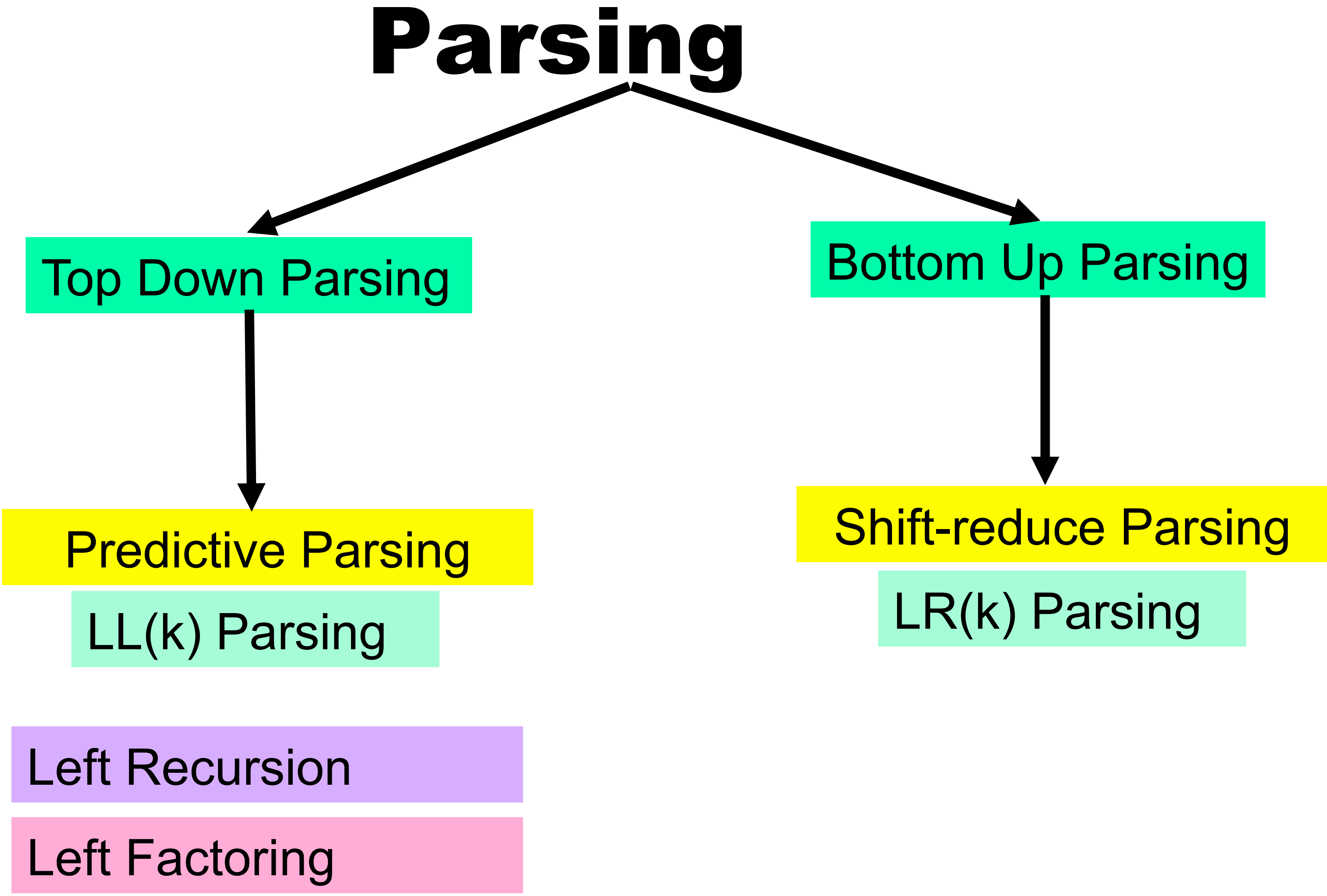
Syntax Analysis
(Parsing)

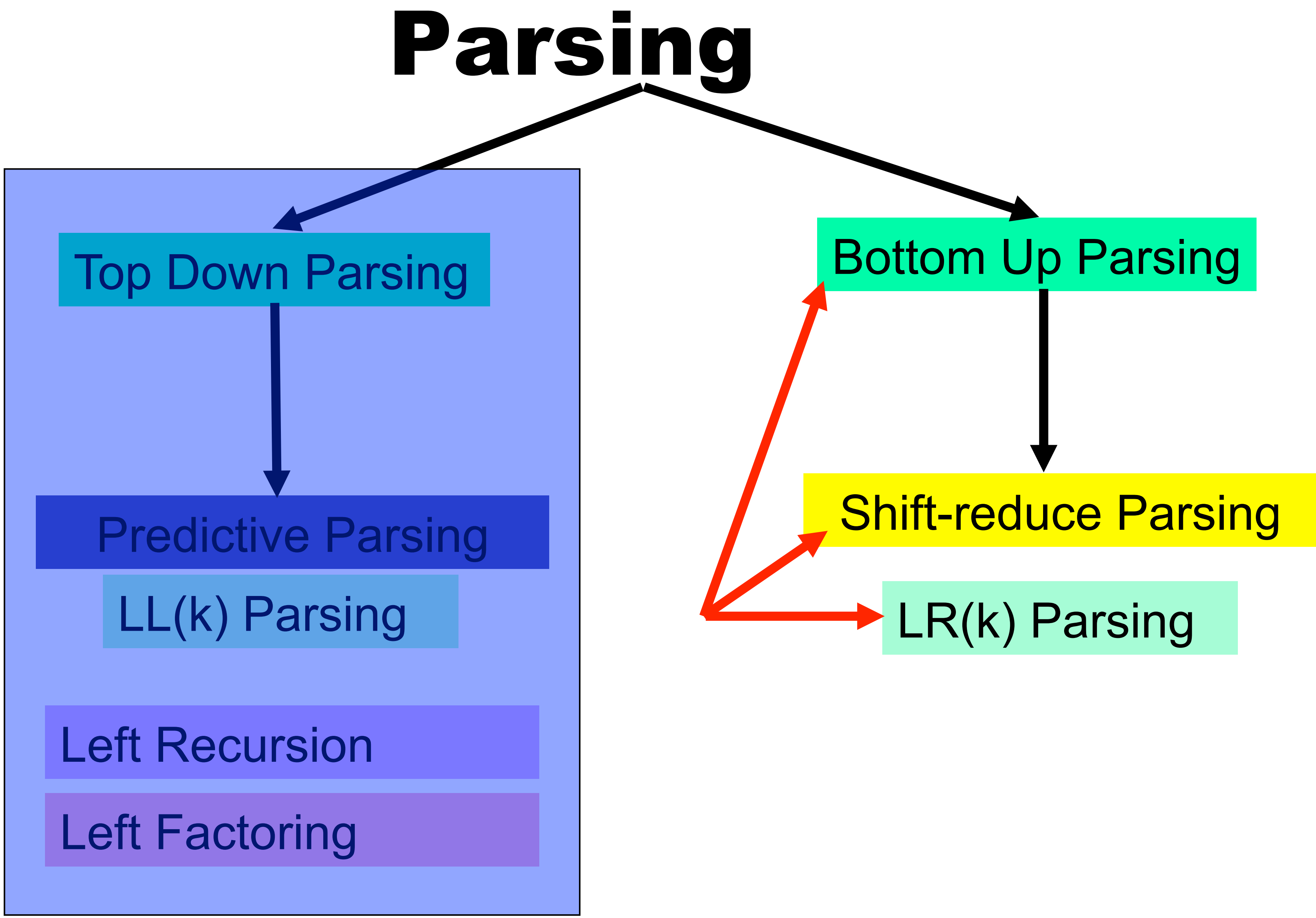
1. **Uses Regular Expressions to define tokens**
2. **Uses Finite Automata to recognize tokens**



Uses Top-down parsing or Bottom-up parsing

To construct a Parse tree


Parsing
Top Down Parsing
Bottom Up Parsing
Predictive Parsing
LL(k) Parsing
Shift-reduce Parsing
LR(k) Parsing
Left Recursion
Left Factoring


Parsing
Top Down Parsing
Predictive Parsing
LL(k) Parsing
Left Recursion
Left Factoring
Bottom Up Parsing
Shift-reduce Parsing
LR(k) Parsing

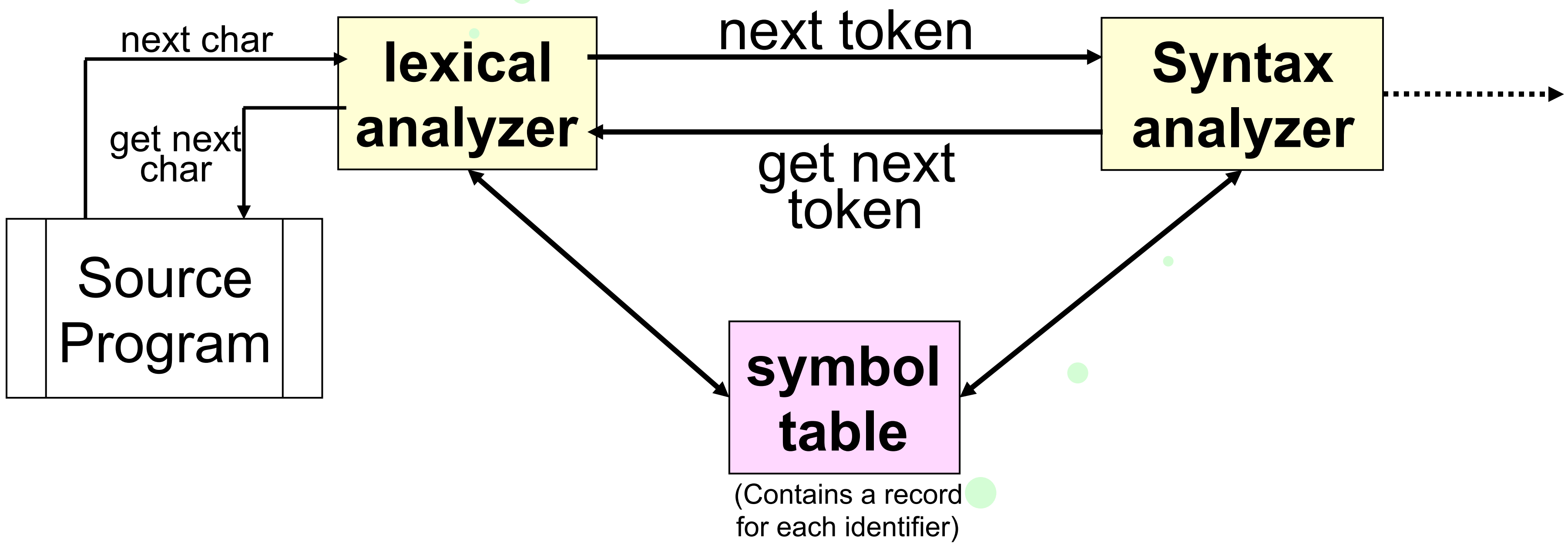
Parsing

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?

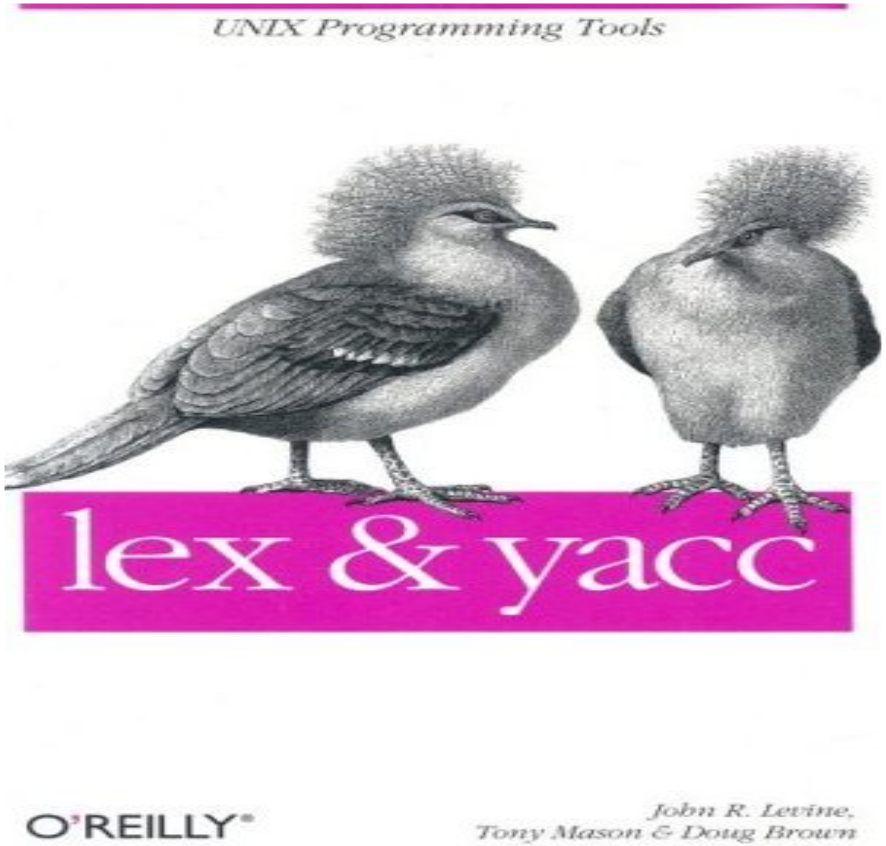
1. Uses Regular Expressions to define tokens
2. Uses Finite Automata to recognize tokens



Uses Top-down parsing or Bottom-up parsing

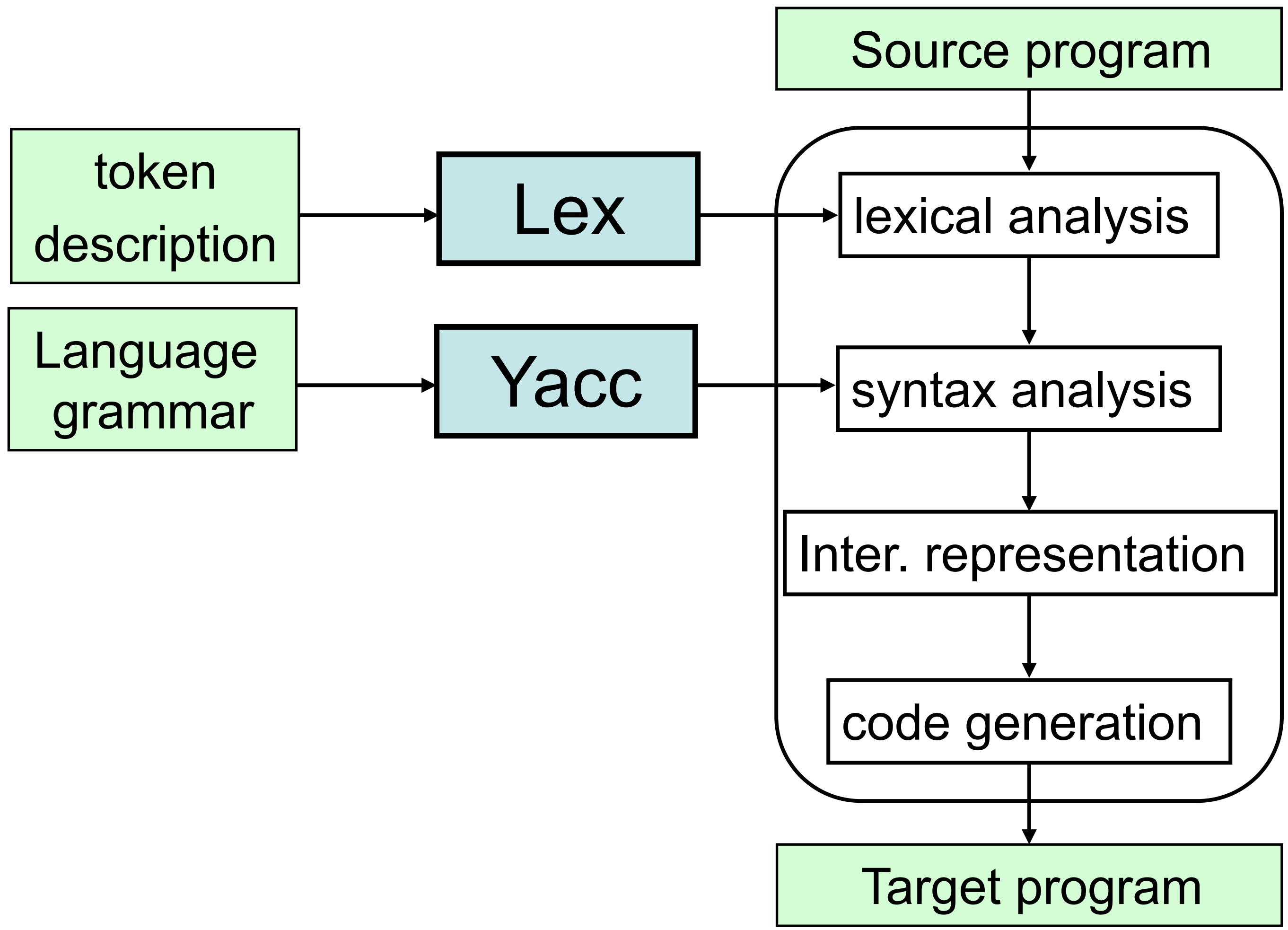
To construct a Parse tree

Yacc


UNIX Programming Tools
lex & yacc
O'REILLY
John R. Levine,
Tony Mason & Doug Brown

Yacc

Compiler



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

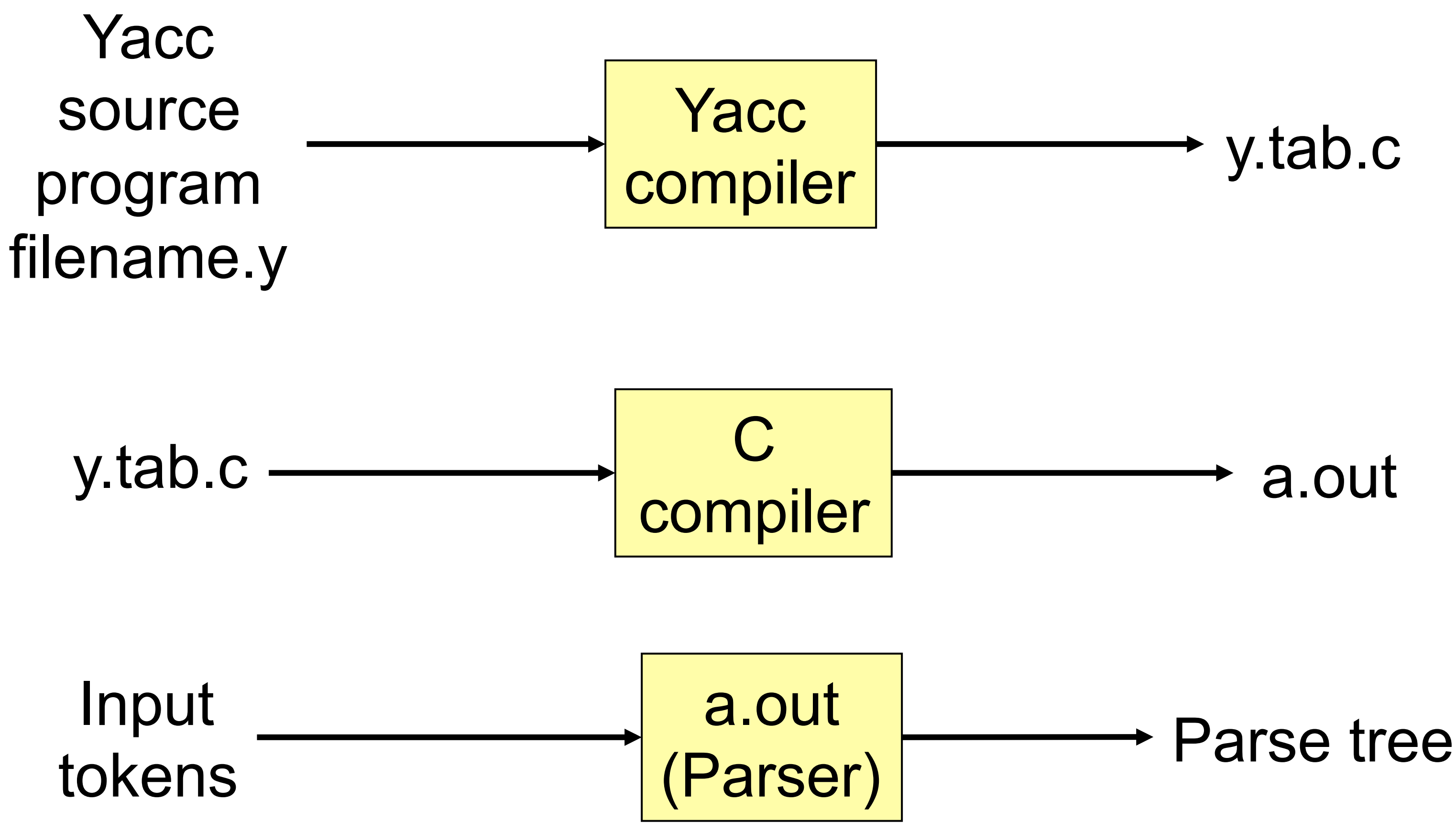
Compiling and linking the C program y.tab.c in a normal way resulting the required parser.

LR parser generators

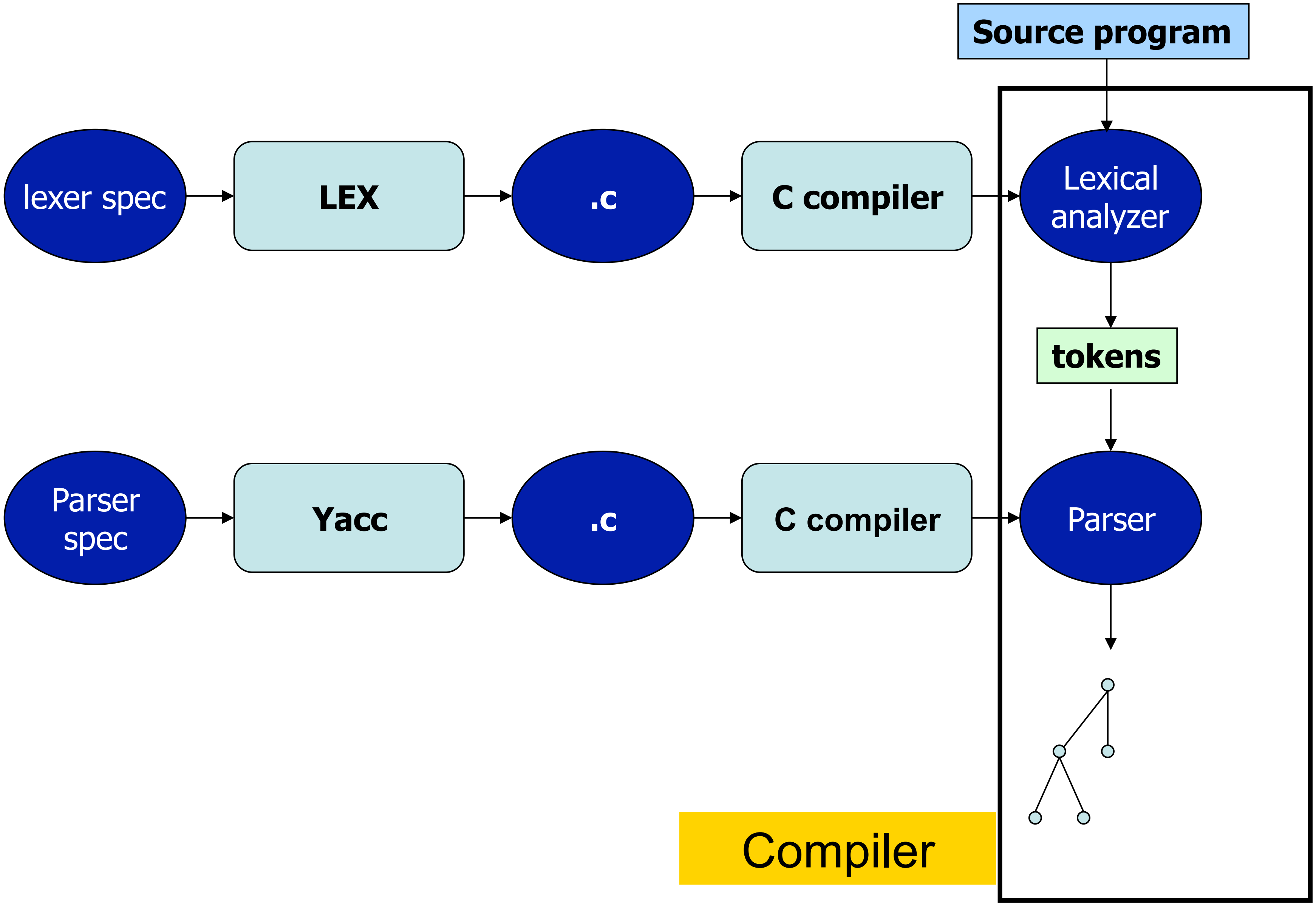
Yacc: Yet another compiler compiler

- Automatically generate LALR parsers
- Created by S.C. Johnson in 1970's

Using Yacc

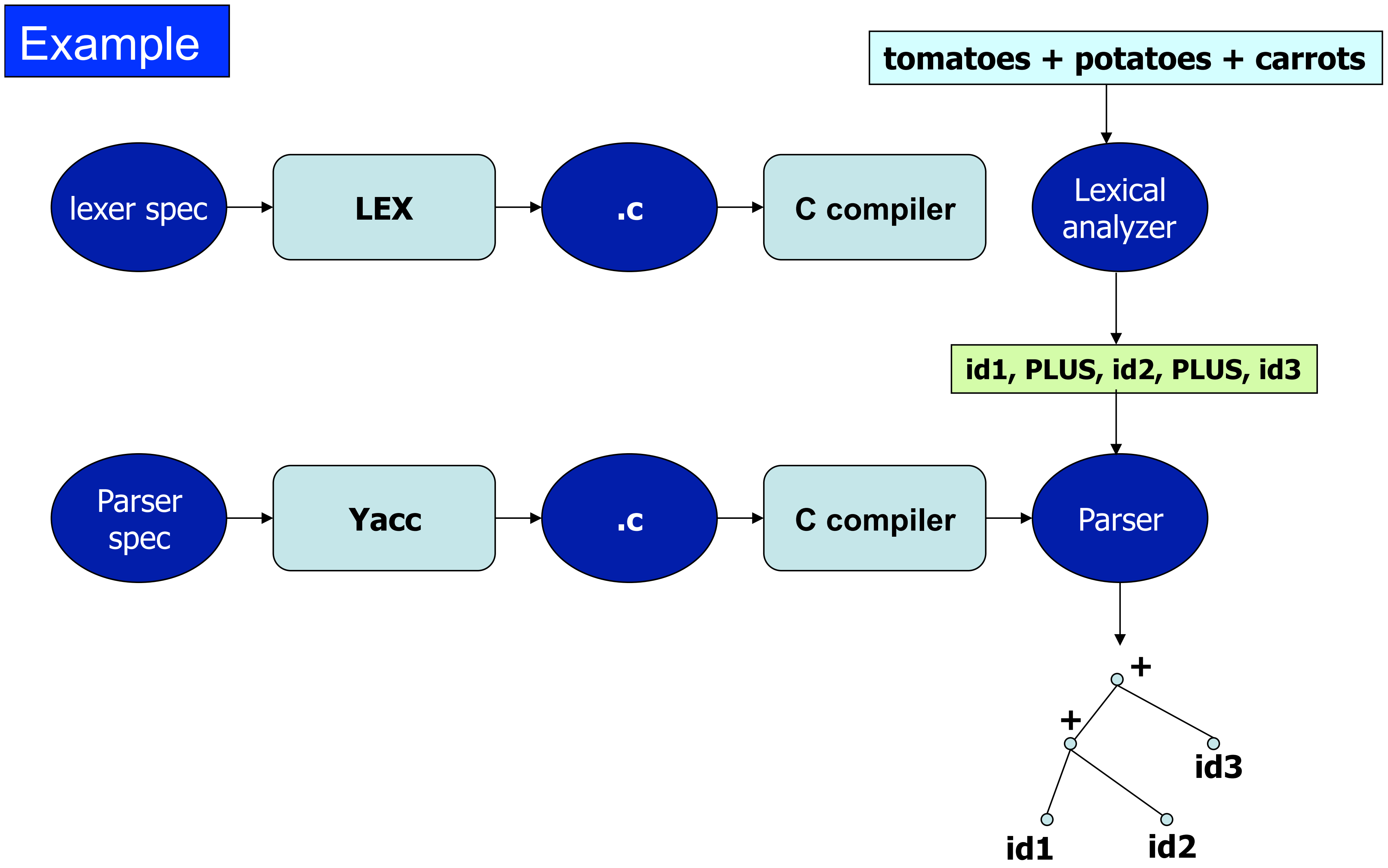

Yacc source program filename.y
Yacc compiler
y.tab.c
y.tab.c
C compiler
a.out
Input tokens
a.out (Parser)
Parse tree

Yacc

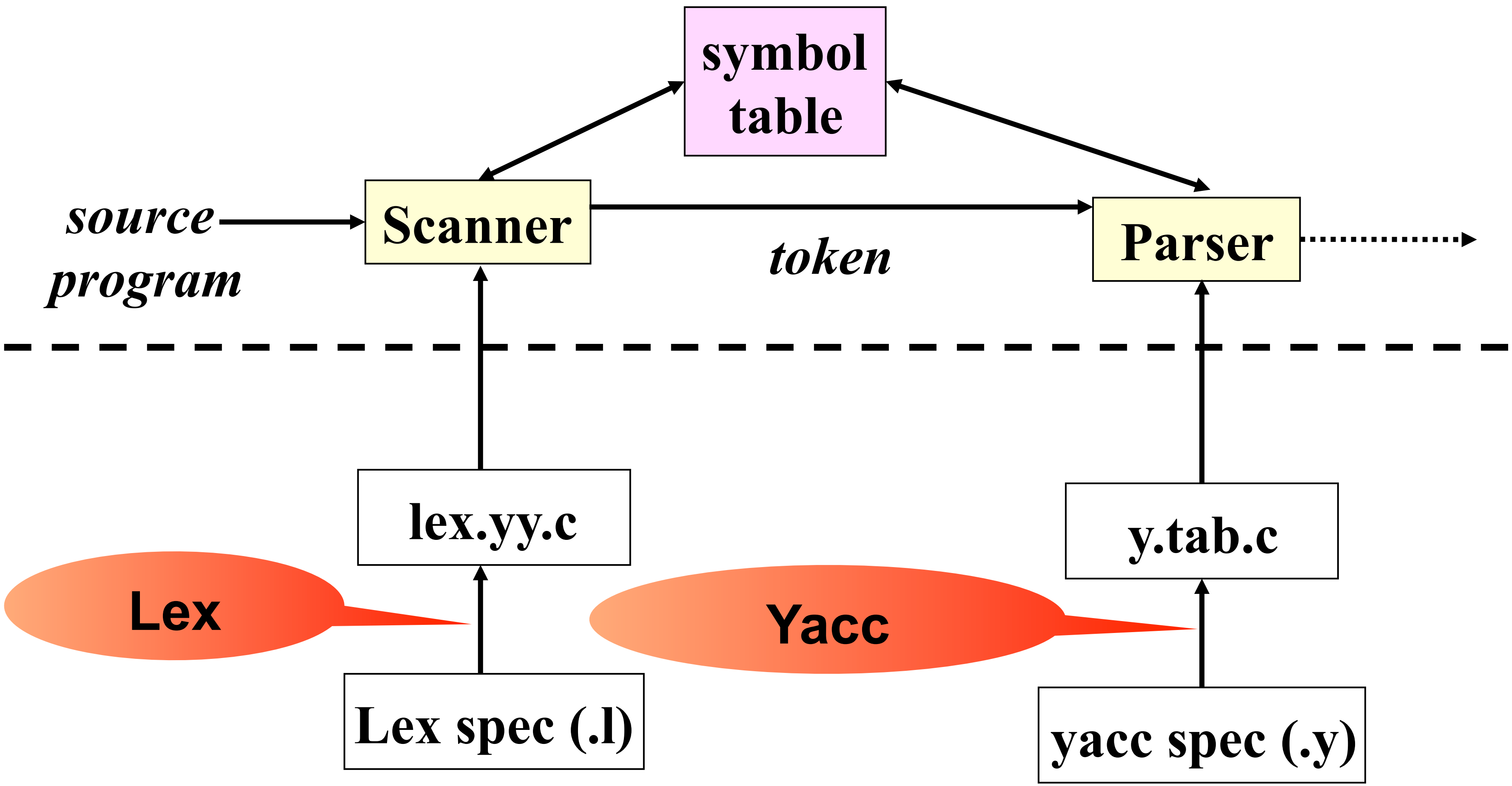


Source program
lexer spec
LEX
.c
C compiler
Lexical analyzer
tokens
Parser spec
Yacc
.c
C compiler
Parser
Compiler

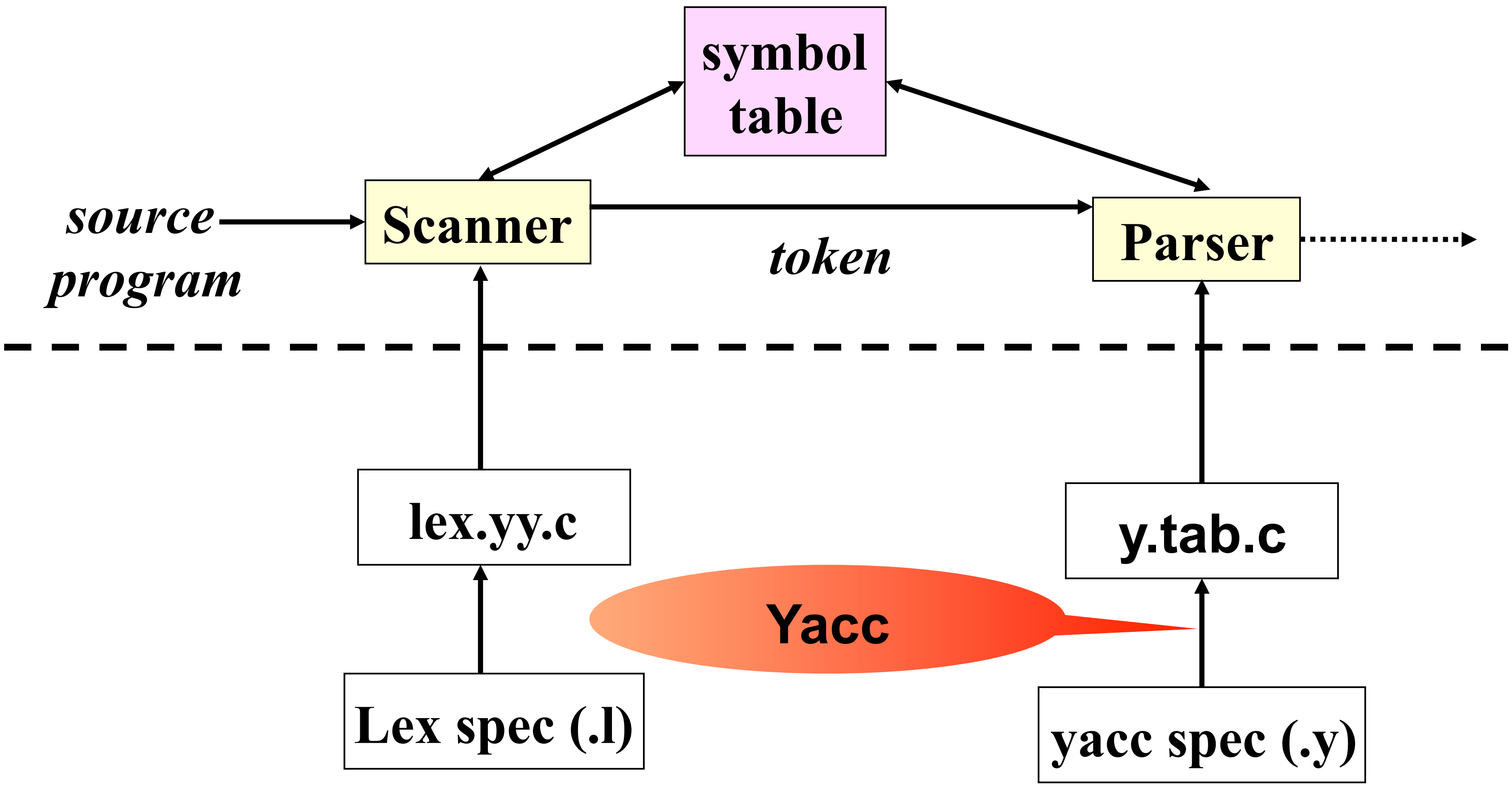
Yacc


Example
tomatoes + potatoes + carrots
lexer spec
LEX
.c
C compiler
Lexical analyzer
id1, PLUS, id2, PLUS, id3
Parser spec
Yacc
.c
C compiler
Parser
+
+
id3
id1
id2

How to write parser



How to write parser



How to write a yacc program

myfile.y

%{
< C global variables, prototypes, comments >
%}

[DEFINITION SECTION]

%%

[PRODUCTION RULES SECTION]

%%

< C auxiliary subroutines>

This part will be embedded into myfile.tab.c

contains token declarations. Tokens are recognized in lexer.

define how to “understand” the input language, and what actions to take for each “sentence”.

any user code. For example, a main function to call the parser function yyparse()

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

Grammar

A production rule: nontermsym → symbol1 symbol2 … | symbol3 symbol4 … | ….

Yacc

```
nontermsym :  symbol1 symbol2 … { actions }
           |  symbol3 symbol4 … { actions }
           |  …
           ;
```

Alternatives

Example:

a productionrule: expr → expr + expr

```
expr : expr '+' expr    { $$ = $1 + $3 }
```

Value of non-terminal on lhs

Value of n-th symbol on rhs

PRODUCTION RULES SECTION

input file

```
%token DIGIT

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

grammar　　Semantics action

Yacc maintains a stack of “values” that may be referenced ($i) in the semantic actions

PRODUCTION RULES SECTION

Semantic Actions in Yacc

- Semantic actions are embedded in RHS of rules.

  An action consists of one or more C statements, enclosed in braces **{** ... **}**.

- *Examples*:

  ident_decl : ID { symtbl_install(id_name); }

  type_decl : type { tval = … } id_list;

PRODUCTION RULES SECTION

Semantic Actions in Yacc

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

Yacc interface to lexical analyzer

Example

- Yacc invokes yylex() to get the next token
- the "value" of a token must be stored in the global variable yylval
- the default value type is int, but can be changed

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

C auxiliary subroutines

Yacc interface to back-end

- Yacc generates a function named yyparse()
- syntax errors are reported by invoking a callback function yyerror()

Example

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

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

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

```
Animal      :   Dog
            |   Cat
            ;

Dog         :   FRED_T;

Cat         :   FRED_T;
```

Causes a reduce-reduce error, because

`FRED_T`

can be parsed in two ways.

Yacc Errors

Yacc

Example 2

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

Conflict resolution in Yacc

Correcting errors

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

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

Definition section

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

Specify the associativity

Higher precedence operators are defined later

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;
}
```

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

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;
}
```