Lexical and Syntax Analysis

In Text: Chapter 4

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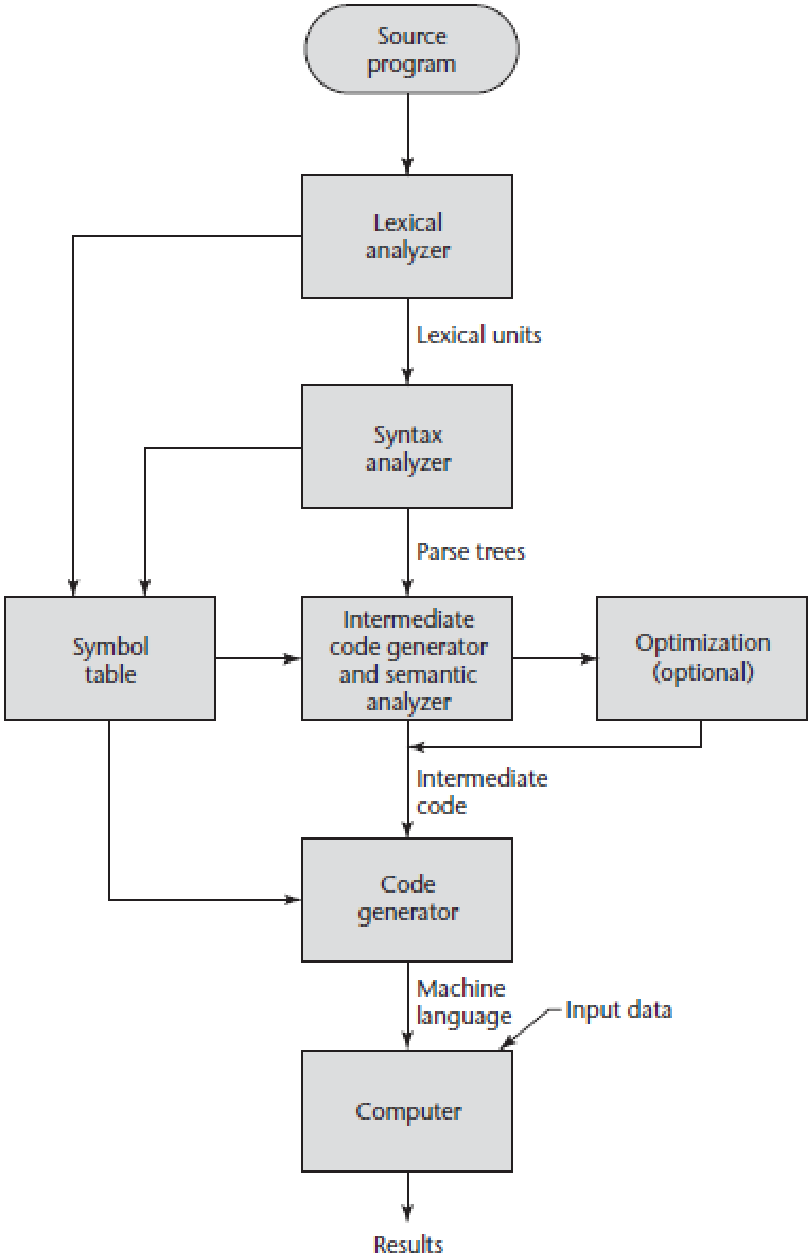
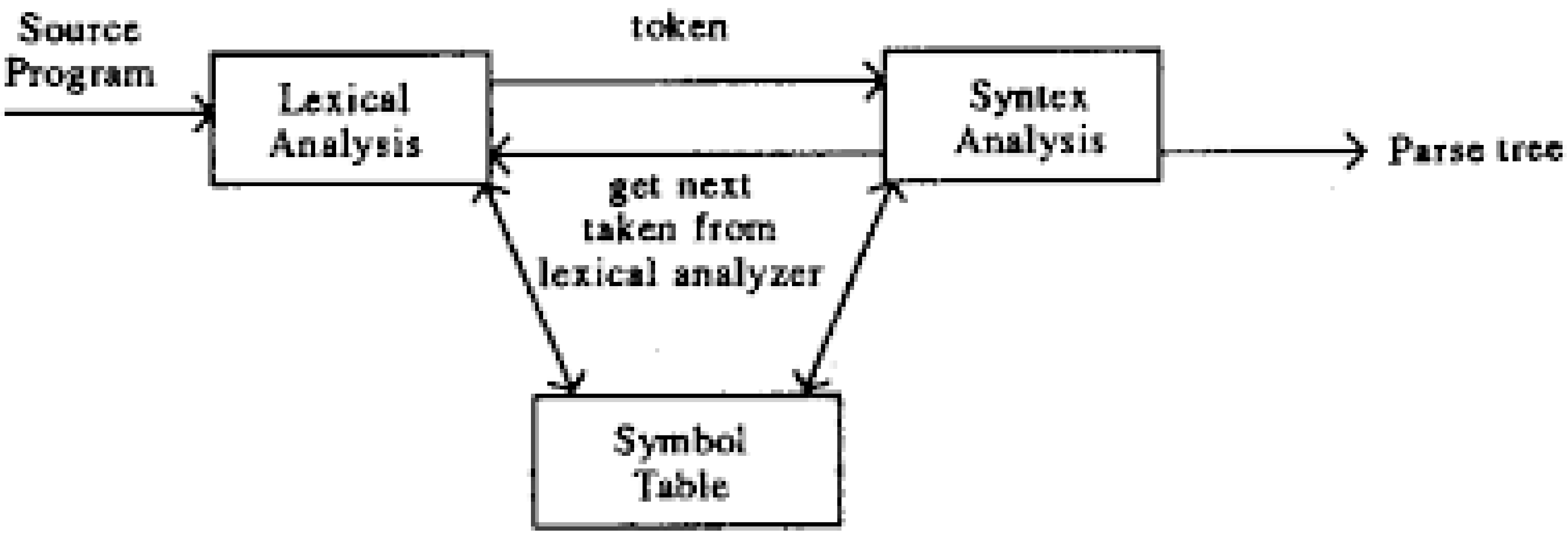
Lexical and Syntactic Analysis

- Two steps to discover the syntactic structure of a program
  - Lexical analysis (Scanner): to read the input characters and output a sequence of tokens
  - Syntactic analysis (Parser): to read the tokens and output a parse tree and report syntax errors if any

Compilation Process



Interaction between lexical analysis and syntactic analysis



Reasons to Separate Lexical and Syntax Analysis

- *Simplicity* - less complex approaches can be used for lexical analysis; separating them simplifies the parser
- *Efficiency* - separation allows optimization of the lexical analyzer
- *Portability* - parts of the lexical analyzer may not be portable, but the parser is always portable

Scanner

- Pattern matcher for character strings
  - If a character sequence matches a pattern, it is identified as a token
- Responsibilities
  - Tokenize source, report lexical errors if any, remove comments and whitespace, save text of interesting tokens, save source locations, (optional) expand macros and implement preprocessor functions

Tokenizing Source

- Given a program, identify all lexemes and their categories (tokens)

Lexeme, Token, & Pattern

- Lexeme
  - A sequence of characters in the source program with the lowest level of syntactic meanings
    - E.g., sum, +, -
- Token
  - A category of lexemes
  - A lexeme is an instance of token
  - The basic building blocks of programs

Token Examples

Token	Informal Description	Sample Lexemes
keyword	All keywords defined in the language	if else
comparison	<, >, <=, >=, ==, !=	<=, !=
id	Letter followed by letters and digits	pi, score, D2
number	Any numeric constant	3.14159, 0, 6
literal	Anything surrounded by “’s, but exclude “	“core dumped”

Another Token Example

Consider the following example of an assignment statement:

result = oldsum - value / 100;

- Following are the tokens and lexemes of this statement:

Token	*Lexeme*
IDENT	result
ASSIGN_OP	=
IDENT	oldsum
SUB_OP	-
IDENT	value
DIV_OP	/
INT_LIT	100
SEMICOLON	;

Lexeme, Token, & Pattern

- Pattern
  - A description of the form that the lexemes of a token may take
  - Specified with regular expressions

Motivating Example

- Token set:
  - assign -> :=
  - plus -> +
  - minus -> -
  - times -> *
  - div -> /
  - lparen -> (
  - rparen ->)
  - id -> letter(letter|digit)*
  - number -> digit digit*|digit*(.digit|digit.)digit*

Motivating Example

- What are the lexemes in the string “a_var:=b*3” ?
- What are the corresponding tokens ?
- How do you identify the tokens?

Lexical Analysis

- Three approaches to build a lexical analyzer:
  - Write a formal description of the tokens and use a software tool that constructs a table-driven lexical analyzer from such a description
  - Design a state diagram that describes the tokens and write a program that implements the state diagram
  - Design a state diagram that describes the tokens and hand-construct a table-driven implementation of the state diagram

State Diagram

- A **state transition diagram**, or just state diagram, is a directed graph.
- The nodes of a state diagram are labeled with state names.
- The arcs are labeled with the input characters that cause the transitions among the states.
- An arc may also include actions the lexical analyzer must perform when the transition is taken.

State Diagram

- State diagrams of the form used for lexical analyzers are *representations of* a class of mathematical machines called **finite automata**.
- Finite automata can be designed to recognize members of a class of languages called **regular languages**.
- Regular grammars are generative devices for regular languages.
- The tokens of a programming language are a regular language, and a *lexical analyzer is a finite automaton.*

State Diagram Design

- A naïve state diagram would have a transition from every state on every character in the source language - such a diagram would be very large!

- Reason? Because every node in the state diagram would need a transition for every character in the character set of the language being analyzed.
- Solution: Consider ways to simplify

State Diagram Design - Example

- Design a lexical analyzer that recognizes only arithmetic expressions, including variable names and integer literals as operands.
- Assume that the variable names consist of strings of uppercase letters, lowercase letters, and digits but must begin with a letter.
- Names have no length limitation.

- How many transitions for initial state?
- How can we simplify it?

Example (continued)

- There are 52 different characters (any uppercase or lowercase letter) that can begin a name, which would require 52 transitions from the transition diagram's initial state.
- However, a lexical analyzer is interested only in determining that it is a name and is not concerned with which specific name it happens to be.
- Therefore, we **define a character class named LETTER** for all 52 letters and use a single transition on the first letter of any name.

Example (continued)

- Another opportunity for simplifying the transition diagram is with the
- integer literal tokens.
- There are 10 different characters that could begin an integer literal lexeme. This would require 10 transitions from the start state of the state diagram.
- define a character class named DIGIT for digits and use a single transition on any character in this character class to a state that collects integer literals

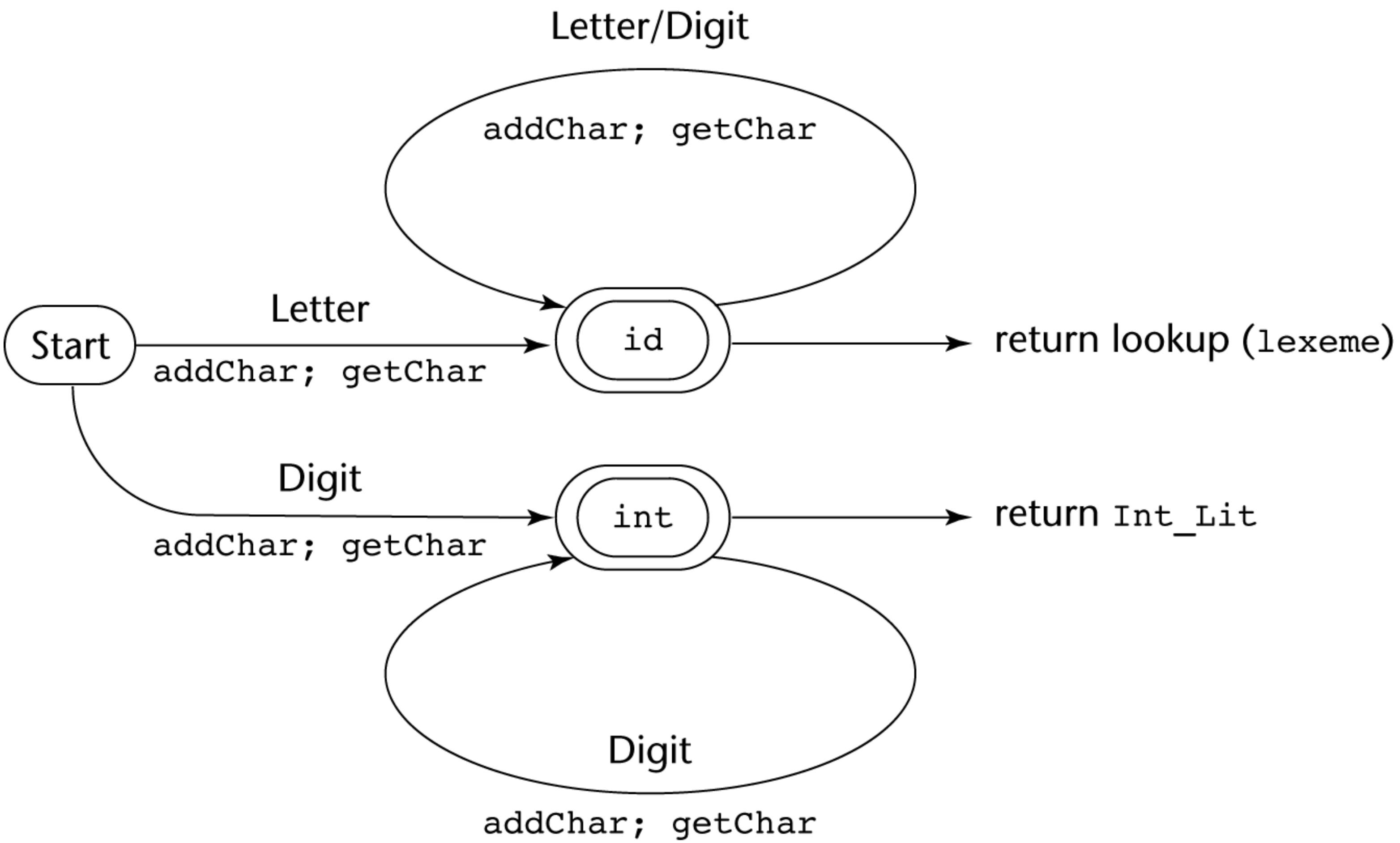
Lexical Analysis (continued)

- In many cases, transitions can be combined to simplify the state diagram
  - When recognizing an identifier, all uppercase and lowercase letters are equivalent
    - Use a character class that includes all letters
  - When recognizing an integer literal, all digits are equivalent - use a digit class

Lexical Analysis (continued)

- Reserved words and identifiers can be recognized together (rather than having a part of the diagram for each reserved word)
  - Use a table lookup to determine whether a possible identifier is in fact a reserved word

State Diagram



Lexical Analysis (continued)

- Convenient utility subprograms:
  - **`getChar`** - gets the next character of input, puts it in nextChar, determines its class and puts the class in charClass
  - **`addChar`** - puts the character from nextChar into the place the lexeme is being accumulated
  - **`lookup`** - determines whether the string in lexeme is a reserved word (returns a code)

```
/* Function declarations */
void addChar();
void getChar();
void getNonBlank();
int lex();


/* Character classes */
#define LETTER 0
#define DIGIT 1
#define UNKNOWN 99


/* Token codes */
#define INT_LIT 10
#define IDENT 11
#define ASSIGN_OP 20
#define ADD_OP 21
#define SUB_OP 22
#define MULT_OP 23
#define DIV_OP 24
#define LEFT_PAREN 25
#define RIGHT_PAREN 26
```

Implementation Pseudo-code

```
static TOKEN nextToken;

static CHAR_CLASS charClass;

int lex() {
  switch (charClass) {
    case LETTER:
    // add nextChar to lexeme
      addChar();
    // get the next character and determine its class
      getChar();
      while (charClass == LETTER || charClass == DIGIT)
      {
        addChar();
        getChar();
      }
      nextToken = ID;
      break;
```

```
case DIGIT:
  addChar();
  getChar();
  while (charClass == DIGIT) {
    addChar();
    getChar();
  }
  nextToken = INT_LIT;
  break;
…
case EOF:
  nextToken = EOF;
  lexeme[0] = 'E';
  lexeme[1] = 'O';
  lexeme[2] = 'F';
  lexeme[3] = 0;
}
printf ("Next token is: %d, Next lexeme is %s\n",
   nextToken, lexeme);
  return nextToken;
}  /* End of function lex */
```

Lexical Analyzer

- Implementation:
  → `front.c` (pp. 166–170)

  – Following is the output of the lexical analyzer of `front.c` when used on `(sum + 47) / total`

```
Next token is: 25 Next lexeme is (
Next token is: 11 Next lexeme is sum
Next token is: 21 Next lexeme is +
Next token is: 10 Next lexeme is 47
Next token is: 26 Next lexeme is )
Next token is: 24 Next lexeme is /
Next token is: 11 Next lexeme is total
Next token is: -1 Next lexeme is EOF
```

The Parsing Problem

- Given an input program, the goals of the parser:
  - Find all syntax errors; for each, produce an appropriate diagnostic message and recover quickly
  - Produce the parse tree, or at least a trace of the parse tree, for the program

The Parsing Problem (continued)

- The Complexity of Parsing
  - Parsers that work for any unambiguous grammar are complex and inefficient (O(n3), where n is the length of the input)
  - Compilers use parsers that only work for a subset of all unambiguous grammars, but do it in linear time (O(n), where n is the length of the input)

Two Classes of Grammars

- Left-to-right, Leftmost derivation (LL)
- Left-to-right, Rightmost derivation (LR)
- We can build parsers for these grammars that run in linear time

Grammar Comparison

LL	LR
E -> T E' E' -> + T E' | ε T -> F T' T' -> * F T' | ε F -> id	E -> E + T | T T -> T * F | F F -> id

Two Categories of Parsers

- LL(1) Parsers
  - L: scanning the input from left to right
  - L: producing a leftmost derivation
  - 1: using one input symbol of lookahead at each step to make parsing action decisions
- LR(1) Parsers
  - L: scanning the input from left to right
  - R: producing a rightmost derivation **in reverse**
  - 1: the same as above

Two Categories of Parsers

- LL(1) parsers (predicative parsers)
  - Top down
    - Build the parse tree from the root
    - Find a left most derivation for an input string
- LR(1) parsers (shift-reduce parsers)
  - Bottom up
    - Build the parse tree from leaves
    - Reducing a string to the start symbol of a grammar

Top-down Parsers

- Given a sentential form, $xA\alpha$, the parser must choose the correct A-rule to get the next sentential form in the leftmost derivation, using only the first token produced by A
- The most common top-down parsing algorithms:
  - Recursive descent - a coded implementation
  - LL parsers - table driven implementation

Bottom-up parsers

- Given a right sentential form, α, determine what substring of α is the right-hand side of the rule in the grammar that must be reduced to produce the previous sentential form in the right derivation
- The most common bottom-up parsing algorithms are in the LR family

Recursive Descent Parsing

- Parsing is the process of tracing or **constructing a parse tree** for a given input string
- Parsers usually do not analyze lexemes; that is done by a lexical analyzer, which is called by the parser
- A **recursive descent parser** traces out a parse tree in top-down order; it is a **top-down parser**
- Each nonterminal has an **associated subprogram**; the subprogram parses all sentential forms that the nonterminal can generate
- The recursive descent parsing subprograms are **built directly from the grammar rules**
- Recursive descent parsers, like other top-down parsers, cannot be built from **left-recursive grammars**

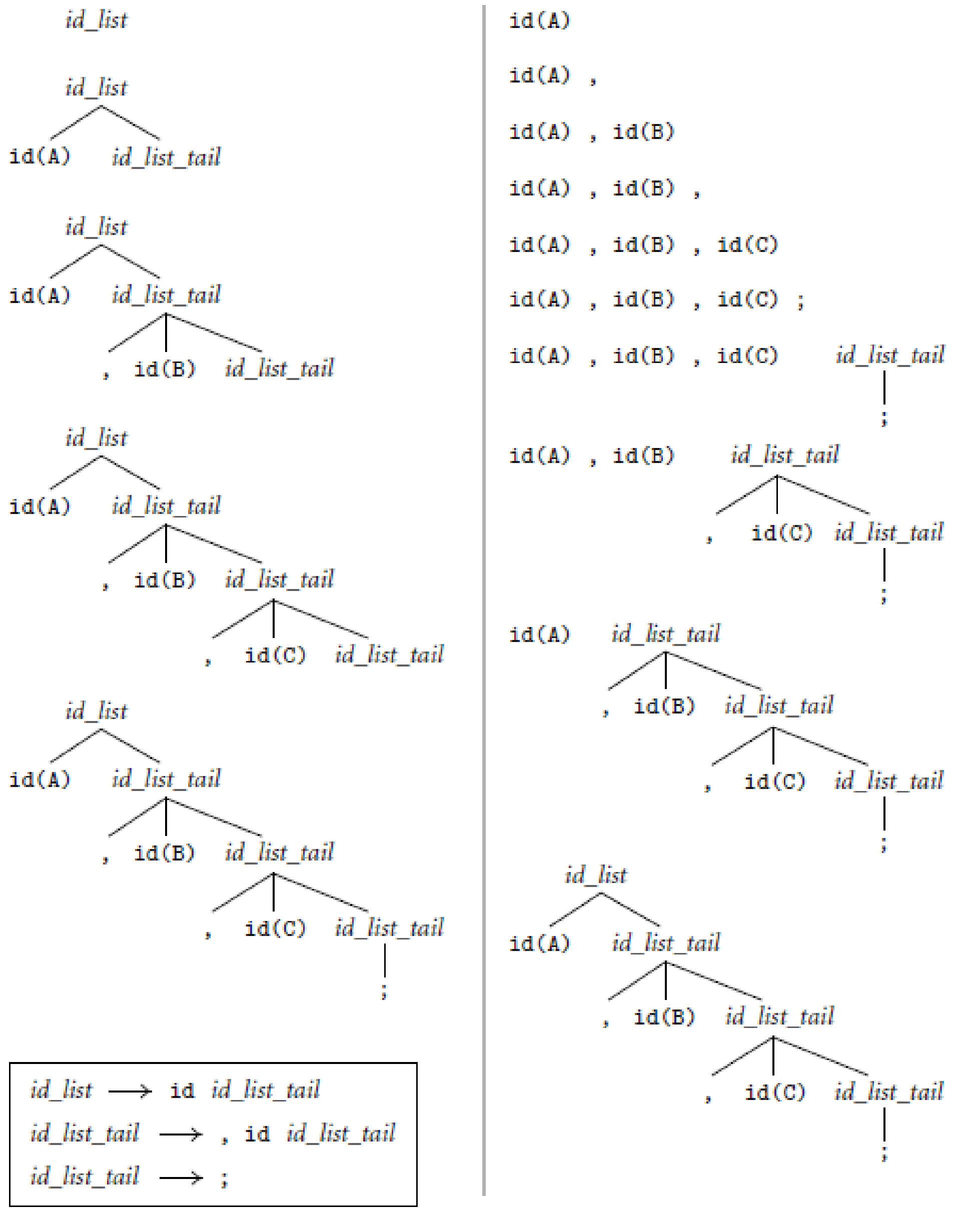
Recursive Descent Example

- Example: For the grammar:

  <term> -> <factor> {(* | /) <factor>}

- Simple recursive descent parsing subprogram:

```
void term() {
    factor();  /* parse the first factor*/
    while (next_token == ast_code ||
          next_token == slash_code) {
      lexical();  /* get next token */
      factor();  /* parse the next factor */
    }
}
```



Top-down (left) and bottom-up parsing (right) of the input string A, B, C;. Grammar appears at lower left.