Chapter 3 Describing Syntax and Semantics

3.1 Introduction

- Providing a concise yet understandable description of a programming language is difficult but essential to the language's success.
  - ALGOL 60 and ALGOL 68 were first.
- For programming language implementors
- Language reference manual

3.1 Introduction (Cont'd)

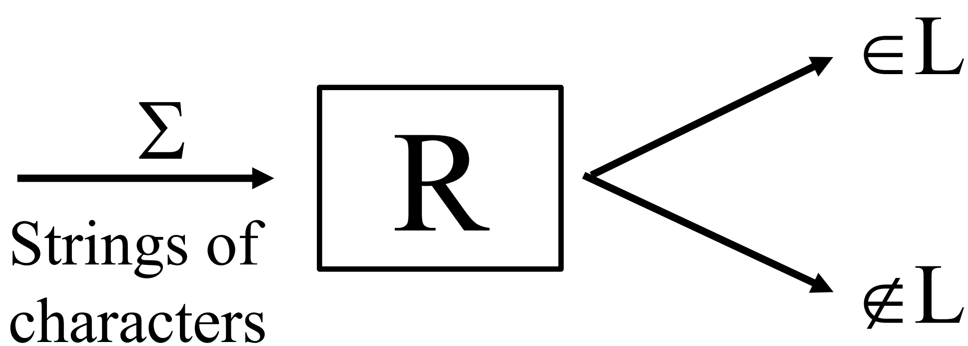
- Definition of Syntax and Semantics
  - Syntax:
    - Form, context-free
  - Semantics:
    - Meaning, context-sensitive

3.2 The General Problem of Describing Syntax

- Alphabet, Strings, Sentences, Language
- Lexemes and Tokens

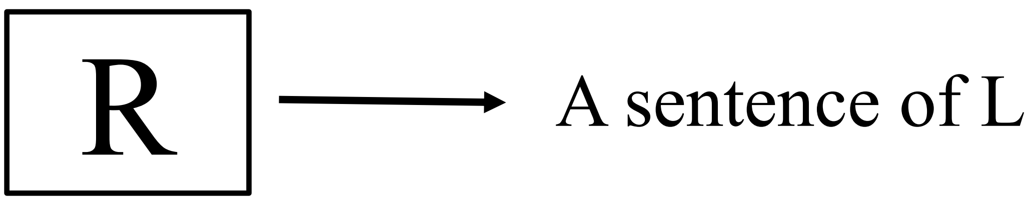
3.2.1 Language Recognizers

- R: Recognition device



3.2.1 Language Recognizers

- G: Language generator



3.3 Formal Methods of Describing Syntax

- Backus-Naur Form and Context-free Grammars
  - Appeared in late 1950s
  - Context-free Grammers
    - Chomsky, a noted linguist, advised it.
      - Context-free and regular grammars turned out to be useful for describing the syntax of programming languages
        - » Context-free grammar: Syntax
        - » Regular grammar: Token

3.3 Formal Methods of Describing Syntax

– Backus-Naur Form
    - Shortly after Chomsky's work
    - John Backus and Peter Naur
    - Describing the syntax of ALGOL 58
    - BNF

Backus-Naur Form and Context-free Grammars

- Fundamentals
  - A metalanguage is a language that is used to describe another language.
    - E.g., BNF

Context-free grammar (CFG)

- CFG consists of a set of production rules,

$$\underline{A} \rightarrow \underline{B\ C\ D \ldots\ Z}$$

LHS must be a single **nonterminal**

RHS consists 0 or more **terminals** or **nonterminals**

Context-free grammar (CFG)

- Two kinds of symbols
  - Nonterminals
    - Delimited by < and >
    - Represent syntactic structures
  - Terminals
    - Represent tokens
- E.g.

  <program> → **begin** <statement list> **end**

- Start or goal symbol
- λ : empty or null string

Context-free grammar (Cont'd)

- E.g.

<statement list> → <statement><statement tail>

<statement tail> → λ

<statement tail> → <statement><statement tail>

Context-free grammar (Cont'd)

- Extended BNF: some abbreviations

1. optional: [ ]   0 or 1

   <stmt> → if <exp> then <stmt>

   <stmt> → if <exp> then <stmt> else <stmt>

   can be written as

   <stmt> → if <exp> then <stmt> [else <stmt>]

2. repetition: { }   0 or more

   <stmt list> → <stmt> <tail>

   <tail> → λ

   <tail> → <stmt> <tail>

   can be written as

   <stmt list> → <stmt> { <stmt> }

Context-free grammar (Cont'd)

- Extended BNF: some abbreviations

3. alternative: | or

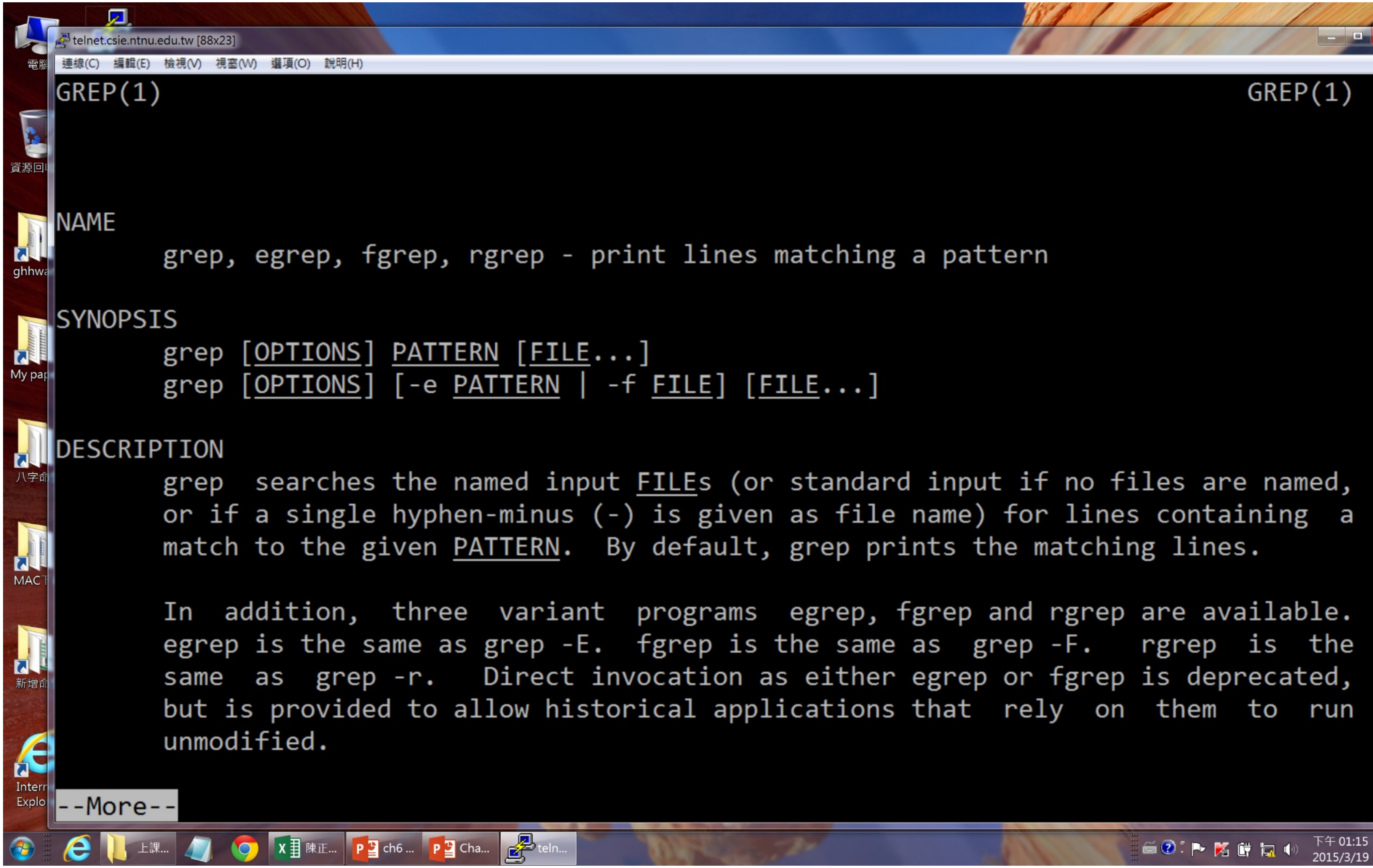
   <stmt> → <assign>

   <stmt> → <if stmt>

   can be written as

   <stmt> → <assign> | <if stmt>

- Extended BNF ≡ BNF
  - Either can be transformed to the other.
  - Extended BNF is more compact and readable




```
GREP(1)                                                                    GREP(1)



NAME
       grep, egrep, fgrep, rgrep - print lines matching a pattern

SYNOPSIS
       grep [OPTIONS] PATTERN [FILE...]
       grep [OPTIONS] [-e PATTERN | -f FILE] [FILE...]

DESCRIPTION
       grep  searches the named input FILEs (or standard input if no files are named,
       or if a single hyphen-minus (-) is given as file name) for lines containing  a
       match to the given PATTERN.  By default, grep prints the matching lines.

       In  addition,  three  variant  programs  egrep, fgrep and rgrep are available.
       egrep is the same as grep -E.  fgrep is the same as  grep -F.   rgrep  is  the
       same  as  grep -r.   Direct invocation as either egrep or fgrep is deprecated,
       but is provided to allow historical applications that  rely  on  them  to  run
       unmodified.

--More--
```

The Syntax of Micro (Cont'd)

1.	<program>	→	**begin** <statement list> **end**
2.	<statement list>	→	<statement> {<statement>}
3.	<statement>	→	ID := <expression> ;
4.	<statement>	→	**read** (<id list>) ;
5.	<statement>	→	**write** (<expr list>) ;
6.	<id list>	→	ID {, ID}
7.	<expr list>	→	<expression> {, <expression>}
8.	<expression>	→	<primary> {<add op> <primary>}
9.	<primary>	→	(<expression>)
10.	<primary>	→	ID
11.	<primary>	→	INTLITERAL
12.	<add op>	→	PLUSOP
13.	<add op>	→	MINUSOP
14.	<system goal>	→	<program> SCANEOF

Figure 2.4 Extended CFG Defining Micro

- The **derivation** of

begin ID:= ID + (INTLITERAL – ID); end

<program>	
⇒ **begin** <statement list> **end**	(Apply rule 1)
⇒ **begin** <statement> {<statement>} **end**	(Apply rule 2)
⇒ **begin** <statement> **end**	(Choose 0 repetitions)
⇒ **begin** ID := <expression> ; **end**	(Apply rule 3)
⇒ **begin** ID := <primary> {<add op> <primary>} ; **end**	(Apply rule 8)
⇒ **begin** ID := <primary> <add op> <primary> ; **end**	(Choose 1 repetition)
⇒ **begin** ID := <primary> + <primary> ; **end**	(Apply rule 12)
⇒ **begin** ID := ID + <primary> ; **end**	(Apply rule 10)
⇒ **begin** ID := ID + (<expression>) ; **end**	(Apply rule 9)
⇒ **begin** ID := ID + (<primary> {<add op> <primary>}) ; **end**	(Apply rule 8)
⇒ **begin** ID := ID + (<primary> <add op> <primary>) ; **end**	(Choose 1 repetition)
⇒ **begin** ID := ID + (<primary> – <primary>) ; **end**	(Apply rule 13)
⇒ **begin** ID := ID + (INTLITERAL – <primary>) ; **end**	(Apply rule 11)
⇒ **begin** ID := ID + (INTLITERAL – ID) ; **end**	(Apply rule 10)

Backus-Naur Form and Context-free Grammars

- Describing Lists
  - Variable-length lists in mathematics are often written using an ellipsis (…)
  - For BNF, the alternative is recursion

```
<id_list> → id
          | id, <id_list>
```

Backus-Naur Form and Context-free Grammars

- Grammars and Derivations
  - start symbol
  - derivation
  - sentential form & leftmost derivations
    - See next slice

- A grammar

```
<program> → <stmts>
   <stmts> → <stmt> | <stmt> ; <stmts>
   <stmt> → <var> = <expr>
   <var> → a | b | c | d
   <expr> → <term> + <term> | <term> - <term>
   <term> → <var> | const
```

- A derivation

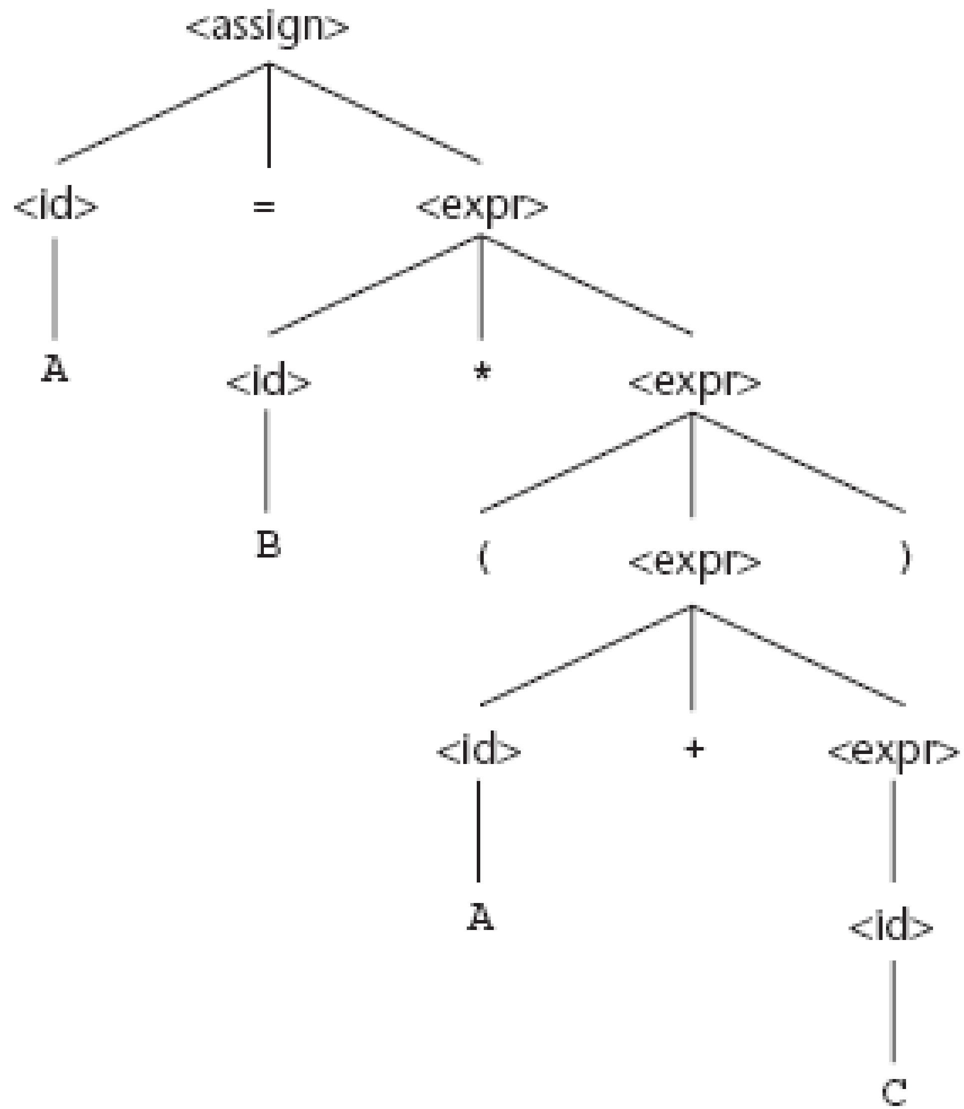
```
<program> => <stmts> => <stmt>
                      => <var> = <expr>
                      => a = <expr>
                      => a = <term> + <term>
                      => a = <var> + <term>
                      => a = b + <term>
                      => a = b + const
```

Backus-Naur Form and Context-free Grammars

- Parse trees
  - One of the most attractive features of grammars is that they naturally describe the hierarchical syntactic structure of the sentences of the languages they define.
    - Internal node: nonterminal symbol
    - Leaf node: terminal symbol

Figure 3.1

A parse tree for the simple statement
`A = B * (A + C)`



Backus-Naur Form and Context-free Grammars

- Ambiguity
  - A grammar that generates a sentential form for which there are two or more distinct parse tree is said to be ambiguous
    - See next slice
  - Why may ambiguity cause problem?
    - Code generation for compilers

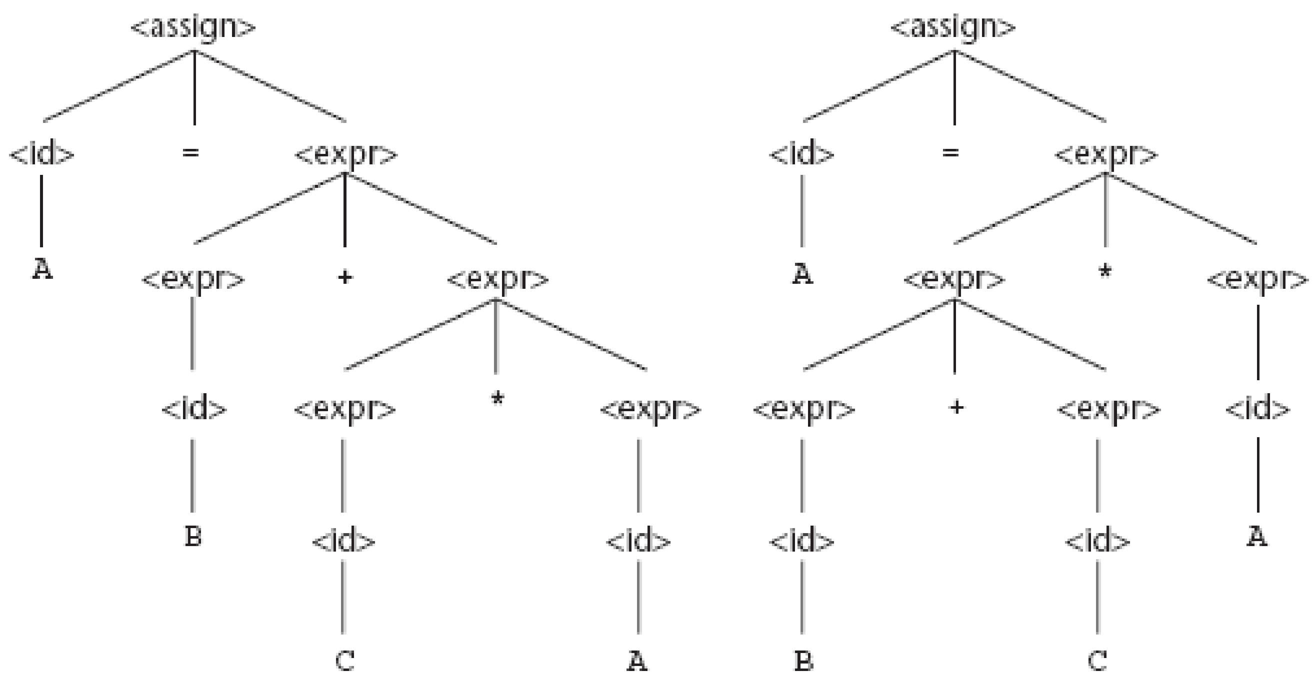


Figure 3.2

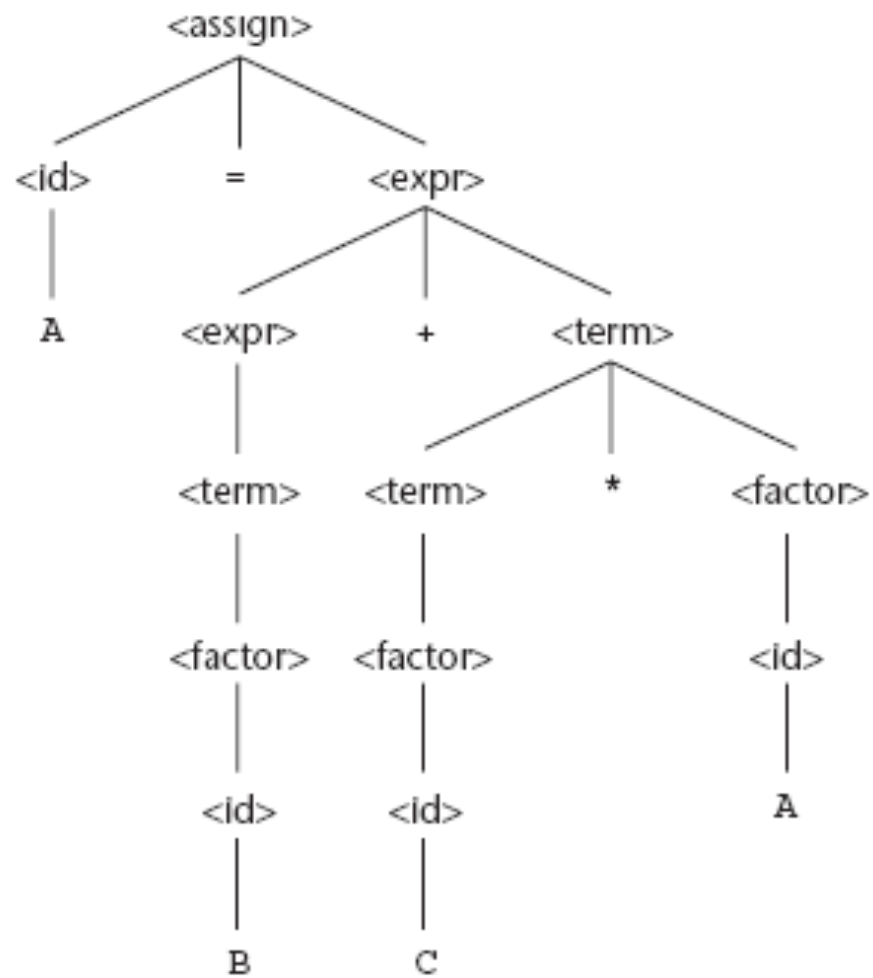
Two distinct parse trees for the same sentence, `A = B + C * A`

Backus-Naur Form and Context-free Grammars

- Operator precedence
  - The order of evaluation of operators
  - Can the BNF demonstrate the operator precedence?
    - See EXAMPLE 3.4 and the derivation of A=B+C ∗A

Figure 3.3

The unique parse tree for `A = B + C * A` using an unambiguous grammar

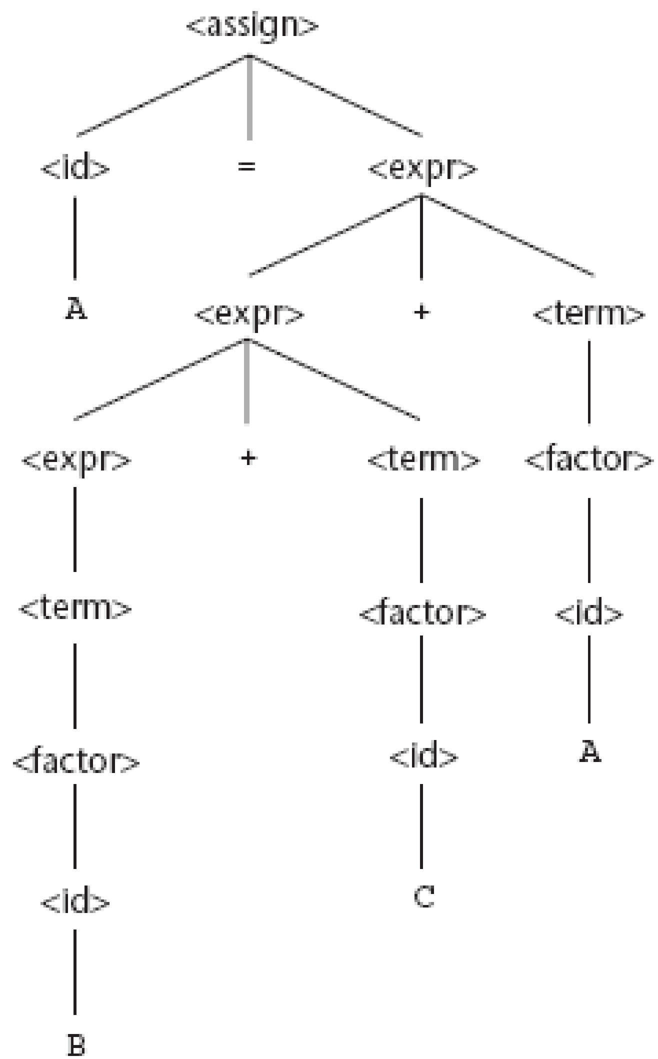


Backus-Naur Form and Context-free Grammars

- Associativity of operators
  - When an expression includes two operators that have the same precedence, a semantic rule is required to specify which should have precedence
  - The left recursion specifies left associativity

Figure 3.4

A parse tree for `A = B + C + A` illustrating the associativity of addition



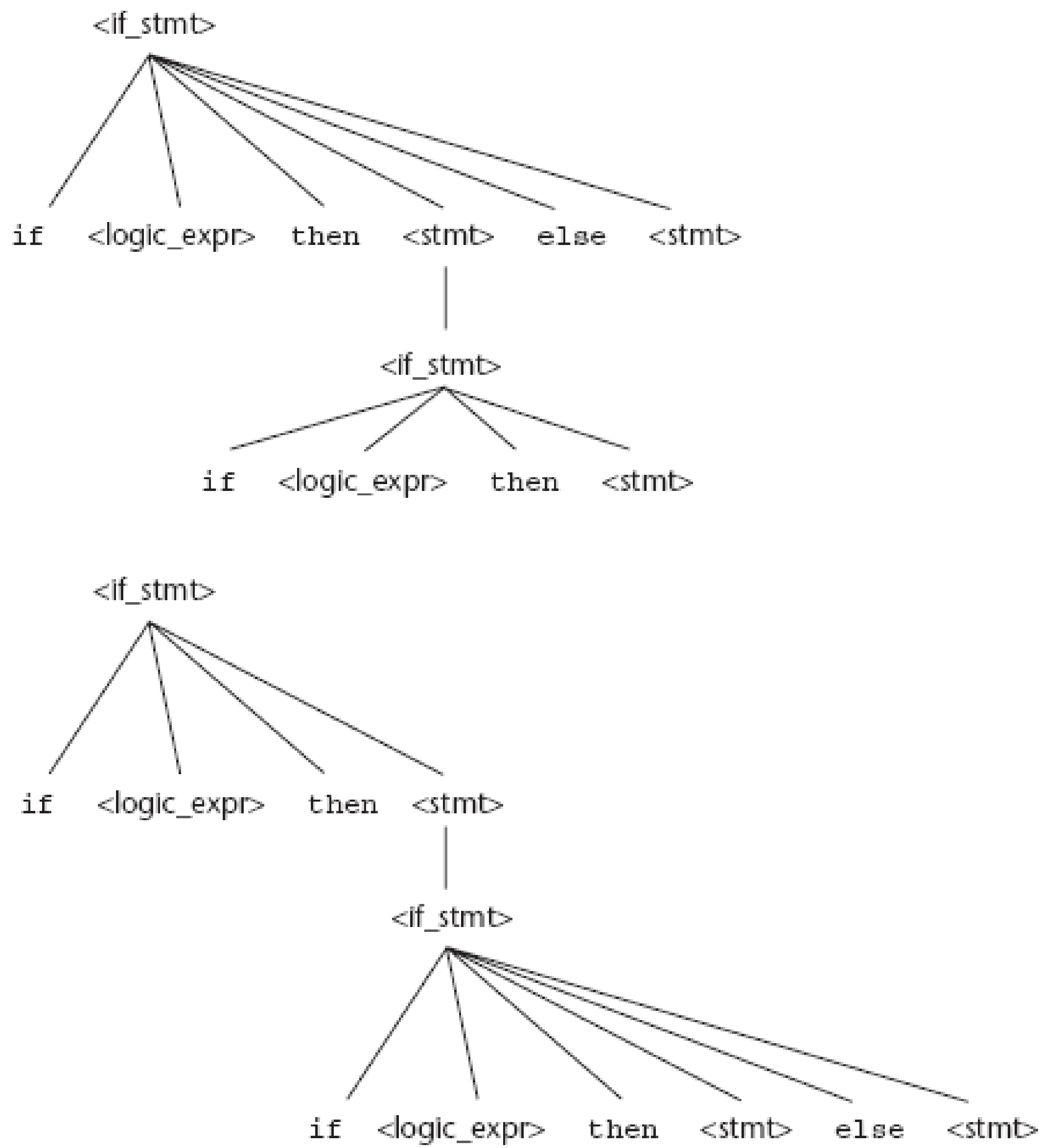
An unambiguous grammar for if-then-else

- An intuitive BNF for if-then-else

```
<if_stmt> → if <logic_expr> then <stmt>
          | if <logic_expr> then <stmt> else <stmt>
```

Figure 3.5

Two distinct parse trees for the same sentential form



An unambiguous grammar for if-then-else

- The unambiguous grammar

<stmt> → <matched> | <unmatched>

<matched>→ **if** <logic_expr> **then** <matched> **else** <matched>

| <any_non-if_statement>

<unmatched>→ **if** <logic_expr> **then** <stmt>

| **if** <logic_expr> **then** <matched> **else** <unmatched>