Programming Languages:

Lecture 3

Chapter 3: Syntax and Semantics

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Chapter 3 Topics

- Introduction
- The General Problem of Describing Syntax
- Formal Methods of Describing Syntax
- Attribute Grammars
- Describing the Meanings of Programs: Dynamic Semantics

Introduction

- **Syntax:** the form or structure of the expressions, statements, and program units

- **Semantics:** the meaning of the expressions, statements, and program units

- Syntax and semantics provide a language's definition
  - Users of a language definition
    - **Other language designers**
    - **Implementers**
    - **Programmers (the users of the language)**

The General Problem of Describing Syntax: Terminology

- A *sentence* is a string of characters over some alphabet
- A *language* is a set of sentences
- A *lexeme* is the lowest level syntactic unit of a language (e.g., `*`, `sum`, `begin`)
- A *token* is a category of lexemes (e.g., identifier)

(Example)

index = 2 * count + 17;

Lexemes	*Tokens*
Index	identifier
=	equal_sign
2	int_literal
*	mult_op
count	identifier
+	plus_op
17	int_literal
;	semicolon

Formal Definition of Languages

- Recognizers
  - A recognition device reads input strings of the language and decides whether the input strings belong to the language
  - Example: syntax analysis part of a compiler
  - Detailed discussion in Chapter 4
- Generators
  - A device that generates sentences of a language
  - One can determine if the syntax of a particular sentence is correct by comparing it to the structure of the generator

Formal Methods of Describing Syntax

- Backus-Naur Form and Context-Free Grammars
  - Most widely known method for describing programming language syntax
- Extended BNF
  - Improves readability and writability of BNF
- Grammars and Recognizers

BNF and Context-Free Grammars

- Context-Free Grammars
  - Developed by Noam Chomsky in the mid-1950s
  - Language generators, meant to describe the syntax of natural languages
  - Define a class of languages called context-free languages

Backus-Naur Form (BNF)

- Backus-Naur Form (1959)
  - Invented by John Backus to describe Algol 58
  - BNF is equivalent to context-free grammars
  - BNF is a *metalanguage* used to describe another language
  - In BNF, abstractions are used to represent classes of syntactic structures--they act like syntactic variables (also called *nonterminal symbols*)

BNF Fundamentals

- Non-terminals: BNF abstractions
- Terminals: lexemes and tokens
- Grammar: a collection of rules
  - Examples of BNF rules:

```
<ident_list> → identifier | identifier, <ident_list>
<if_stmt> → if <logic_expr> then <stmt>
```

BNF Rules

- A rule has a left-hand side (LHS) and a right-hand side (RHS), and consists of *terminal* and *nonterminal* symbols

- A grammar is a finite nonempty set of rules

- An abstraction (or nonterminal symbol) can have more than one RHS

```
<stmt> → <single_stmt>
       | begin <stmt_list> end
```

Describing Lists

- Syntactic lists are described using recursion

```
<ident_list> → ident
             | ident, <ident_list>
```

- A derivation is a repeated application of rules, starting with the start symbol and ending with a sentence (all terminal symbols)

An Example Grammar

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

An Example Derivation

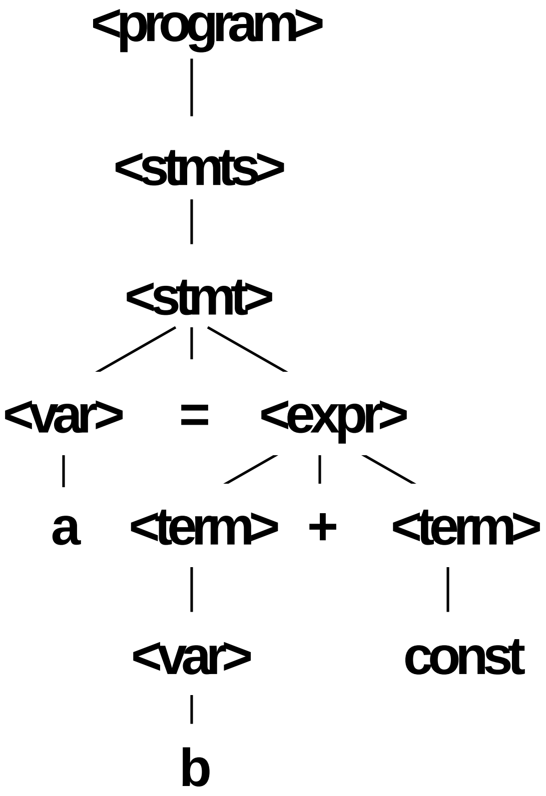
```
<program> => <stmts>
          => <stmt>
          => <var> = <expr>
          => a = <expr>
          => a = <term> + <term>
          => a = <var> + <term>
          => a = b + <term>
          => a = b + const
```

Derivation

- Every string of symbols in the derivation is a sentential form
- A sentence is a sentential form that has only terminal symbols
- A leftmost derivation is one in which the leftmost nonterminal in each sentential form is the one that is expanded
- A derivation may be neither leftmost nor rightmost

Parse Tree

- A hierarchical representation of a derivation

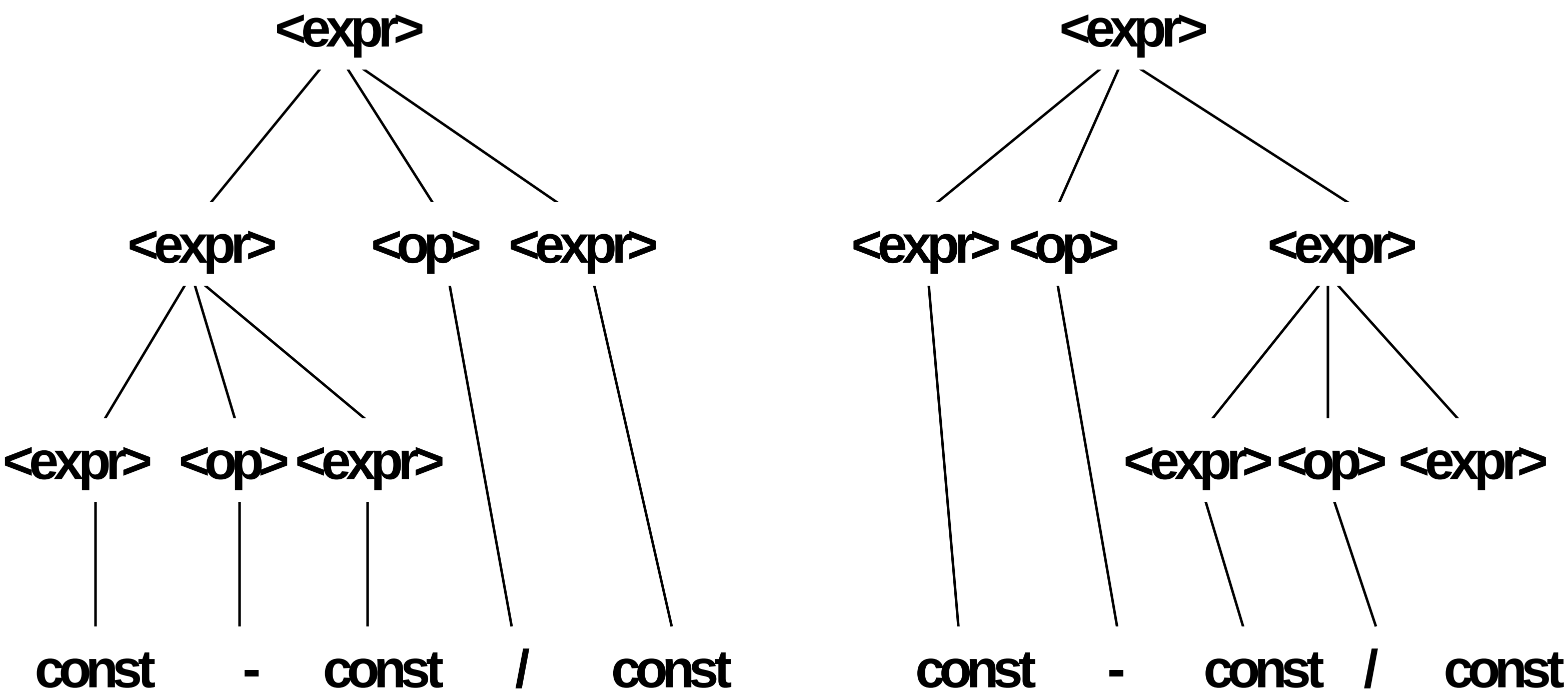


Ambiguity in Grammars

- A grammar is *ambiguous* if and only if it generates a sentential form that has two or more distinct parse trees

An Ambiguous Expression Grammar

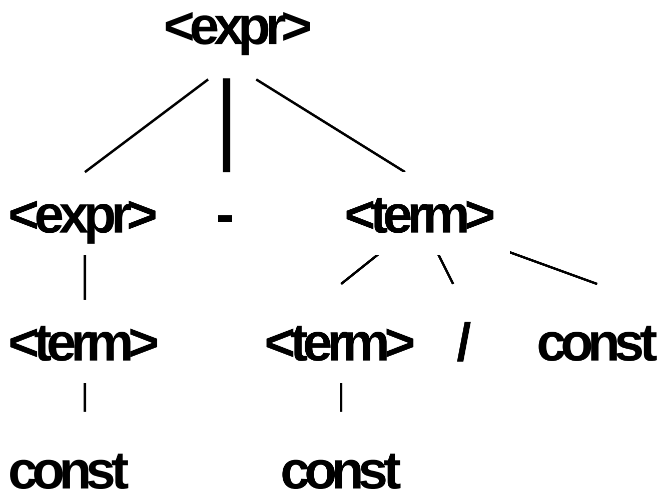
```
<expr> → <expr> <op> <expr>  |  const
<op> → /  |  -
```



An Unambiguous Expression Grammar

- If we use the parse tree to indicate precedence levels of the operators, we cannot have ambiguity

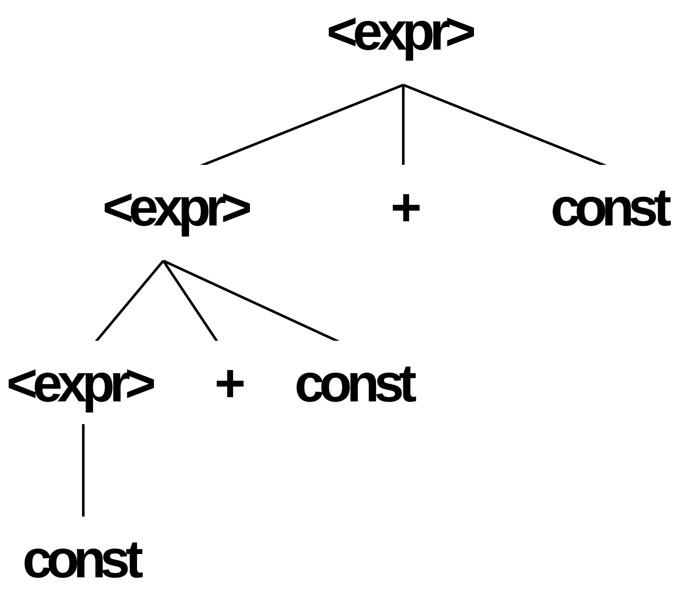
```
<expr> → <expr> - <term>  |  <term>
<term> → <term> / const| const
```



Associativity of Operators

- Operator associativity can also be indicated by a grammar

```
<expr> -> <expr> + <expr> |  const  (ambiguous)
<expr> -> <expr> + const  |  const  (unambiguous)
```

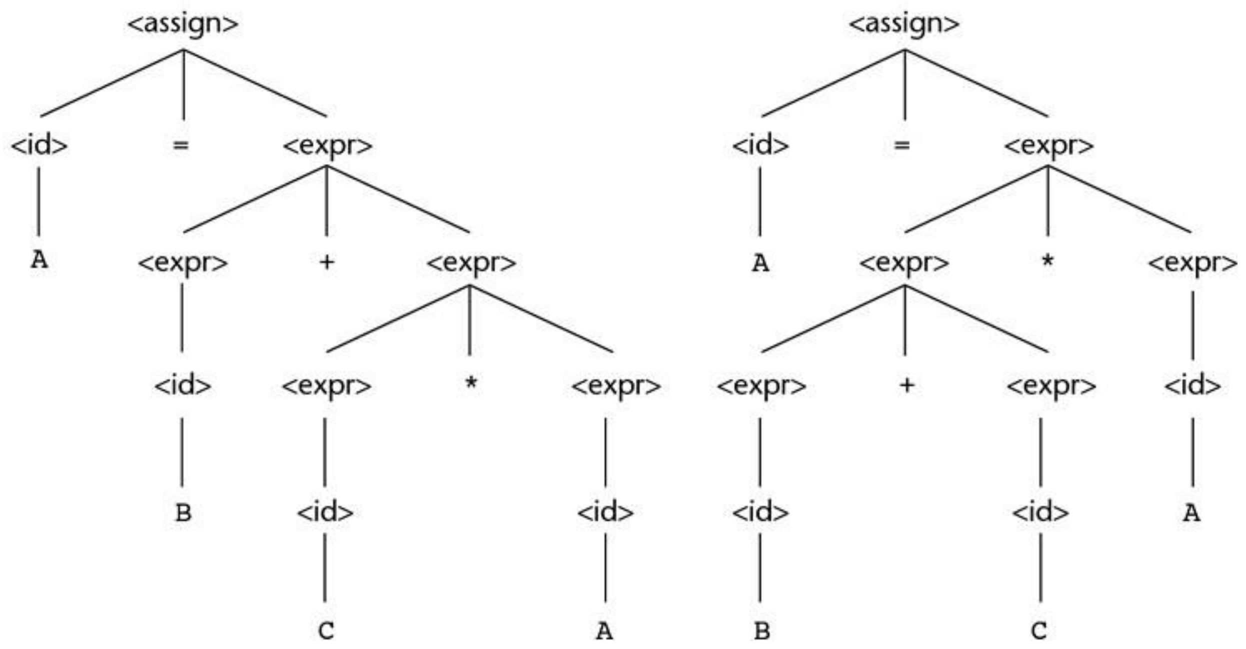


EXAMPLE 3.3 An Ambiguous Grammar for Simple Assignment Statements

```
<assign> → <id> = <expr>
<id> → A | B | C
<expr> → <expr> + <expr>
       | <expr> * <expr>
       | ( <expr> )
       | <id>
```

Figure 3.2

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



EXAMPLE 3.4 An Unambiguous Grammar for Expressions

<assign> → <id> = <expr>
<id> → A | B | C
<expr> → <expr> + <term>
| <term>
<term> → <term> * <factor>
| <factor>
<factor> → (<expr>)
| <id>

Figure 3.3

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

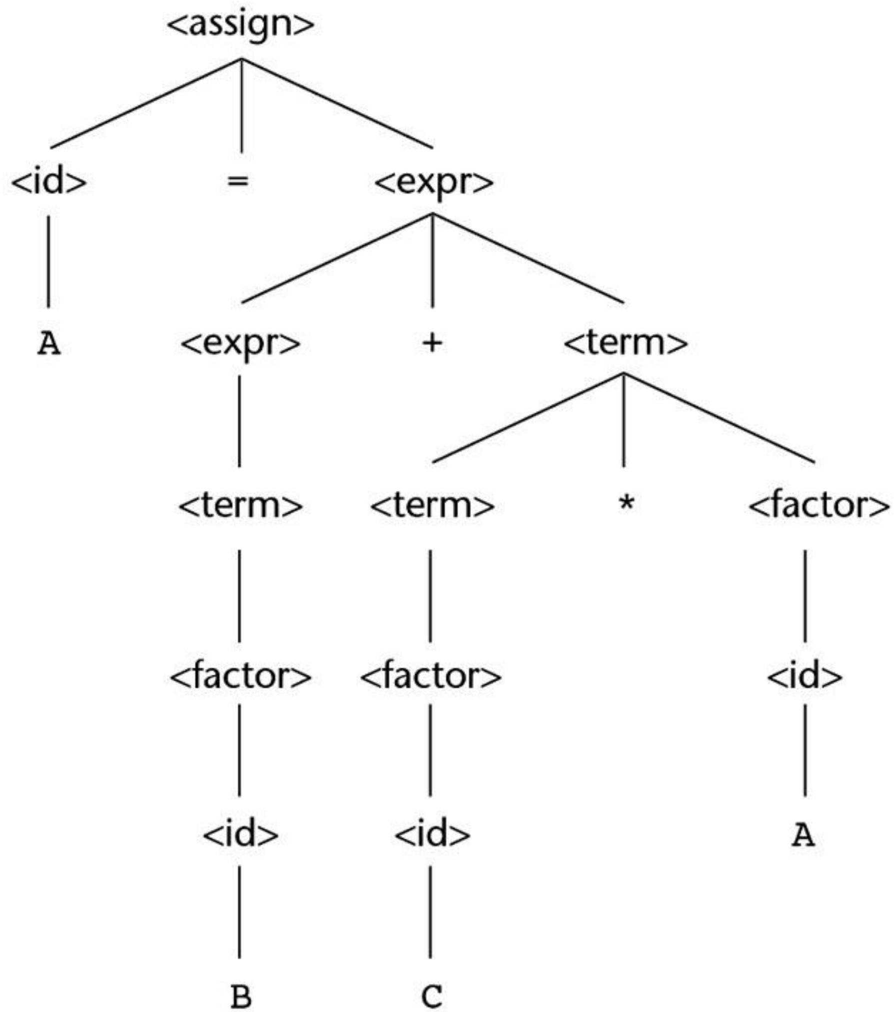
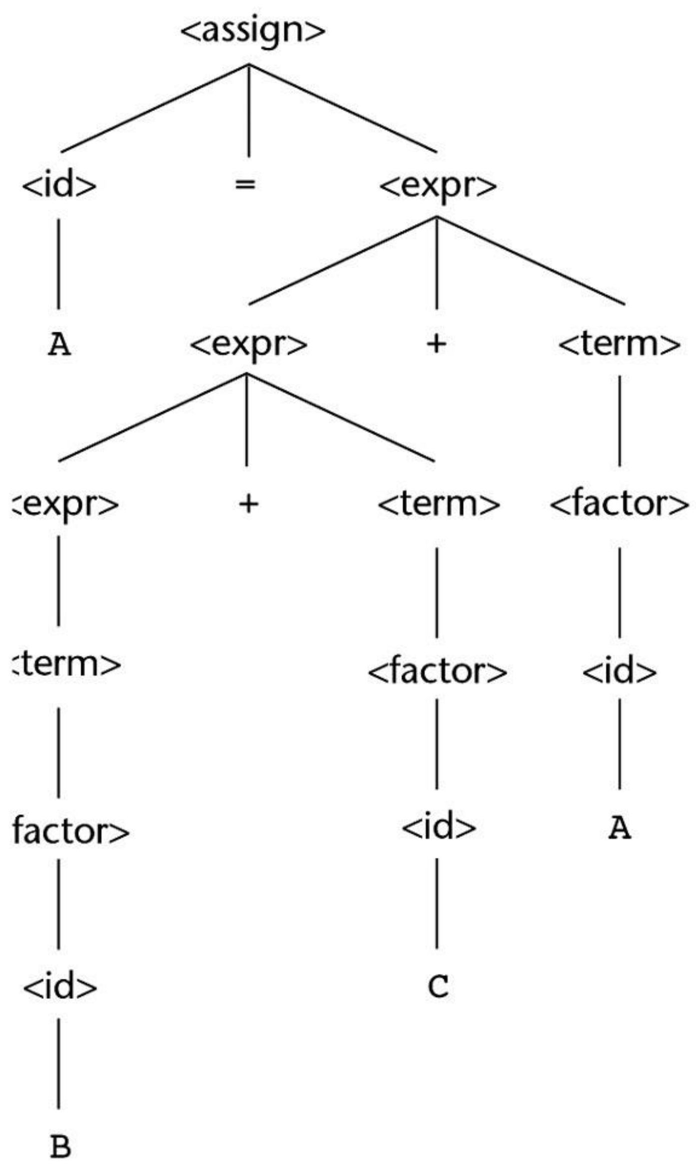


Figure 3.4

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



Extended BNF

- Optional parts are placed in brackets [ ]

```
<proc_call> -> ident [(<expr_list>)]
```

- Alternative parts of RHSs are placed inside parentheses and separated via vertical bars

```
<term> → <term> (+|-) const
```

- Repetitions (0 or more) are placed inside braces { }

```
<ident> → letter {letter|digit}
```

BNF and EBNF

- BNF

```
<expr> → <expr> + <term>
       | <expr> - <term>
       | <term>
<term> → <term> * <factor>
       | <term> / <factor>
       | <factor>
```

- EBNF

```
<expr> → <term> {(+ | -) <term>}
<term> → <factor> {(* | /) <factor>}
```

EXAMPLE 3.5 BNF and EBNF Versions of an Expression Grammar

BNF:

```
<expr> → <expr> + <term>
       | <expr> - <term>
       | <term>
<term> → <term> * <factor>
       | <term> / <factor>
       | <factor>
<factor> → <exp> ** <factor>
         | <exp>
<exp> → ( <expr> )
      | id
```

EBNF:

```
<expr> → <term> {(+ | -) <term>}
<term> → <factor> {(* | /) <factor>}
<factor> → <exp> { ** <exp>}
<exp> → ( <expr> )
      | id
```

Summary

- BNF and context-free grammars are equivalent meta-languages
  – Well-suited for describing the syntax of programming languages
- An attribute grammar is a descriptive formalism that can describe both the syntax and the semantics of a language
- Three primary methods of semantics description
  – Operation, axiomatic, denotational

Homework #2

- Read articles introduced in this lecture
  - The Chomsky Hierarchy
    - **http://jjcweb.jjay.cuny.edu/~jwkim/class/csci374-spring-25/Chomsky_Hierarchy.pdf**
- Problem Solving (Chapter 3)
  - 2.c, 3, 6.a, 8, 9, 10, 11, 15, 16, 17
  - HW 2
  - Refer class homepage for Chapter 3 problems
  - Please email your hw in word or pdf format
  - No late homework will be accepted