Chapter 3

Describing Syntax and Semantics

Chapter 3 Topics

Introduction

The General Problem of Describing Syntax

Formal Methods of Describing Syntax

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)

Formal Definition of Languages

Recognizers

A recognition device reads input strings over the alphabet of the language and decides whether the input strings belong to the language

Example: syntax analysis part of a compiler

- Detailed discussion of syntax analysis appears in Chapter 4

Generators

A device that generates sentences of a language

One can determine if the syntax of a particular sentence is syntactically correct by comparing it to the structure of the generator

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 (1959)

- Invented by John Backus to describe Algol 58
- BNF is equivalent to context-free grammars

BNF Fundamentals

In BNF, abstractions are used to represent classes of syntactic structures--they act like syntactic variables (also called *nonterminal symbols,* or just *terminals*)

Terminals are lexemes or tokens

A rule has a left-hand side (LHS), which is a nonterminal, and a right-hand side (RHS), which is a string of terminals and/or nonterminals

Nonterminals are often enclosed in angle brackets

Grammar: a finite non-empty set of rules

A ***start symbol*** is a special element of the nonterminals of a grammar

BNF Rules

Examples of BNF rules:

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

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
```

Derivations

Every string of symbols in a derivation is a *sentential form*

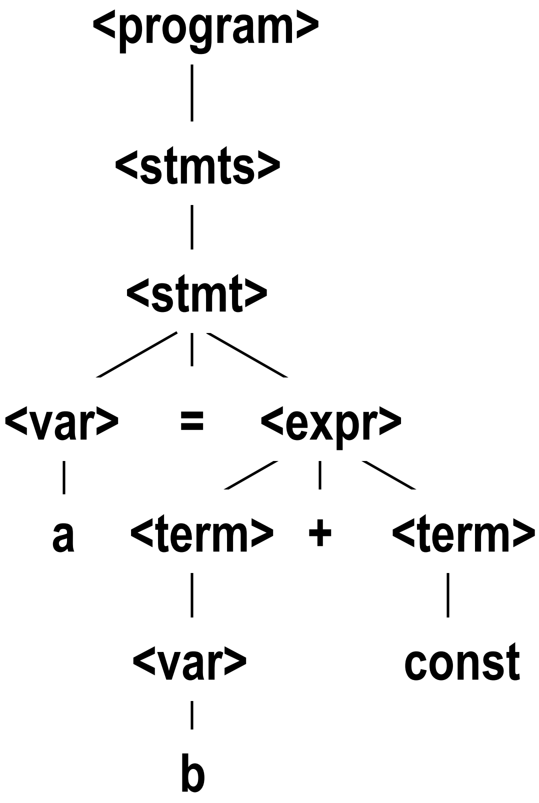
A *sentence* is a sentential form that has only terminal symbols

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



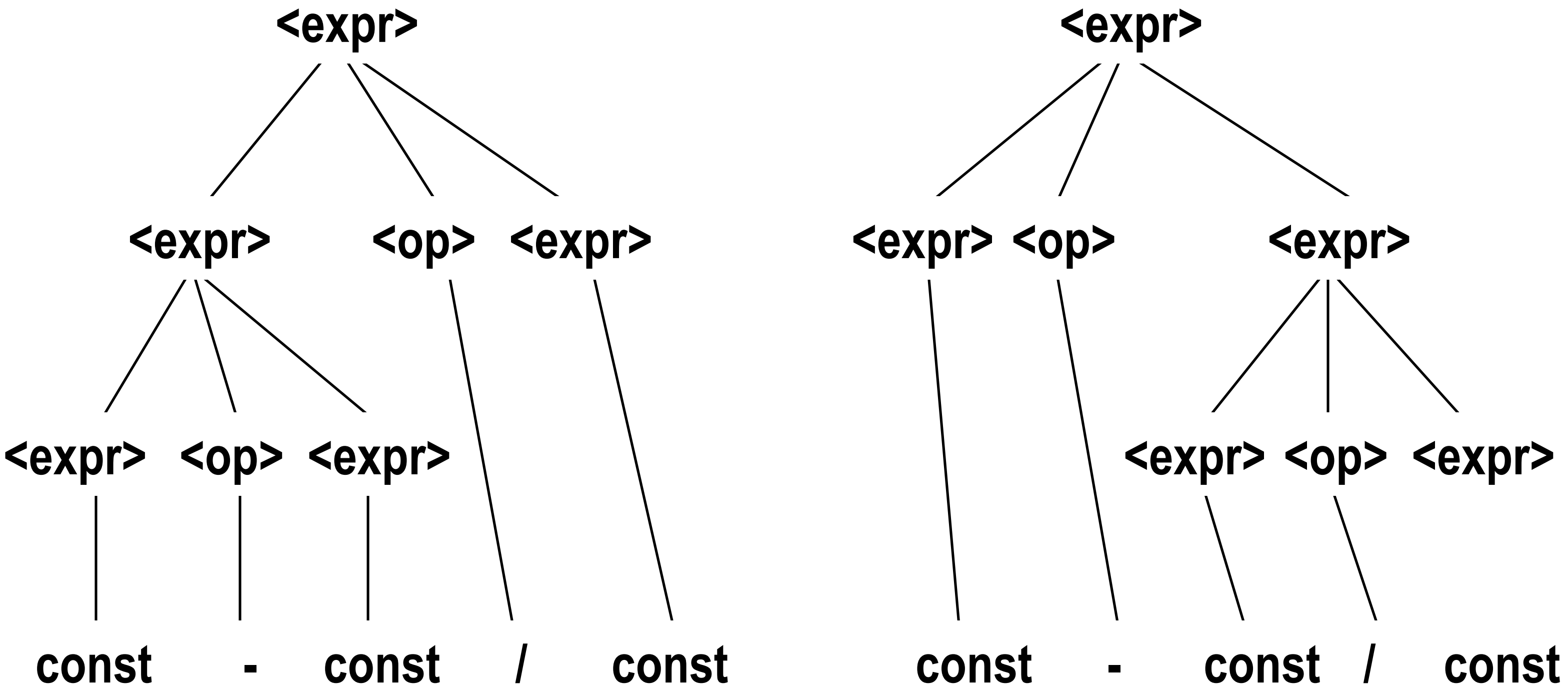
Ambiguity in Grammars

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

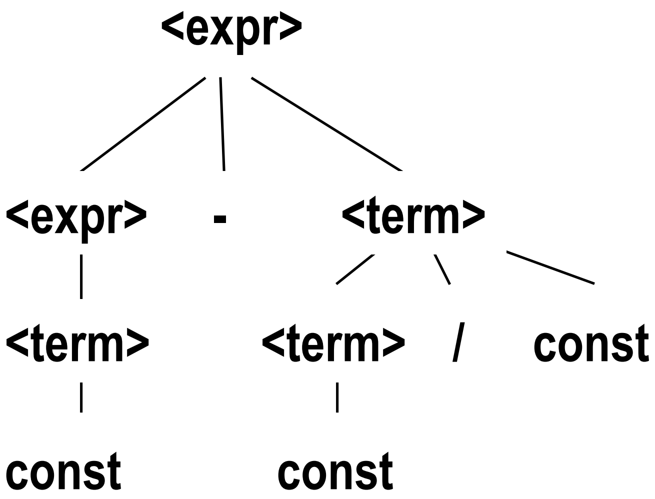
<op> → / | -



An Unambiguous Expression Grammar

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

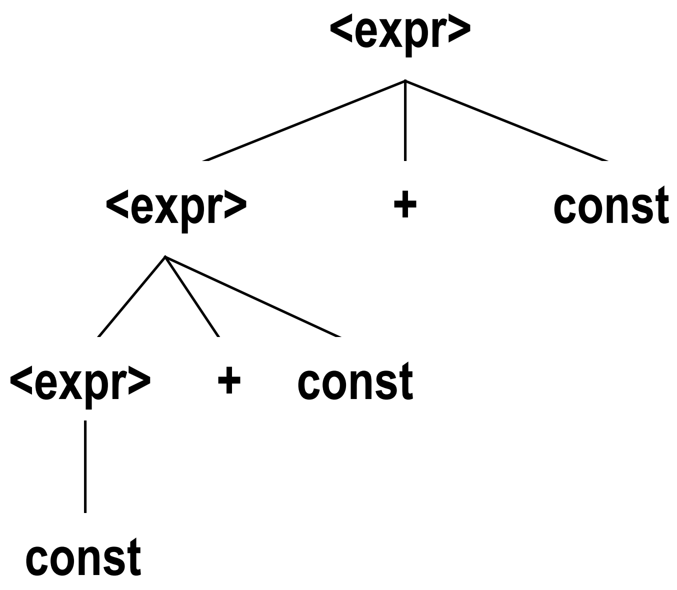
```
<expr> → <expr> - <term>   |  <term>
<term> → <term> / const| const
```



Associativity of Operators

Operator associativity can also be indicated by a grammar

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



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>}
```

Recent Variations in EBNF

Alternative RHSs are put on separate lines

Use of a colon instead of =>

Use of $_{\texttt{opt}}$ for optional parts

Use of `oneof` for choices

Summary

- BNF and context-free grammars are equivalent meta-languages
  - Well-suited for describing the syntax of programming languages