Sebesta: Concepts of Programming Languages Chapter 3

Describing Syntax and Semantics

CS 4100

Dr. Martin

Some 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 of the language and decides whether the input strings belong to the language
  - Example: syntax analysis part of a compiler
- **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

Chomsky Hierarchy

- Type-0 Recursively enumerable
  - Turing machine
  - any string of non-terminals ::= any other string of non-terminals and terminals
- Type-1 Context-sensitive
  - Linear-bounded non-deterministic Turing machine
  - any string of non-terminals ::= any other string of non-terminals and terminals
- Type-2 Context-free
  - Non-deterministic pushdown automaton
  - <nt> ::= any string of terminal and non-terminal symbols
- Type-3 Regular
  - Finite state automaton
  - <nt> ::= k <nt> or <nt> ::= k

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>
<expr> → <term> + <term> | <term> - <term>
<term> → <var> | const
<var> → a | b | c | d

An Example Derivation

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

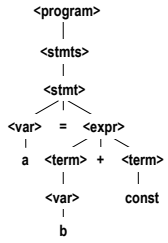
<program> → <stmts>
<stmts> → <stmt> | <stmt> ; <stmts>
<stmt> → <var> = <expr>
<expr> → <term> + <term> | <term> - <term>
<term> → <var> | const
<var> → a | b | c | d

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

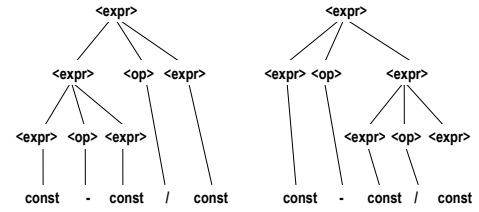


Ambiguity in Grammars

- 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

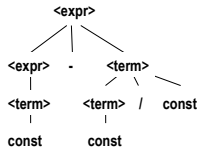
<expr> → <expr> <op> <expr> | const
<op> → / | -



An Unambiguous Expression Grammar

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

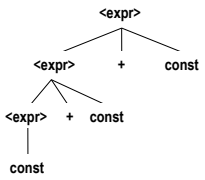
```
<expr> → <expr> - <term>  |  <term>
<term> → <term> / const| const
```



Associativity of Operators

- Operator associativity can also be indicated by a grammar

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



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>}
```