Program Syntax

In Text: Chapter 3 & 4

Overview

- Basic concepts
  - Programming language, regular expression, context-free grammars
- Lexical analysis
  - Scanner
- Syntactic analysis
  - Parser

Basic Definitions

- **Syntax**—the form or structure of the expressions, statements, and program units
- **Semantics**—the meaning of the expressions, statements, and program units

- Why write a language definition; who will use it?
  - Other language designers
  - Implementers (compiler writers)
  - Programmers (the users of the language)

What is a “Language”?

- 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)

Lexemes	*Tokens*
`index`	identifier
`=`	equal_sign
`2`	int_literal

Natural Languages Are Ambiguous

- “I saw a man on a hill with a telescope”
- Programming languages should be precise and unambiguous
  - Both programmers and computers can tell what a program is supposed to do

Recognizers vs. Generators

- We don’t want to use English to describe a language (too long, tedious, imprecise), so …
- There are *two formal approaches to describing syntax*:
  - Recognizers
    - Given a string, a recognizer for a language L tells whether or not the string is in L (e.g.: Compiler – syntax analyzer)
  - Generators
    - A generator for L will produce an arbitrary string in L on demand. (e.g.: Grammar, BNF)
  - Recognition and generation are useful for different things, but are closely related

Programming Language Definition

- Syntax
  - To describe what its programs look like
  - Specified using **regular expressions** and **context-free grammars**
- Semantics
  - To describe what its programs mean
  - Specified using axiomatic semantics, operational semantics, or denotational semantics

Grammars

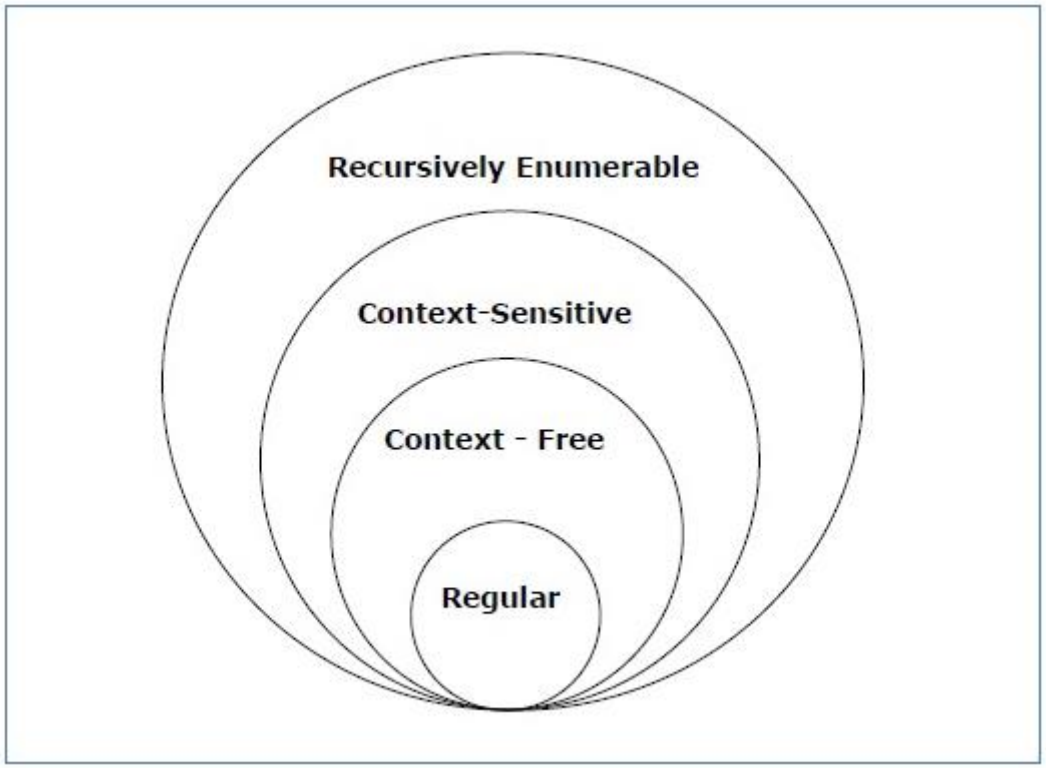
- Developed by Noam Chomsky in the mid-1950s
- 4-level hierarchy (0-3)
- Language generators, meant to describe the syntax of natural languages
- **Context-free** grammars define a class of languages called **context-free languages** (level 2)

Chomsky Classification of Grammars

Grammar Type	Grammar Accepted	Automaton
Type 0	**Unrestricted** grammar	Turing Machine
Type 1	Context-**sensitive** grammar	**Linear-bounded** automaton
Type 2	Context-free grammar	**Pushdown** automaton
Type 3	Regular grammar	**Finite** state automaton

Chomsky Classification of Grammars

The following illustration shows the scope of each type of grammar:



Type-2 grammars

- **Type-2 grammars** generate context-free languages.
- The productions must be in the form **A → γ**
- where **A ∈ N** (Non terminal)
- and **γ ∈ (T ∪ N)*** (String of terminals and non-terminals).
- These languages generated by these grammars are be recognized by a non-deterministic pushdown automaton.
- Example:

S → Xa
X → a
X → aX
X → abc
X → ε

Regular Expressions

- A regular expression is one of the following:
  - A character
  - The empty string, denoted by ε
  - Two or more regular expressions concatenated
  - Two or more regular expressions separated by | (or)
  - A regular expression followed by the Kleene star (concatenation of zero or more strings)

Regular Expressions

- The pattern of numeric constants can be represented as:

$$
\begin{aligned}
digit &\longrightarrow \texttt{0} \mid \texttt{1} \mid \texttt{2} \mid \texttt{3} \mid \texttt{4} \mid \texttt{5} \mid \texttt{6} \mid \texttt{7} \mid \texttt{8} \mid \texttt{9} \\
unsigned\_integer &\longrightarrow digit\ digit* \\
unsigned\_number &\longrightarrow unsigned\_integer\ (\ (\ \texttt{.}\ unsigned\_integer\ ) \mid \epsilon\ ) \\
&\qquad (\ (\ (\ \texttt{e} \mid \texttt{E}\ )\ (\ \texttt{+} \mid \texttt{-} \mid \epsilon\ )\ unsigned\_integer\ ) \mid \epsilon\ )
\end{aligned}
$$

What is the meaning of following expressions ?

- [0-9a-f]+
- b[aeiou]+t
- a*(ba*ba*)*

Define Regular Expressions

- Match strings only consisting of ‘a’, ‘b’, or ‘c’ characters
- Match only the strings “Buy more milk”, “Buy more bread”, or “Buy more juice”
- Match identifiers which contain letters and digits, starting with a letter

Context-Free Grammars

- Context-Free Grammars
  - Developed by Noam Chomsky in the mid-1950s
  - Describe the syntax of natural languages
  - Define a class of languages called context-free languages
  - Was originally designed for natural languages

Context-Free Grammars

- Using the notation Backus-Naur Form (BNF)
- A context-free grammar consists of
  - A set of *terminals* *T*
  - A set of *non-terminals* *N*
  - A *start symbol* *S* (a non-terminal)
  - A set of *productions* *P*

Terminals T

- The basic symbols from which strings are formed
- Terminals are tokens
  - if, foo, ->, ‘a’

Non-terminals **N**

- Syntactic variables that denote sets of strings or classes of syntactic structures
  - expr, stmt
- Impose a hierarchical structure on the language

Start Symbol **S**

- One nonterminal
- Denote the language defined by the grammar

Production **P**

- Specify the manner in which terminals and nonterminals are combined to form strings
- Each production has the format

  nonterminal -> a string of nonterminals and terminals
- One nonterminal can be defined by a list of nonterminals and terminals

Production **P**

- Nonterminal symbols can have more than one distinct definition, representing all possible syntactic forms in the language

<if_stmt> -> if <logic_expr> then <stmt>

<if_stmt> -> if <logic_expr> then <stmt> else <stmt>

Or

<if_stmt> -> if <logic_expr> then <stmt>

| if <logic_expr> then <stmt> else <stmt>

Backus-Naur Form

- Invented by John Backus and Peter Naur to describe syntax of Algol 58/60
- Used to describe the context-free grammars
- A **meta-language**: a language used to describe another language

BNF Rules

- A rule has a left-hand side(LHS), one or more right-hand side (RHS), and consists of **terminal** and **nonterminal** symbols
- For a nonterminal, when there is more than one RHS, there are multiple alternative ways to expand/replace the nonterminal
  - E.g., <stmt> -> <single_stmt>
    | begin <stmt_list> end

BNF Rules

- Rules can be defined using recursion

```
<ident_list> -> ident
                | ident, <ident_list>
```

- Two types of recursion
  - Left recursion:
    - id_list_prefix -> id_list_prefix, id | id
  - Right recursion
    - The above example

How does BNF work?

- It is like a mathematical game:
  - You start with a symbol **S**
  - You are given rules (**P**s) describing how you can replace the symbol with other symbols (**T**s or **N**s)
  - The language defined by the BNF grammar is the set of all terminal strings (**sentences**) you can produce by following these rules

Derivation

- A grammar is a generative device for defining languages
- The sentences of the language are generated through a sequence of rule applications
- The sequence of rule applications is called a **derivation**

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 Exemplar Derivation