Chapter 4

Lexical and Syntax Analysis

Topics

- Introduction
- Lexical Analysis
- Syntax Analysis
- Recursive-Descent Parsing
- Bottom-Up parsing

Language Implementation

- There are three possible approaches to translating human readable code to machine code
  1. Compilation
  2. Interpretation
  3. Hybrid

Compilation

Introduction

- The syntax analysis portion of a language processor nearly always consists of two parts:
  - A low-level part called a *lexical analyzer*
    - Based on a regular grammar.
    - Output: set of tokens.
  - A high-level part called a *syntax analyzer*
    - Based on a context-free grammar or BNF
    - Output: parse tree.

Issues in Lexical and Syntax Analysis

Reasons for separating both analysis:

1) Simpler design.
   - Separation allows the simplification of one or the other.
   - Example: A parser with comments or white spaces is more complex
2) Compiler efficiency is improved.
   - Optimization of lexical analysis because a large amount of time is spent reading the source program and partitioning it into tokens.
3) Compiler portability is enhanced.
   - Input alphabet peculiarities and other device-specific anomalies can be restricted to the lexical analyzer.

Lexical Analyzer

- First phase of a compiler.
- It is also called *scanner.*
- Main task: read the input characters and produce as output a sequence of tokens.
- Process:
  - Input: program as a single string of characters.
  - Collects characters into logical groupings and assigns internal codes to the groupings according to their structure.
    - Groupings: lexemes
    - Internal codes: tokens

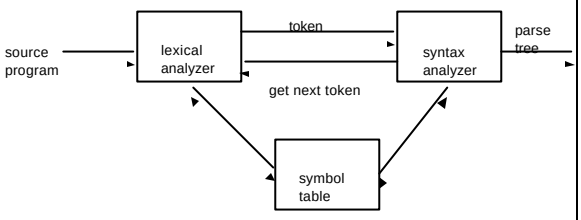
Examples of Tokens

- Example of an assignment

```
result = value / 100;
```

Token	Lexeme
IDENT	result
ASSIGNMENT_OP	=
IDENT	value
DIVISION_OP	/
INT_LIT	100
SEMICOLON	;

Interaction between lexical and syntax analyzers



Lexical Analysis

- Secondary tasks:
  - Stripping out from the source program comments and white spaces in the form of blank, tab, and new line characters.
  - Correlating error messages from the compiler with the source program.
  - Inserting lexemes for user-defined names into the symbol table.

Building a Lexical Analyzer

- Three different approaches:
  - Write a formal description of the tokens and use a software tool that constructs table-driven lexical analyzers given such a description (e,g, lex)
  - Design a state diagram that describes the tokens and write a program that implements the state diagram
  - Design a state diagram that describes the tokens and hand-construct a table-driven implementation of the state diagram

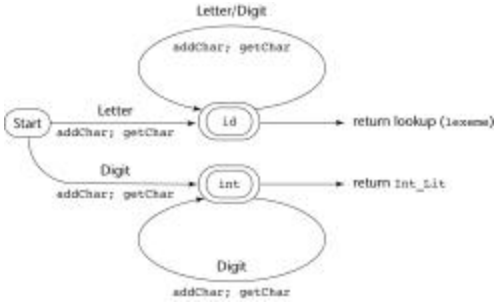
State Transition Diagram

- Directed graph
- Nodes are labeled with state names.
- Arcs are labeled with the input characters that cause the transitions
- An arc may also include actions the lexical analyzer must perform when the transition is taken.
- A state diagrams represent a finite automaton which recognizes regular languages (expressions).

State Diagram Design

- A naive state diagram would have a transition from every state on every character in the source language - such a diagram would be very large.
- In many cases, transitions can be combined to simplify the state diagram
  - When recognizing an identifier, all uppercase and lowercase letters are equivalent
    - Use a character class that includes all letters
  - When recognizing an integer literal, all digits are equivalent - use a digit class

State Diagram: Example



Syntax Analyzer

- The syntax analyzer or *parser* must determine the structure of the sequence of tokens provided to it by the scanner.
- Check the input program to determine whether is syntactically correct.
  - Produce either a complete parse tree of at least trace the structure of the complete parse tree.
  - Error: produce a diagnostic message and recover (gets back to a normal state and continue the analysis of the input program: find as many errors as possible in one pass).

Parser

- Two categories of parsers
  - **Top-down**: produce the parse tree, beginning at the root down to the leaves.
  - **Bottom-up**: produce the parse tree, beginning at the leaves upward to the root.

Conventions

- *Terminal symbols*: lowercase letters at the beginning of the alphabet (a,b,…)
- *Nonterminal symbols*: uppercase letters at the beginning of the alphabet (A,B,…)
- *Terminals or nonterminals*: uppercase letters at the end of the alphabet (W,X,Y,Z)
- *Strings of terminals*: lowercase letters at the end of the alphabet (w,x,y,z)
- *Mixed strings* (terminals and/or nonterminals): lowercase Greek letters ($\alpha,\beta,\delta,\gamma$)

Top-Down Parser

- Build the parse tree in preorder.
  - Begins with the root.
  - Each node is visited before its branches are followed.
  - Branches from a particular node are followed in left-to-right order.
- Uses leftmost derivation.

Next sentential form?

- Given a sentential form *xAa*, *A* is the leftmost nonterminal that could be expanded to get the next sentential form in a leftmost derivation.
  - Current sentential form: *xAa*
  - A-rules: *A? bB*, *A? cBb*, and *A? a*
  - Next sentential form?:
    - *xbBa* or *xcBba* or *xaa*
- This is known as the parsing decision problem for top-down parsers.

Example

<*S*> ::= <*NP*> <*VP*>	<Det> ::= that| this| a
<*S*> ::= <*aux*> <*NP*> <*VP*>	<*Noun*> ::= *book* | *flight* | *meal*
<*S*> ::= <*VP*>	<Verb> ::= book | prefer
<*NP*> ::= <*Proper_Noun*>	<Aux> ::= does
<*NP*> ::= <*Det*> <*Nom*>	<Prep> ::= from | to | on
<*Nom*> ::= <*Noun*>	<Proper_Noun> ::= Houston
<*Nom*> ::= <*Noun*> <*Nom*>	
<*VP*> ::= <*Verb*>	
<*VP*> ::= <*Verb*> <*NP*>	

A miniature English grammar

Example: *"Book that flight"*

- Suppose the parser is able to build all possible partial trees at the same time.
- The algorithm begins assuming that the input can be derived by the designated start symbol *S*.
- The next step is to find the tops of all trees which can start with *S*, by looking for all the grammars rules with *S* on the LHS.
  - There are 3 rules that expand *S*, so the second ply, or level, has 3 partial trees.

Example: *"Book that flight"*

- These constituents of these 3 new trees are expanded in the same way we just expanded *S*; and so on.
- At each ply we use the RHS of the rules to provide new sets of expectations for the parser, which are then used to recursively generate the rest of the tree.
- Trees are grown downward until they eventually reach the terminals at the bottom of the tree.

Example: *"Book that flight"*

- At this point, trees whose leaves fail to match all the words in the input can be rejected, leaving behind those trees that represent successful parses.
- In this example, only the fifth parse tree (the one which has expanded the rule <*VP*> ::= <*Verb*><*NP*>) will eventually match the input sentence.

Top-Down Parser

- Parsers look only one token ahead in the input
  - Given a sentential form, xAα , the parser must choose the correct A-rule to get the next sentential form in the leftmost derivation, using only the first token produced by A
- The most common top-down parsing algorithms:
  - Recursive descent - a coded implementation
  - LL parsers - table driven implementation

Bottom-Up Parser

- Bottom-up parsing is the earliest know parsing algorithm.
- Build the parse tree beginning at the leaves and progressing towards the root.
- Order corresponds to the reverse of a rightmost derivation.
  - The parse is successful if the parser succeeds in building a tree rooted in the start symbol that covers all of the input.

Example: *"Book that flight"*

- The parse beginning by looking to each word and building 3 partial trees with the category of each terminal.
  - The word *book* is ambiguous (it can be a noun or a verb). Thus the parser must consider two possible sets of trees.
  - Each of the trees in the second ply is then expanded, and so on.

Example: *"Book that flight"*

- In general, the parser extends one ply to the next by looking for places in the parse-in-progress where the right-hand-side of some rule might fit.
- In the fifth ply, the interpretation of *book* as a noun has been pruned because this parse cannot be continued: there is no rule in the grammar with RHS <*Nominal*><*NP*>
- The final ply is the correct parse tree.

- The most common bottom-up parsing algorithms are in the LR family

Top-Down vs. Bottom-Up

- Advantage (top-down)
  - Never waste time exploring trees that cannot result in the root symbol (*S*), since it begins by generating just those trees.
  - Never explores subtrees that cannot find a place in some S-rooted tree
  - Bottom-up: left branch is completely wasted effort because it is based on interpreting *book* as *Noun* at the beginning of the sentence despite the fact no such tree can lead to an *S* given this grammar.

Top-Down vs. Bottom-Up

- Disadvantage (top-down)
  - Spend considerable effort on *S* trees that are not consistent with the input.
  - Firsts four of six trees in the third ply have left branches that cannot match the word *book*.
  - This weakness arises from the fact that they can generate trees before ever examining the input.