The Role of Lexical Analyzer

Compiler Design Lexical Analysis

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Outline

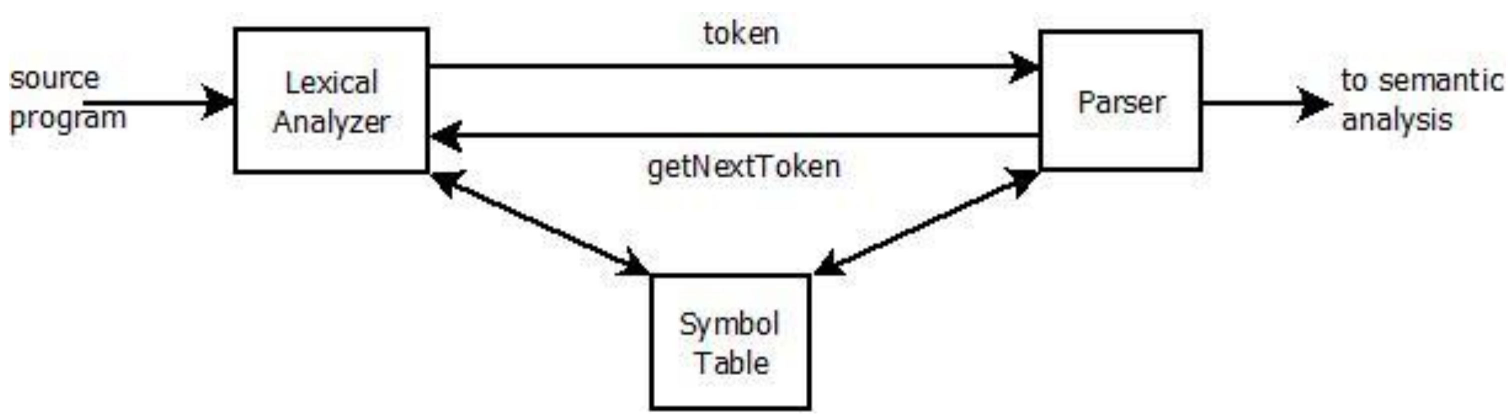
- Lexical Analysis vs. Parsing
- Tokens, Patterns and Lexemes
- Attributes for Tokens
- Lexical Errors

Lexical Analysis

- Manual approach – by hand
  - To identify the occurrence of each lexeme
  - To return the information about the identified token
- Automatic approach - lexical-analyzer generator
  - Compiles lexeme patterns into code that functions as a lexical analyzer
  - e.g. Lex, Flex, …
  - Steps
    - Regular expressions - notation for lexeme patterns
    - Nondeterministic automata
    - Deterministic automata
    - Driver - code which simulates automata

The Role of the Lexical Analyzer

- Read input characters
- To group them into lexemes
- Produce as output a sequence of tokens
  - input for the syntactical analyzer
- Interact with the symbol table
  - Insert identifiers



The Role of the Lexical Analyzer

- to strip out
  - comments
  - whitespaces: blank, newline, tab, …
  - other separators
- to correlate error messages generated by the compiler with the source program
  - to keep track of the number of newlines seen
  - to associate a line number with each error message

Lexical Analyzer Processes

- Scanning
  - to not require input tokenization
  - deletion of comments
  - compaction of consecutive white spaces into one
- Lexical analysis
  - to produce sequence of tokens as output

Lexical Analysis vs. Parsing

- Simplicity of design
  - Separation of lexical from syntactical analysis -> simplify at least one of the tasks
  - e.g. parser dealing with white spaces -> complex
  - Cleaner overall language design
- Improved compiler efficiency
  - Liberty to apply specialized techniques that serves only lexical tasks, not the whole parsing
  - Speedup reading input characters using specialized buffering techniques
- Enhanced compiler portability
  - Input device peculiarities are restricted to the lexical analyzer

Tokens, Patterns, Lexemes

- Token - pair of:
  - token name – abstract symbol representing a kind of lexical unit
    - keyword, identifier, …
  - optional attribute value
- Pattern
  - description of the form that the lexeme of a token may take
  - e.g.
    - for a keyword the pattern is the character sequence forming that keyword
    - for identifiers the pattern is a complex structure that is matched by many strings
- Lexeme
  - a sequence of characters in the source program matching a pattern for a token

Examples of Tokens

Token	Informal Description	Sample Lexemes
if	characters i, f	if
else	characters e, l, s, e	else
comparison	< or > or <= or >= or == or !=	<=, !=
id	Letter followed by letters and digits	pi, score, D2
number	Any numeric constant	3.14159, 0, 02e23
literal	Anything but “, surrounded by “	“core dumped”

Examples of Tokens

- One token for each keyword
  - Keyword pattern = keyword itself
- Tokens for operators
  - Individually or in classes
- One token for all identifiers
- One or more tokens for constants
  - Numbers, literal strings
- Tokens for each punctuation symbol
  - ( ) , ;

Attributes for Tokens

- more than one lexeme can match a pattern
- token **number** matches 0, 1, 100, 77,…
- lexical analyzer must return
  - Not only the token name
  - Also an attribute value describing the lexeme represented by the token
- token **id** may have associated information like
  - lexeme
  - type
  - location – in order to issue error messages
- token **id** attribute
  - pointer to the symbol table for that identifier

Tricky Problems in Token Recognition

- Fortran 90 example
  - assignment

DO 5 I = 1.25

DO5I = 1.25

  - do loop

DO 5 I = 1,25

Example of Attribute Values

- E = M * C ** 2
  - <id, pointer to symbol table entry for E>
  - <assign_op>
  - <id, pointer to symbol-table entry for M>
  - <mult_op>
  - <id, pointer to symbol-table entry for C>
  - <exp_op>
  - <number, integer value 2>

Lexical Errors

- can not be detected by the lexical analyzer alone
  - fi (a == f(x)) …
- lexical analyzer is unable to proceed
  - none of the patterns matches any prefix of the remaining input
  - “panic mode” recovery strategy
    - delete one/successive characters from the remaining input
    - insert a missing character into the remaining input
    - replace a character
    - transpose two adjacent characters

Outline

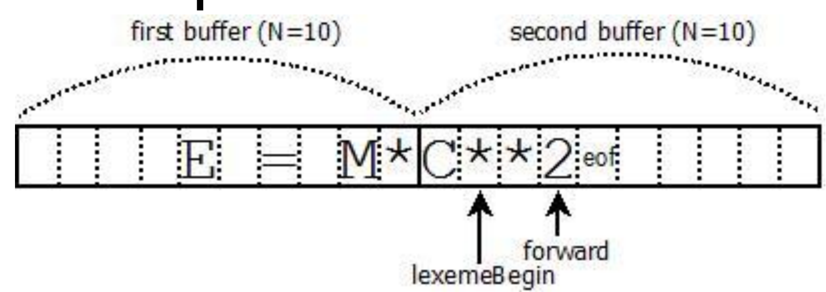
- Input Buffering
  - Buffer Pairs
  - Sentinels

Input Buffering

- How to speed the reading of source program ?
- to look one additional character ahead
- e.g.
  - to see the end of an **identifier** you must see a character
    - which is not a letter or a digit
    - not a part of the lexeme for **id**
  - in C
    - - ,= , <
    - ->, ==, <=
- two buffer scheme that handles large lookaheads safely
- sentinels – improvement which saves time checking buffer ends

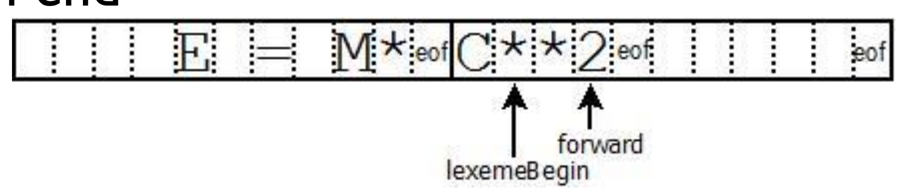
Buffer Pairs

- Buffer size N
- N = size of a disk block (4096)
- read N characters into a buffer
  - one system call
  - not one call per character
- read < N characters we encounter **eof**
- two pointers to the input are maintained
  - *lexemeBegin* – marks the beginning of the current lexeme
  - *forward* – scans ahead until a pattern match is found



Sentinels

- *forward* pointer
  - to test if it is at the end of the buffer
  - to determine what character is read (multiway branch)
- sentinel
  - added at each buffer end
  - can not be part of the source program
  - character **eof** is a natural choice
    - retains the role of entire input end
    - when appears other than at the end of a buffer it means that the input is at an end



Lookahead Code with Sentinels

```
switch(*forward++)
{
    case eof:
            if(forward is at the end of the first buffer)
            {
                        reload second buffer;
                        forward = beginning of the second buffer;
            }
            elseif(forward is at the end of the second buffer)
            {
                        reload first buffer;
                        forward = beginning the first buffer;
            }
            else
            /* eof within a buffer marks the end of input */
                        terminate lexical analysis;
            break;
    cases for the other characters
}
```

Potential Problems

- usually
  - lexemes are short
  - 1-2 characters lookahead are sufficient
- problem: running out of buffer space
  - when N = 3,4,5 x 1000
  - long character strings > N
- solution: concatenation of string components by grammar rules (like in Java using the + operator to catenate multiline strings)
- long lookahead
  - languages where keywords are not reserved
  - in PL/I:
    - DECLARE (ARG1,ARG2,…)
    - ambiguous identifier resolved by the parser (keyword or procedure name)

Bibliography

- Alfred V. Aho, Monica S. Lam, Ravi Sethi, Jeffrey D. Ullman – Compilers, Principles, Techniques and Tools, Second Edition, 2007