CS412/413

Introduction to Compilers
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Lecture 4: Lexical Analyzers
30 Jan 06

Finite Automata

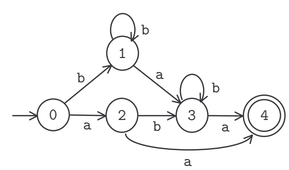
- Finite automata:
  - States, transitions between states
  - Initial state, set of final states
- DFA = deterministic
  - Each transition consumes an input character
  - Each transition is uniquely determined by the input character
- NFA = non-deterministic
  - ε-transitions, multiple transitions from the same state on the same input character

From RE to DFA

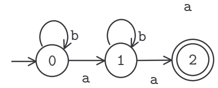
- Two steps:
  - Convert the regular expression to an NFA
  - Convert the resulting NFA to a DFA
- The generated DFAs may have a large number of states
- State Minimization = optimization that converts a DFA to another DFA that recognizes the same language and has a minimum number of states

State Minimization

- Example:
  - DFA1:



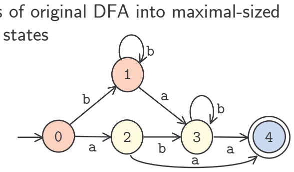
  - DFA2:



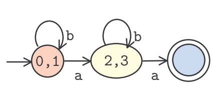
  - Both DFAs accept: `b*ab*a`

State Minimization

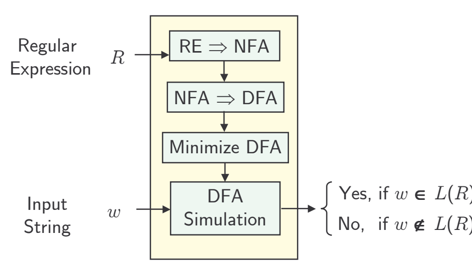
- Step1. Partition states of original DFA into maximal-sized groups of "equivalent" states
  $S = G_1 \cup \ldots \cup G_n$



- Step 2. Construct the minimized DFA such that there is a state for each group G_i



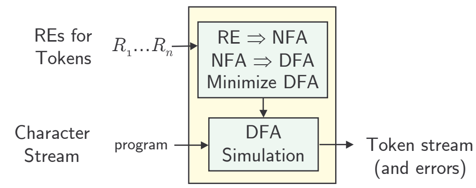
Optimized Acceptor



Lexical Analyzers vs Acceptors

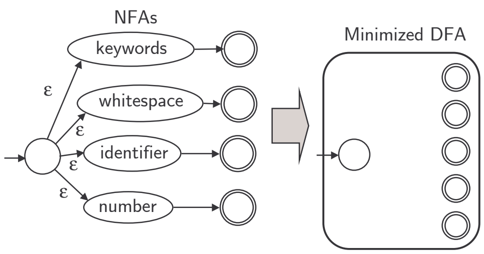
- Lexical analyzers use the same mechanism, but they:
  - Have multiple RE descriptions for multiple tokens
  - Return a sequence of matching tokens at the output (or an error)
  - Always return the longest matching token
  - For multiple longest matching tokens use rule priorities

Lexical Analyzers



Handling Multiple REs

- Combine the NFAs of all the regular expressions into a single finite automata

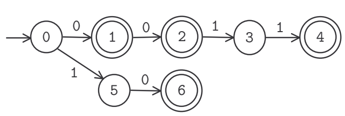


Lexical Analyzers

- Token stream at the output
  - Associate tokens with final states
  - Output the corresponding token when reaching a final state
- Longest match
  - When in a final state, look if there is a further transition; otherwise return the token for the current final state
- Rule priority
  - Same longest matching token when there is a final state corresponding to multiple tokens
  - Associate that final state to the token with the highest priority

Longest Matching Sequence

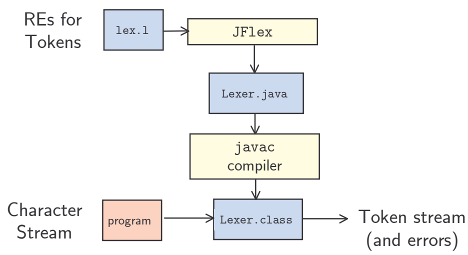
- Problem: lexer goes past a final state of a short token, but then doesn't find a longer matching token
- Consider $R = 0 \mid 00 \mid 10 \mid 0011$ and input: 0010



Automating Lexical Analysis

- All of the lexical analysis process can be automated !
  - RE → NFA → DFA → Minimized DFA
  - Minimized DFA → Lexical Analyzer (DFA Simulation Program)
- We only need to specify:
  - Regular expressions for the tokens
  - Rule priorities for multiple longest match cases

Lexical Analyzer Generators



JFlex Specification File

- JFlex = Lexical analyzer generator
  - written in Java
  - generates a Java lexical analyzer
- Has three parts:
  - Preamble, which contains package/import declarations
  - Definitions, which contains regular expression abbreviations
  - Regular expressions and actions, which contains:
    - the list of regular expressions for all the tokens
    - Corresponding actions for each token (Java code to be executed when the token is returned)

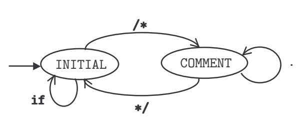
Example Specification File

```
package FrontEnd;
import Error.LexicalError;
%%
digits = 0|[1-9][0-9]*
letter = [A-Za-z]
identifier = {letter}({letter}|[0-9_])*
whitespace = [ \t\n\r]+
%%
{whitespace} { /* discard */ }
{digits}     { return new Token(INT,
                                  Integer.valueOf(yytext()); }
“if”         { return new Token(IF, null); }
“while”      { return new Token(WHILE, null); }
{identifier} { return new Token(ID, yytext()); }
.            { throw new LexicalError(“illegal character"); }
```


Start States

- Mechanism that specifies state in which to start the execution of the DFA
- Define states in the second section
  - `%state STATE`
- Use states as prefixes of regular expressions in the third section:
  - `<STATE> regex {action}`
- Set current state in the actions
  - `yybegin(STATE)`
- There is a pre-defined initial state: `YYINITIAL`

Example




```
%state COMMENT
%%
<YYINITIAL> “/*”   { yybegin(COMMENT); }
<COMMENT>   “*/”   { yybegin(YYINITIAL); }
<COMMENT>    .     { }
```


Start States and REs

- The use of states allow the lexer to recognize more than regular expressions
  - Reason: the lexer can jump across different states in the semantic actions using `yybegin(STATE)`
- Example: nested comments
  - Increment a global variable on open parentheses and decrement it on close parentheses
  - When the variable gets to zero, jump to `YYINITIAL`
  - This models an infinite number of states

Conclusion

- The way lexical analyzers work:
  - Convert REs to NFA
  - Convert NFA to DFA
  - Minimize DFA
  - Use the minimized DFA to recognize tokens in the input
  - Use priorities, longest matching rule
- Lexical analyzer generators automate the process
  - Programmer writes regular expression descriptions of tokens
  - Automatically gets a lexical analyzer program that reads characters from the input stream and generates tokens