CS412/413

Introduction to Compilers
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Lecture 4: Lexical Analyzers
28 Jan 08

Outline

- DFA state minimization
- Lexical analyzers
- Automating lexical analysis
- Jlex lexical analyzer generator

Finite Automata

- Finite automata:
  - States, transitions between states
  - Initial state, set of final states
- DFA: Deterministic Finite Automaton
  - Each transition consumes an input character
  - Each transition is uniquely determined by the input character
- NFA: Non-deterministic Finite Automaton
  - ε-transitions, which do not consume input characters
  - Multiple transitions from the same state on the same input character

From RE to DFA

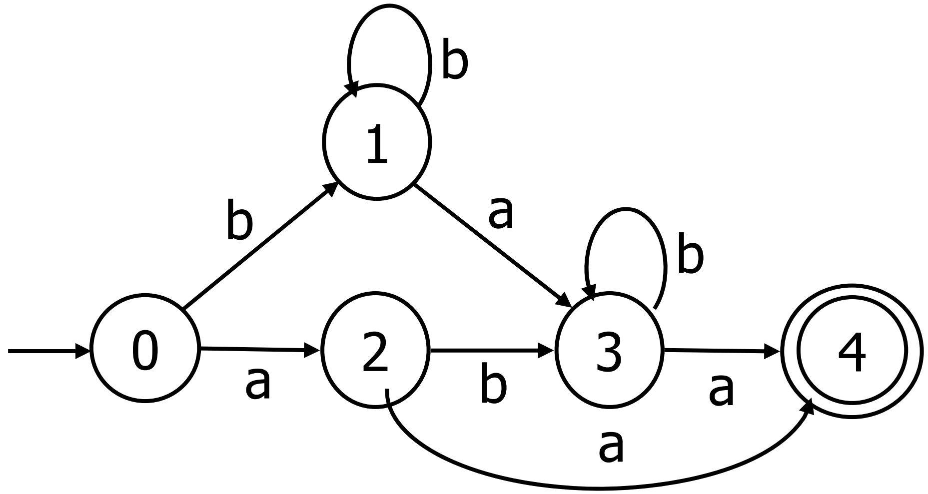
- Two steps:
  - Convert the regular expression to an NFA
  - Convert the resulting NFA to a DFA

- The generated DFAs may have a large number of states

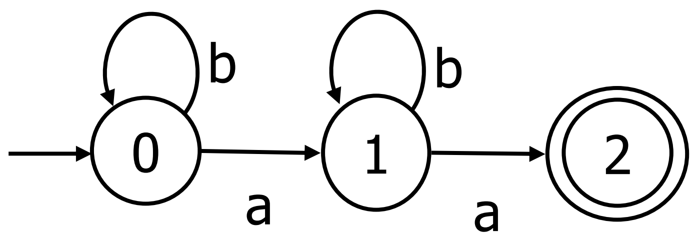
- State Minimization is an optimization that converts a DFA to another DFA that recognizes the same language and has a minimum number of states

State Minimization

- Example:
  - DFA1:



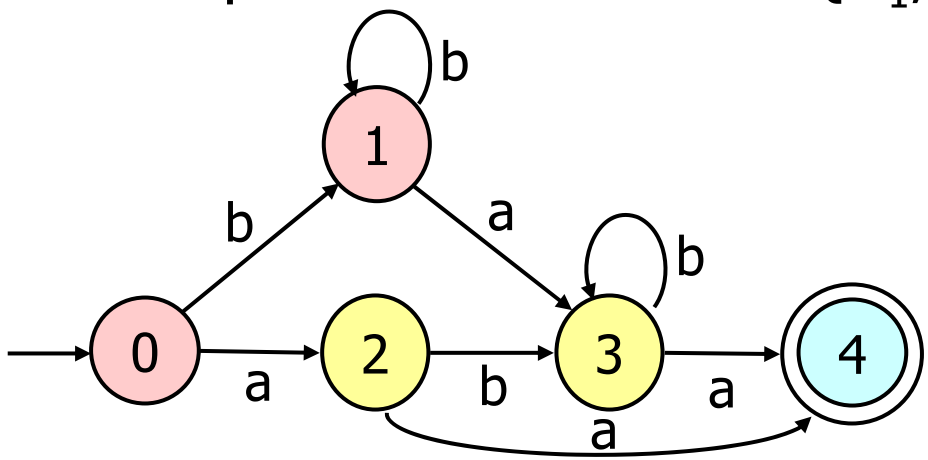
  - DFA2:



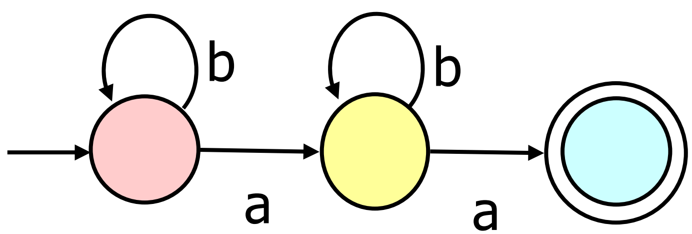
  - Both DFAs accept: b*ab*a

State Minimization

- Step1. Partition states of original DFA into maximal-sized groups of “equivalent” states $S = \{G_1, \ldots, G_n\}$

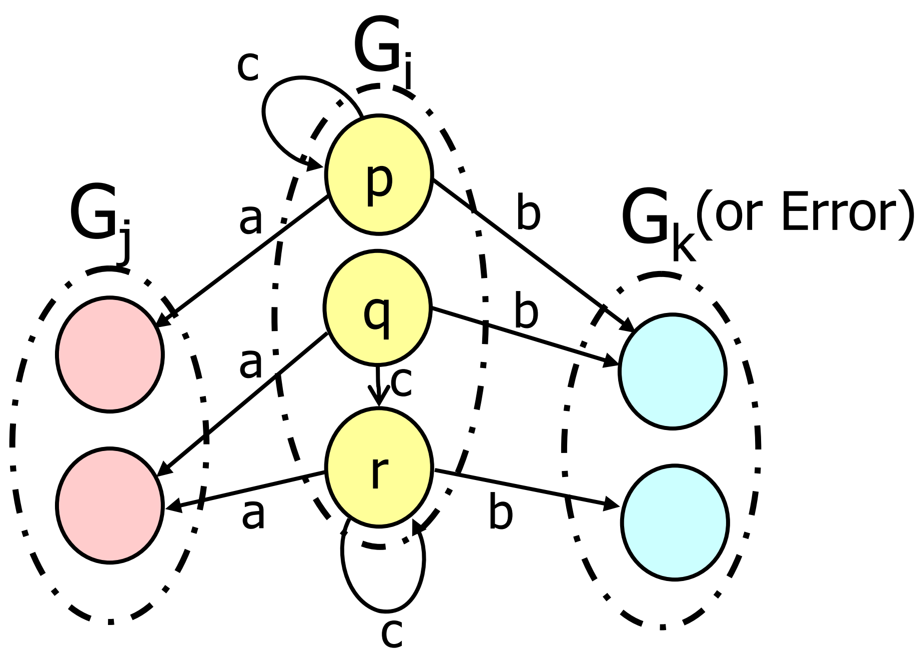


- Step 2. Construct the minimized DFA such that there is a state for each group G_i



DFA Minimization (Equivalence)

- All states in group G_i are equivalent iff for any two states p and q in G_i, and for every symbol σ, transition(p,σ) and transition(q,σ) are either both Error, or are states in the same group G_j (possibly G_i itself).



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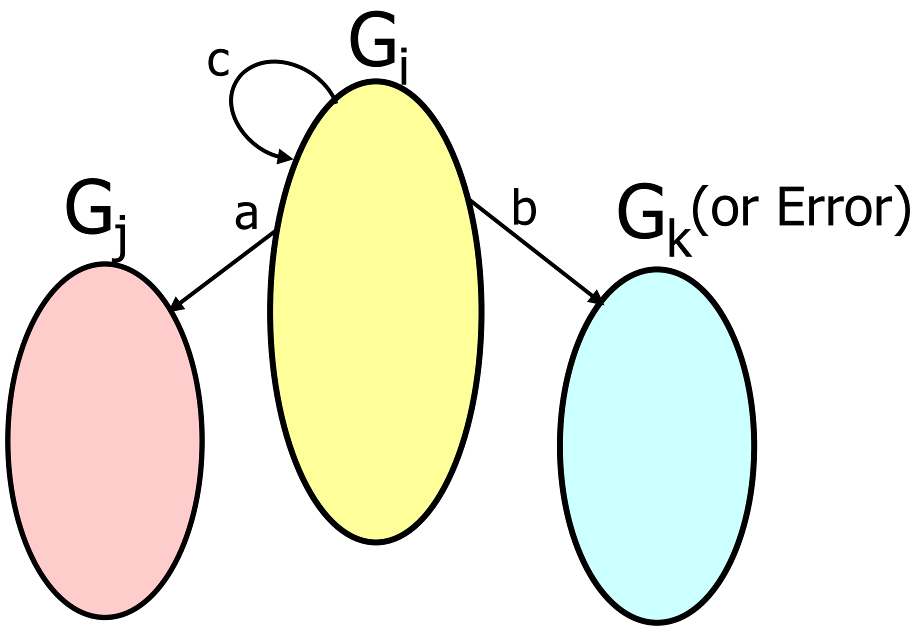
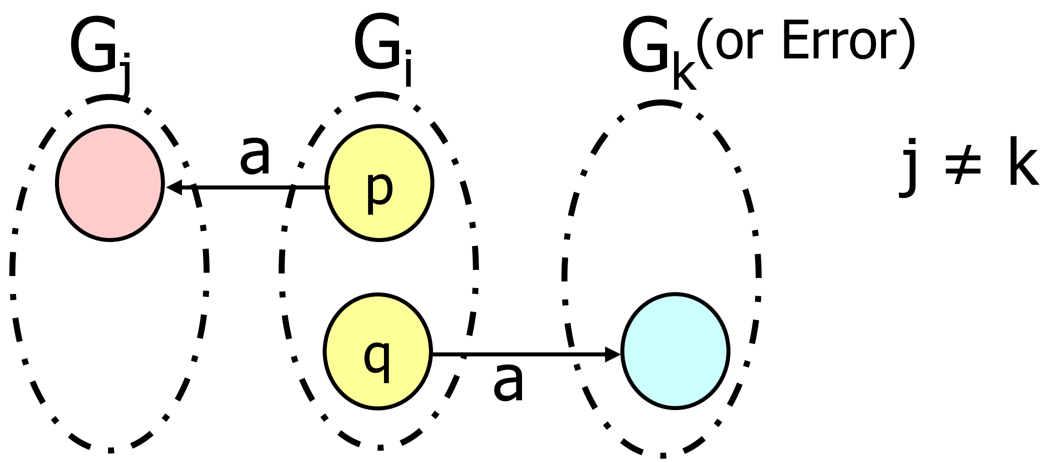


DFA Minimization

- Step1. Partition states of original DFA into maximal-sized groups of equivalent states
  - Step 1a. Discard states not reachable from start state
  - Step 1b. Initial partition is S = {Final, Non-final}
  - Step 1c. Repeatedly refine the partition $\{G_1,\ldots,G_n\}$ while some group G_i contains states p and q such that for some symbol σ, transitions from p and q on σ are to different groups



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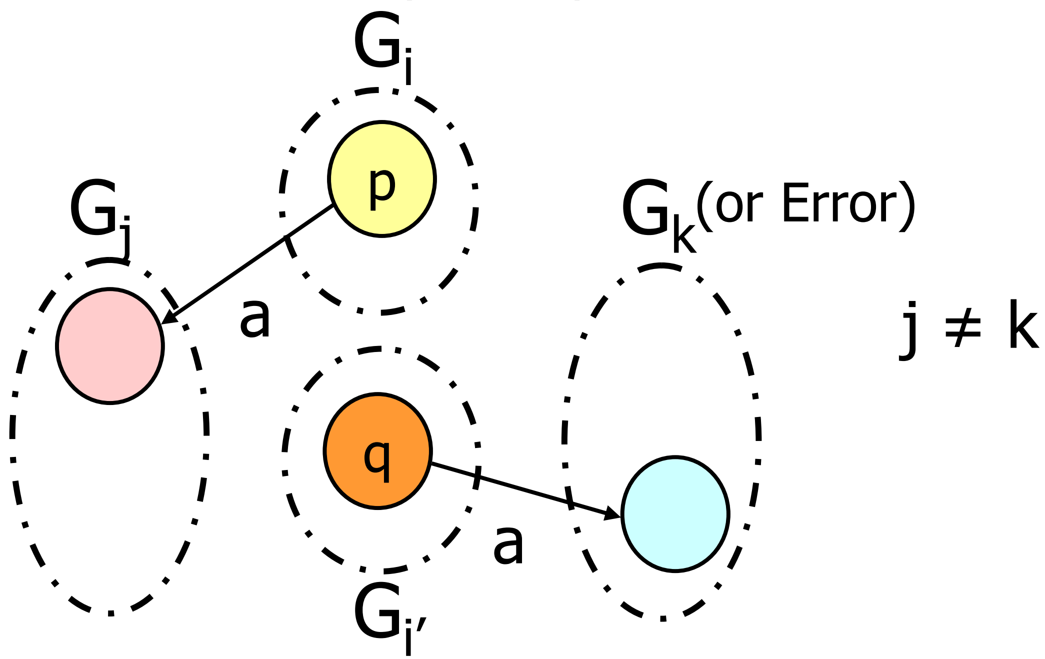
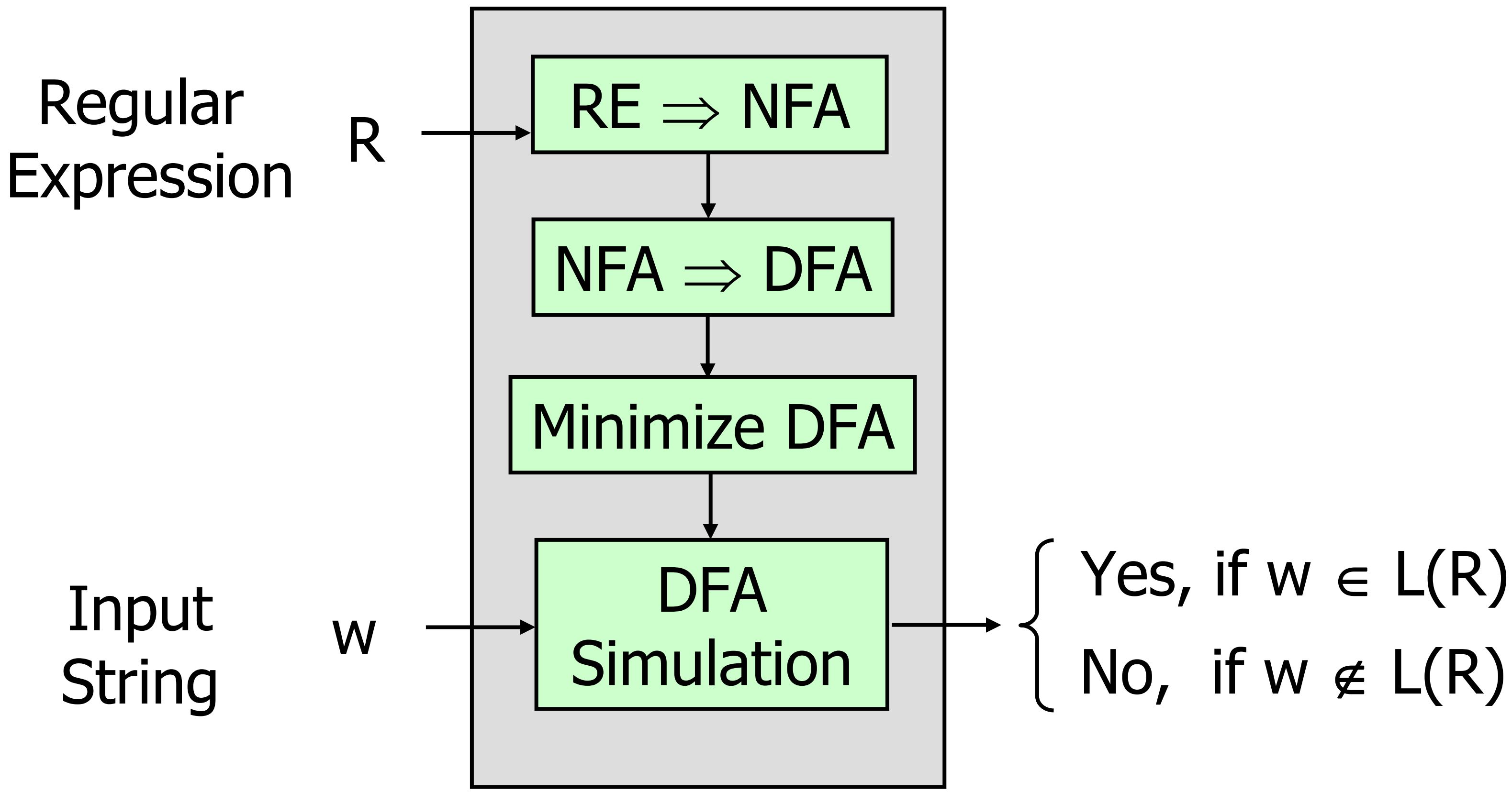


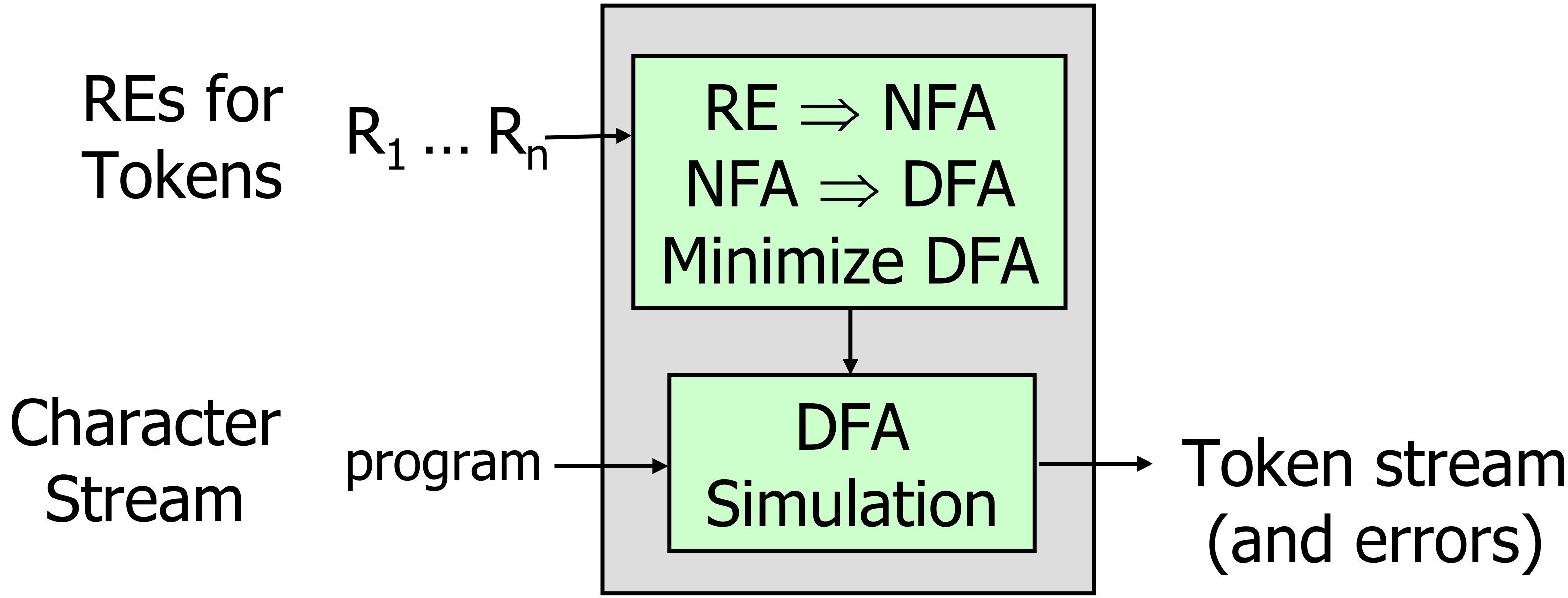
Optimized Acceptor



Lexical Analyzers vs Acceptors

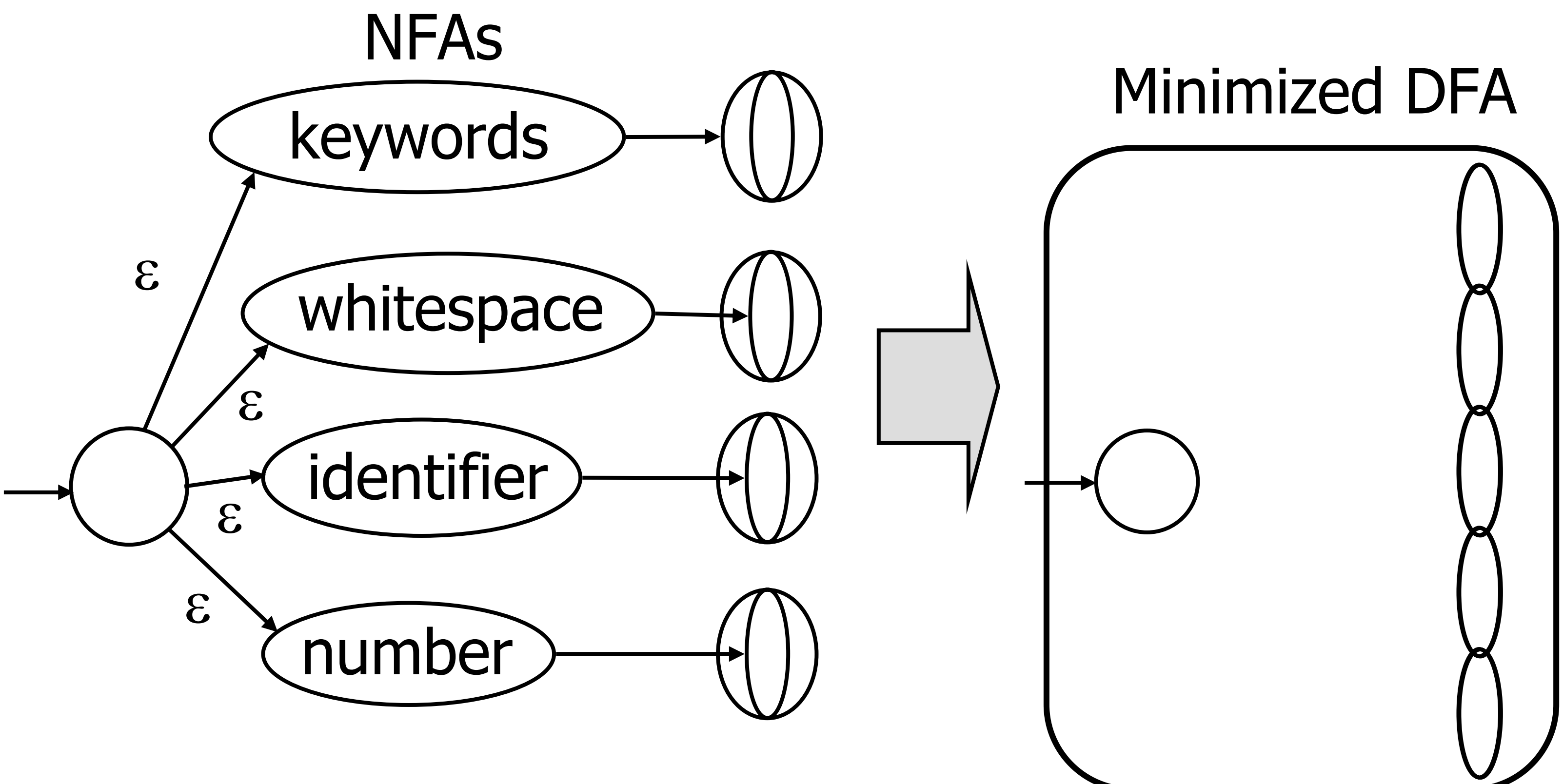
- Lexical analyzers use the same mechanism, but they:
  - Have multiple RE descriptions for multiple tokens
  - Output a sequence of matching tokens (or an error)
  - Always return the longest matching token
  - For multiple longest matching tokens, use rule priorities

Lexical Analyzers



Handling Multiple REs

- Construct one NFA for each RE
- Associate the final state of each NFA with the given RE
- Combine NFAs for all REs into one NFA
- Convert NFA to minimized DFA, associating each final DFA state with the highest priority RE of the corresponding NFA states

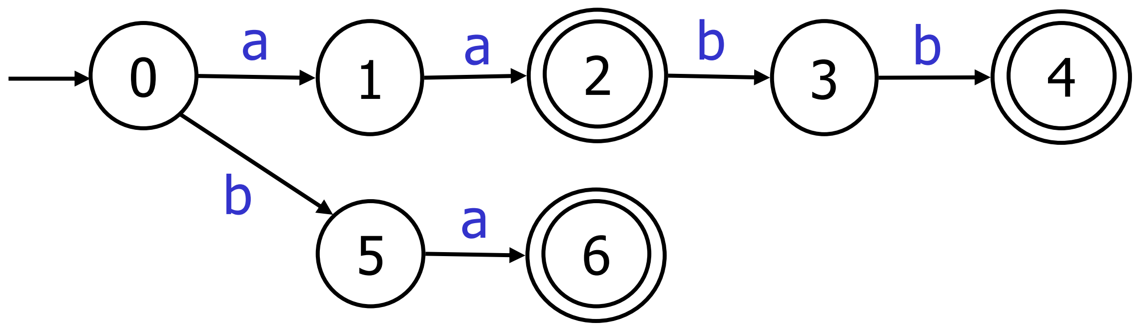


Scanning Algorithm

- Scan input and simulate DFA until no further transition is possible keeping track of most recently visited final state F
- Roll input back to position at the time F was entered
- Emit token associated with F
- For each successive token, scan remaining input and simulate DFA from the start state, i.e., scanner is “stateless” (NB. this is to be changed below.)

Example of Roll Back

Consider three REs: {aa ba aabb] and input: aaba



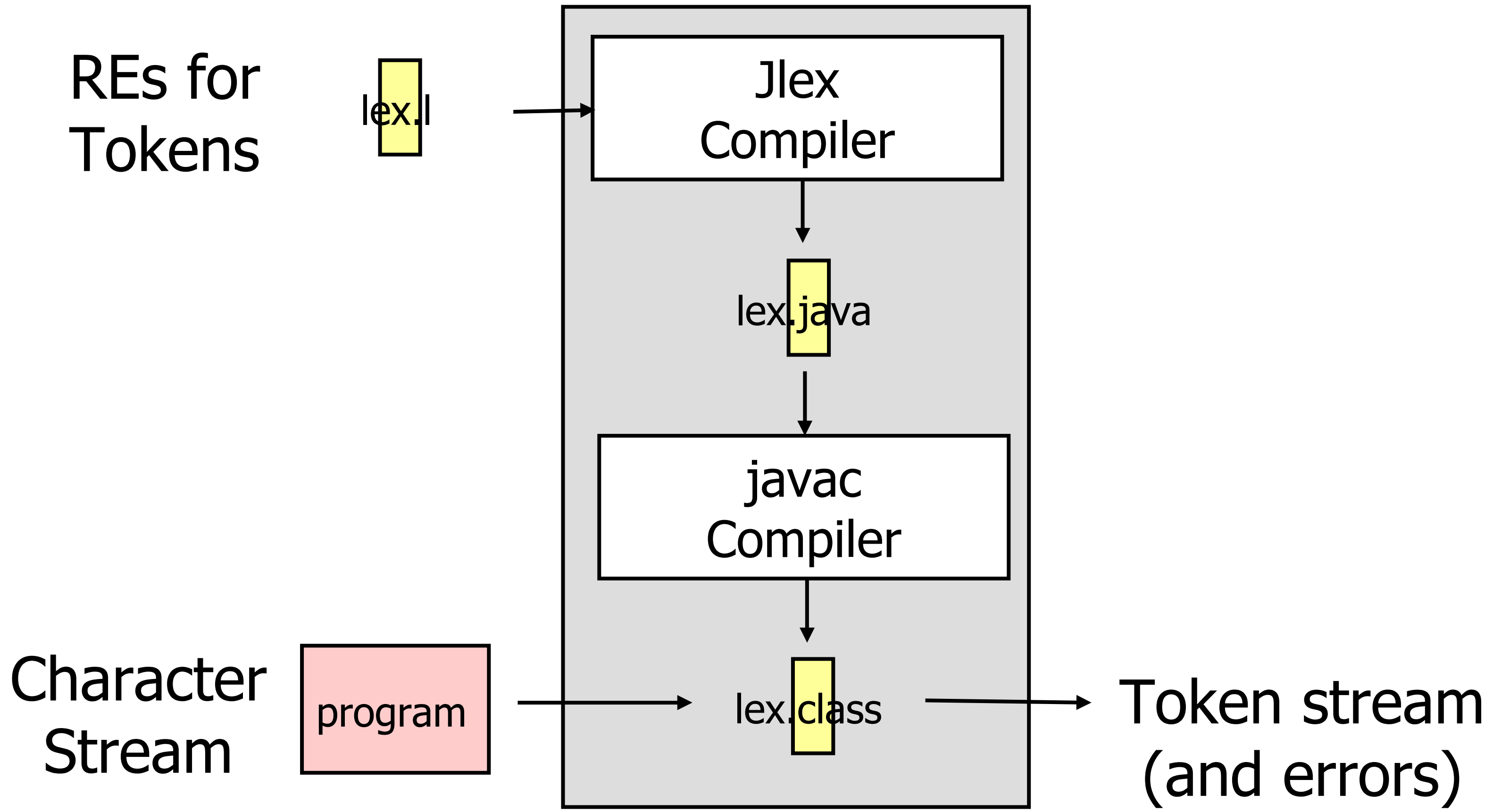
- Reach state 3 with no transition on next character a
- Roll input back to position on entering state 2 (i.e., having read aa)
- Emit token for aa
- On next call to scanner, start in state 0 again with input ba

Automating Lexical Analysis

- All of the lexical analysis process can be automated
  - RE $\rightarrow$ NFA $\rightarrow$ DFA $\rightarrow$ Minimized DFA
  - Minimized DFA $\rightarrow$ 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



Jlex Specification File

- Jlex = 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 recognized)

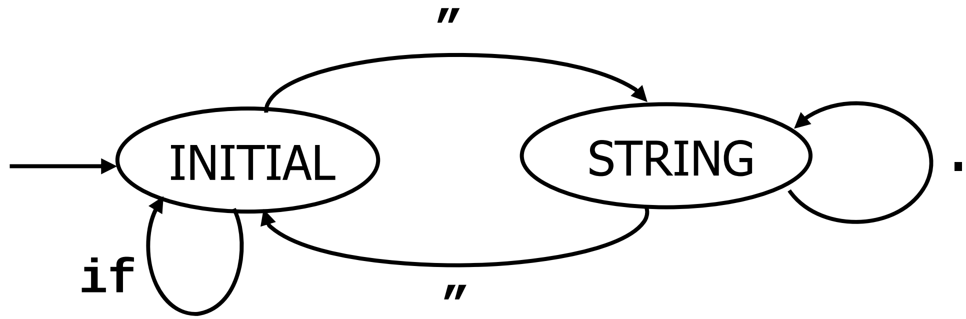
Example Specification File

```
Package Parse;
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()); }
.              { ErrorMsg.error(“illegal character”); }
```

Start States

- Mechanism that specifies state in which to start the execution of the DFA
- Declare 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 STRING
%%
<YYINITIAL> “if”     { return new Token(IF, null); }
<YYINITIAL> “\””     { yybegin(STRING); … }
<STRING>    “\””     { yybegin(YYINITIAL); … }
<STRING>      .      { … }
```

Start States and REs

- The use of start states allows the lexer to recognize more than regular expressions (or DFAs)
  - 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
  - The global variable essentially models an infinite number of states!

Conclusion

- Regular expressions: concise way of specifying tokens
- Can convert RE to NFA, then to DFA, then to minimized DFA
- Use the minimized DFA to recognize tokens in the input stream
- Automate the process using lexical analyzer generators
  - Write regular expression descriptions of tokens
  - Automatically get a lexical analyzer program which identifies tokens from an input stream of characters