CS 442/542

Lexical Analysis
Scanning

Simplified Compiler Organization

- Scanning
- Parsing
- Code Generation

Lexical Analysis

- Languages
- Finite State Automata (FSA)
- Regular Expressions (RE)
- Algorithms

Languages

- Given an finite alphabet ∑ a language is a set of strings where each string is a finite sequence of 0 of more symbols for the alphabet
- Example alphabets
  - {0, 1}
  - {a,b,c,d,e,f,g,h,i,j,k,l,m,n,o,p,q,r,s,t,u,v,w,x,y,z}

Languages

- Example languages over {0, 1}
  - {00, 01, 10, 11}
  - {0, 01, 011, 0111 …}
  - {ϵ, 1, 11, 111, 1111 …}
    - ϵ is the empty string
  - { }
  - {ϵ }
    - The empty set and a set containing the empty string are different

Languages

- In this class we are interested in the languages that are used to define programming languages
- There a two primary types of languages we will look at
  - Regular languages
  - Context free languages
- For the two types of languages we will look at notations to specify the language and at abstract machines to recognize strings in the languages

Definition of a Regular Expression (RE)

- R is a regular expression if R is one of the following
  - 1. a for some a in the alphabet Σ
  - 2. ϵ
  - 3. $\varnothing$
  - 4. if R and S are regular expressions then R | S is a regular expression
  - 5. if R and S are regular expressions then R S is a regular expression
  - 6. if R is a regular expression then R^*

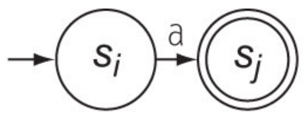
Example Regular Expressions over the alphabet {0, 1}

Regular Expression	**Language**
0	{ 0 }
0 | 1	{0, 1}
0 (0 | 1)	{00, 01}
1*	{ x | x is a string of 0 or more 1s}
(0 | 1) *	{ x | x is any string of 0s and 1s including the empty string}
0*(10*10*)*	{ x | x is a string with an even number of 1s}

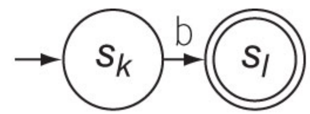
Definition of a Non-deterministic finite automata (NFA)

- A nondeterministic finite automaton is a 5 tuple $(S, \Sigma, \delta, s_0, S_A)$ where
  - 1. S is a finite set of states
  - 2. Σ is a finite set of symbols called an alphabet
  - 3. $\delta: S \times \Sigma \cup \{\epsilon\} \rightarrow P(S)$ is the transition function
  - 4. $s_0 \in S$ is the start state
  - 5. $S_A \subseteq S$ is the set of final or accept states

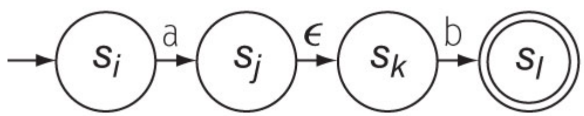
Example NFAs



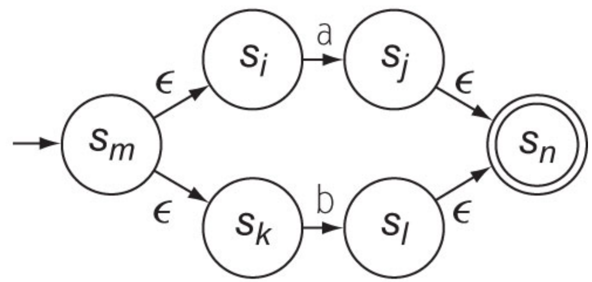
(a) NFA for "*a*"



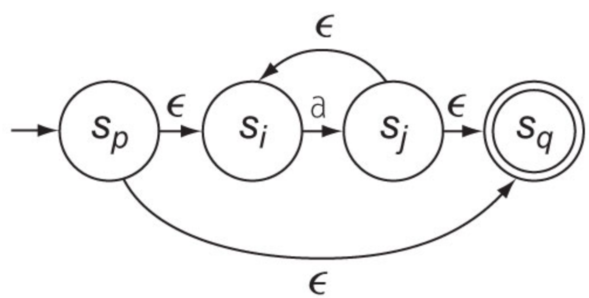
(b) NFA for "*b*"



(c) NFA for "*ab*"

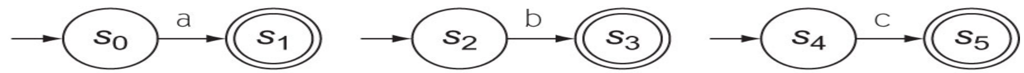


(d) NFA for "*a* | *b*"

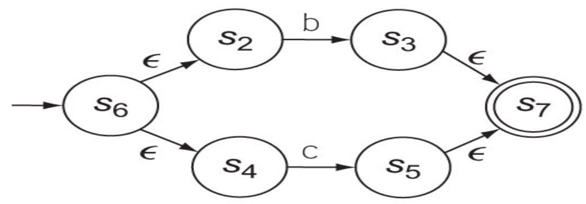


(e) NFA for "*a*∗"

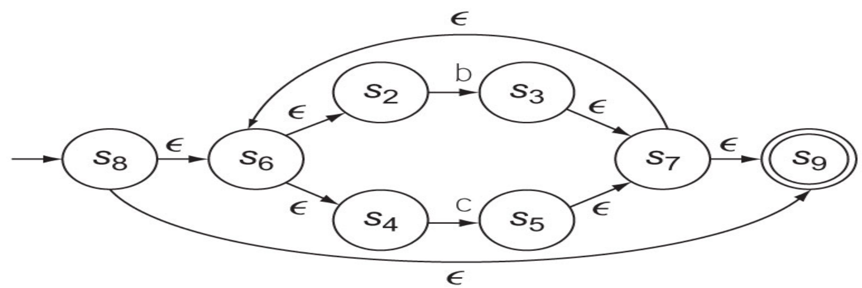
Example NFAs



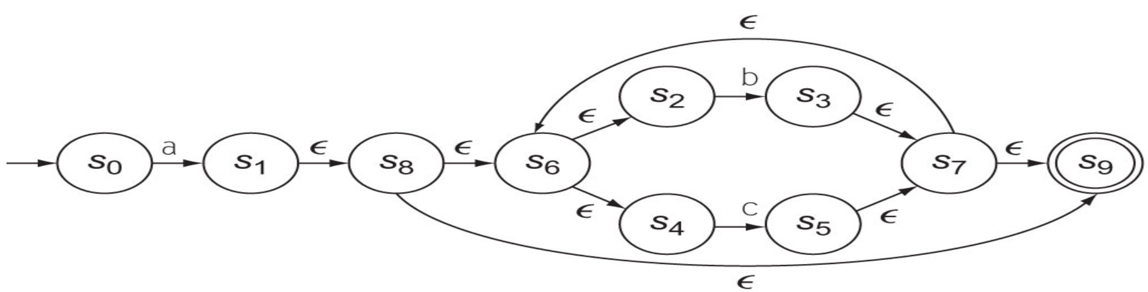
(a) NFAs for "*a*", "*b*", and "*c*"



(b) NFA for "*b* | *c*"

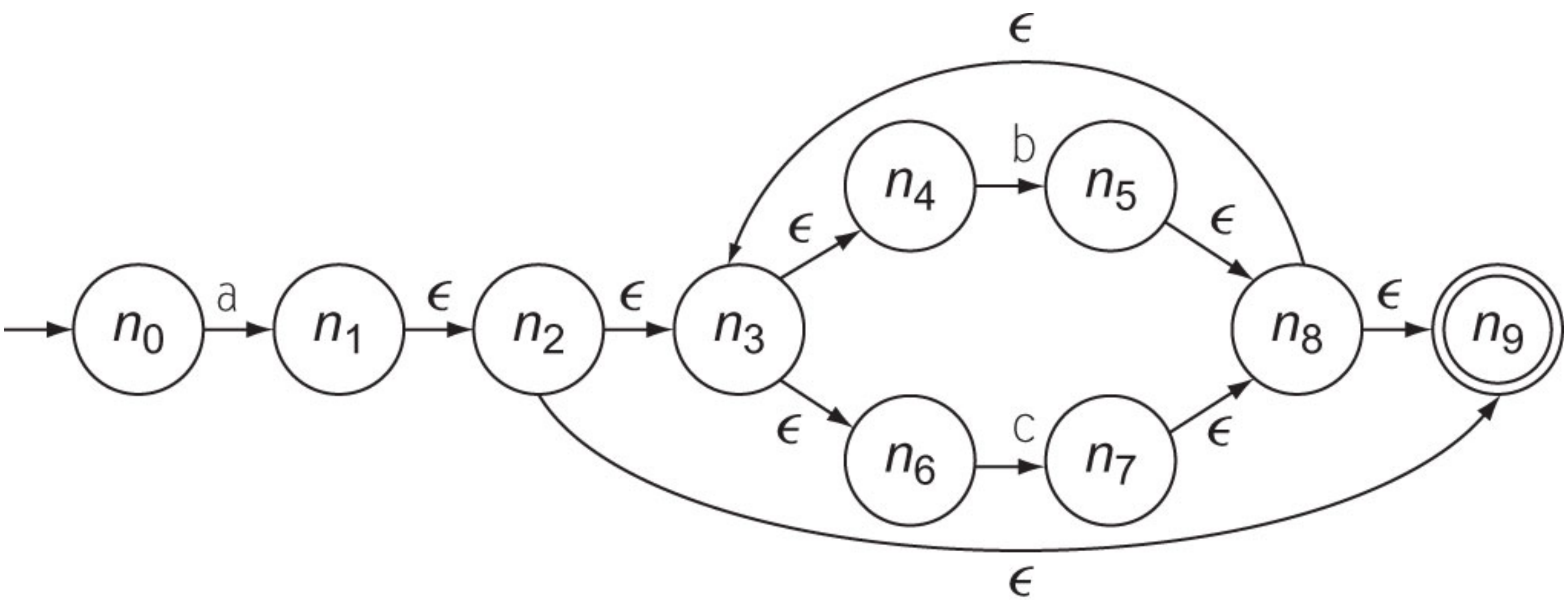


(c) NFA for "(*b* | *c*)*"



(d) NFA for "*a*(*b* | *c*)*"

Example NFAs

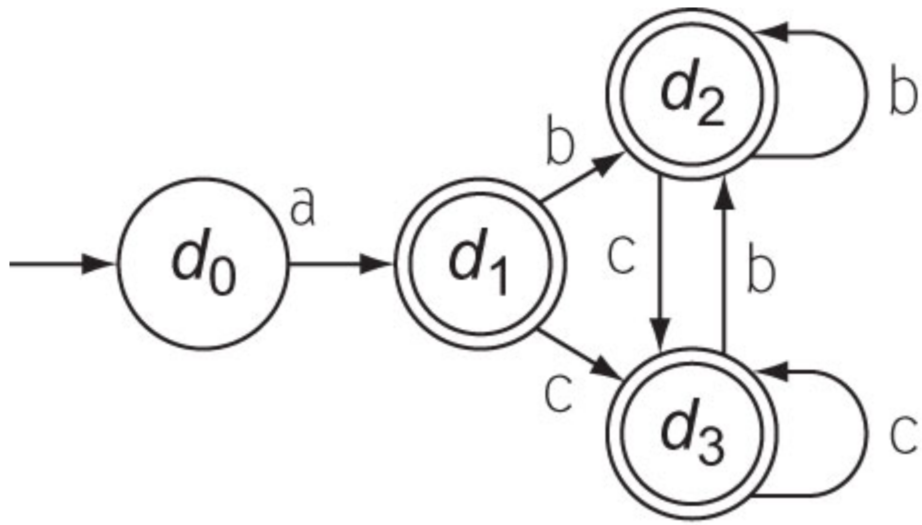


(a) NFA for "$a(b \mid c)^*$" (With States Renumbered)

Definition of a Deterministic finite automata (DFA)

- A deterministic finite automaton is a 5 tuple $(S, \Sigma, \delta, s_0, S_A)$ where
  - 1. S is a finite set of states
  - 2. Σ is a finite set of symbols called an alphabet
  - 3. $\delta: S \times \Sigma \to S$ is the transition function
  - 4. $s_0 \in S$ is the start state
  - 5. $S_A \subseteq S$ is the set of final or accept states

Example DFA



(a) Resulting DFA

DFA

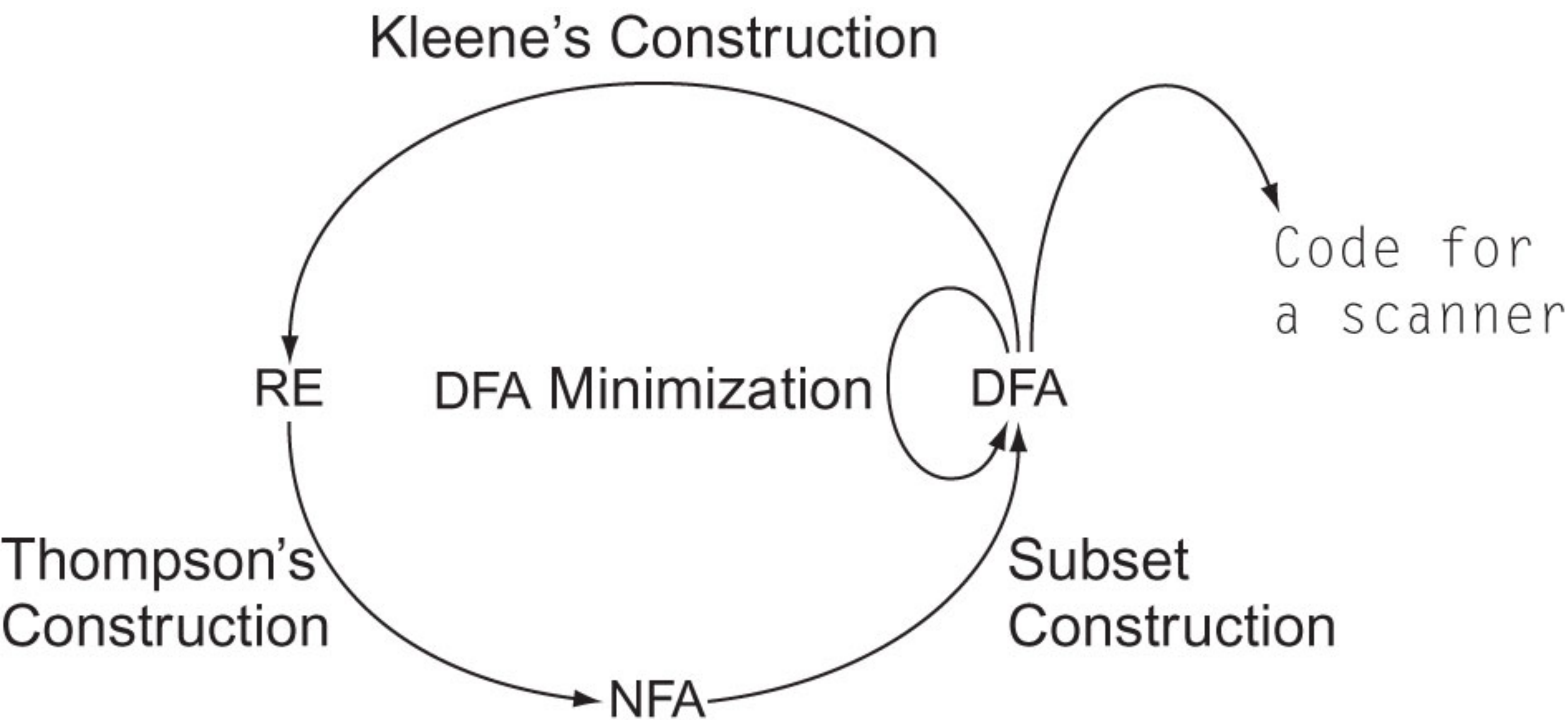
$(S, \Sigma, \delta, s_0, S_A)$

- $S = \{d_0, d_1, d_2, d_3\}$
- $\Sigma = \{a, b, c\}$
- $\delta = \{ (d_0, a, d_1), (d_1, b, d_2), (d_1, c, d_3), (d_2, b, d_2), (d_2, c, d_3), (d_3, b, d_2), (d_3, c, d_3)\}$
- $S_0 = d_0$
- $S_A = \{d_1, d_2, d_3\}$

Algorithms

- Build a NFA from a RE
- Build a DFA from an NFA
- Build a minimized DFA from a DFA
- Build an RE from a DFA

Algorithms



Kleene's Construction
Code for
a scanner
RE
DFA Minimization
DFA
Thompson's
Construction
Subset
Construction
NFA

Scanner

- Input: Stream Characters
- Output: Stream of tokens or words

Scanner Generator

- Input: regular expressions specifying the tokens of a language
- Output: either the minimized DFA or a program that includes the minimized DFA and code that uses the minimized DFA to produce a stream of tokens given an stream of characters as input