# *Lexical Analysis*

Uday Khedker

(www.cse.iitb.ac.in/~uday)

Department of Computer Science and Engineering,
Indian Institute of Technology, Bombay

January 2024



# Outline

- Introduction
- Specifying scanners
- Tokenizing input using DFAs
- Constructing DFAs
- Representing DFAs using four-arrays
- Minimizing DFAs



# Introduction



# Introduction

Prof. Sanyal's slides (scanning-slides-sanyal-part1.pdf)



# Specifying Scanners



# Introduction

Prof. Sanyal's slides (scanning-slides-sanyal-part2.pdf)



# Tokenizing the Input Using DFAs



# An Example for Scanning: Specifications

Let L and D denote the set of all letters and digits, respectively

| Pattern | Token |
|---|---|
| int | INT |
| L(L\|D)* | ID |
| $D^+$ | NUM |
| = | = |
| ; | ; |

We will scan the input string int int32=5;↩



# Example for Scanning: DFA for the Patterns

Formally, a Deterministic Finite Automaton (DFA) is a five tuple

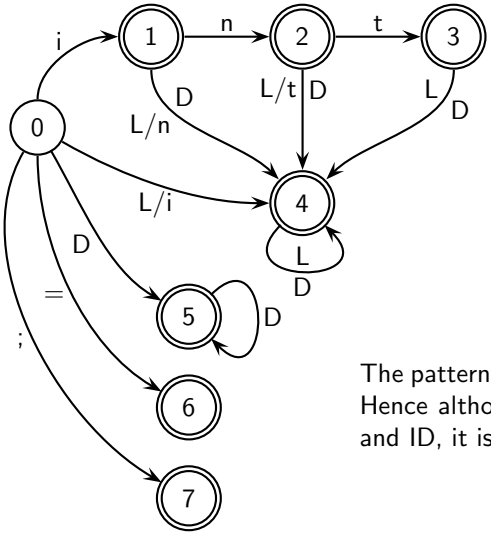
$$(\Sigma, S, s_0, \delta, F)$$

where

- $\Sigma$ is the input alphabet
- $S$ is the set of states
- $s_o \in S$ is a unique start state
- $\delta : S \times \Sigma \rightarrow S$ is a transition function
- $F \subseteq S$ is a set of final states



# Example for Scanning: DFA for the Patterns




| States | Action |
|---|---|
| 3 | Found INT |
| 1, 2, 4 | Found ID |
| 5 | Found NUM |
| 6 | Found = |
| 7 | Found ; |

The patterns for INT precedes the pattern for ID
Hence although state 3 could accept both INT and ID, it is made to accept only INT



# A Format to Show A Trace of Scanning

| Step No | State | MatchedString | Buffer | NextChar | LastFinalState | MarkedPos | Action |
|---|---|---|---|---|---|---|---|

- State (S). Current State
- MatchedString (MS). Prefix of the buffer matched to identify a lexeme
- Buffer.
- NextChar (NC). The next character in the input; it will be shifted to the buffer if there is a valid transition in the DFA
- LastFinalState (LFS). The last final state seen
- MarkedPos (MP). The position of the character (in the buffer) just after the last seen lexeme
- Action.



# A Format to Show A Trace of Scanning

| Step No | State | MatchedString | Buffer | NextChar | LastFinalState | MarkedPos | Action |
|---|---|---|---|---|---|---|---|

- State (S). Current State
- M
- B
- N
  th
- La
- M
  se
- Action.

When there is no transition on Nextchar,

- if MarkedPos is -1, no final state is seen, the first character in the buffer is discarded, and the second character becomes NextChar,
- otherwise, the lexeme upto MarkedPos (excluding it) is returned, the character at MarkedPos becomes NextChar

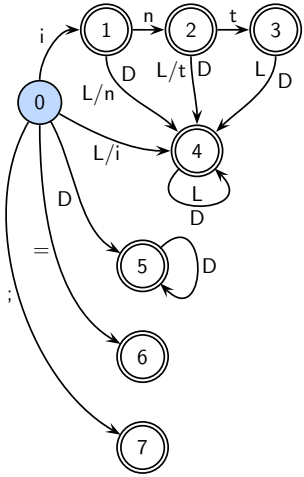
In either case, the LastFinalState is set to -1 and the state is set to 0

if

st



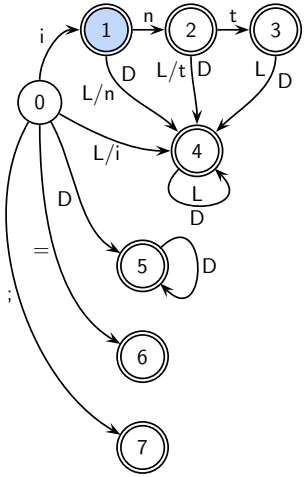
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |



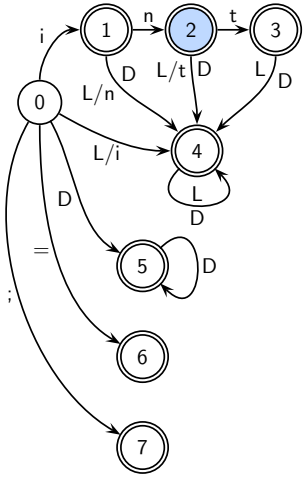
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |



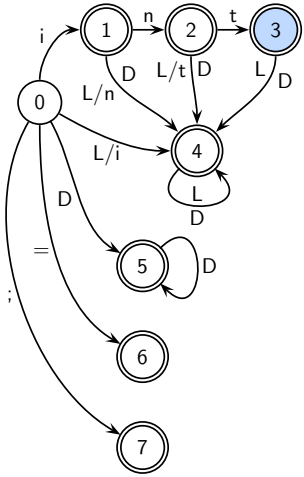
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |



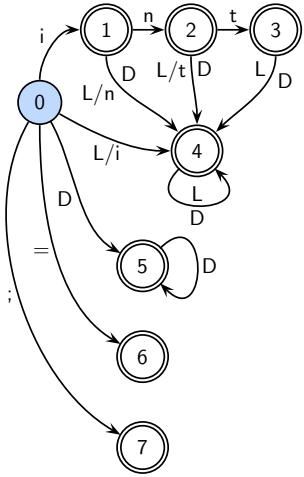
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |



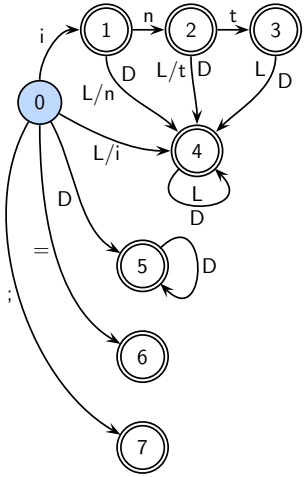
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |



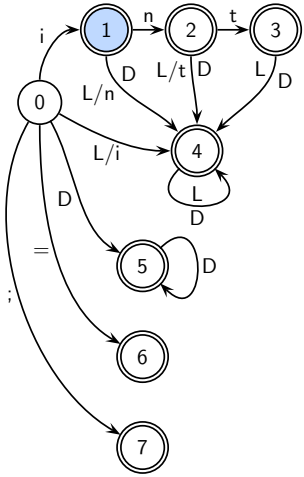
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |



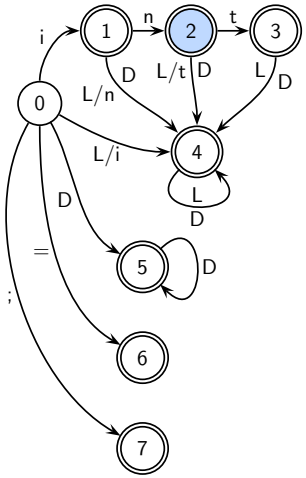
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |



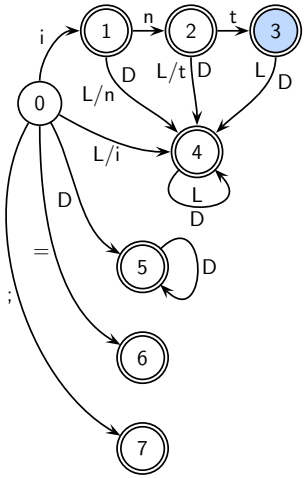
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |



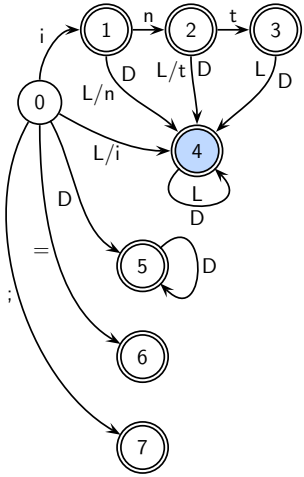
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |
| 9 | 3 | int | int32=5;↩ | 3 | 3 | 3 | |



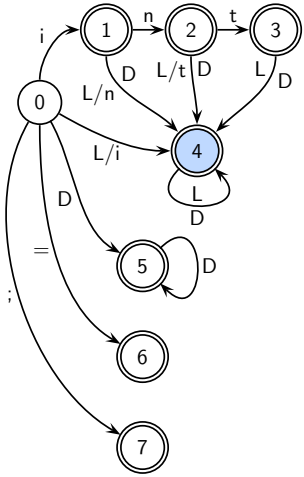
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |
| 9 | 3 | int | int32=5;↩ | 3 | 3 | 3 | |
| 10 | 4 | int3 | int32=5;↩ | 2 | 4 | 4 | |



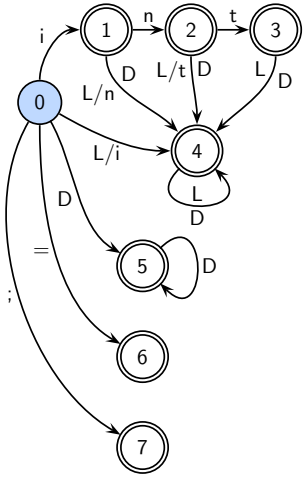
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |
| 9 | 3 | int | int32=5;↩ | 3 | 3 | 3 | |
| 10 | 4 | int3 | int32=5;↩ | 2 | 4 | 4 | |
| 11 | 4 | int32 | int32=5;↩ | = | 4 | 5 | Found ID |



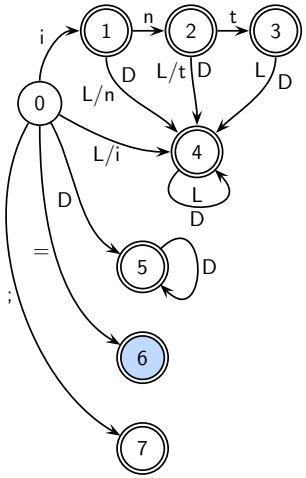
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |
| 9 | 3 | int | int32=5;↩ | 3 | 3 | 3 | |
| 10 | 4 | int3 | int32=5;↩ | 2 | 4 | 4 | |
| 11 | 4 | int32 | int32=5;↩ | = | 4 | 5 | Found ID |
| 12 | 0 | | =5;↩ | = | | | |



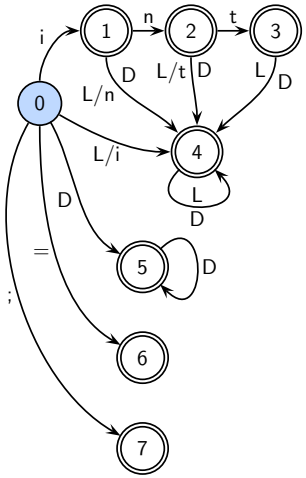
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |
| 9 | 3 | int | int32=5;↩ | 3 | 3 | 3 | |
| 10 | 4 | int3 | int32=5;↩ | 2 | 4 | 4 | |
| 11 | 4 | int32 | int32=5;↩ | = | 4 | 5 | Found ID |
| 12 | 0 | | =5;↩ | = | | | |
| 13 | 6 | = | =5;↩ | 5 | 6 | 1 | Found = |



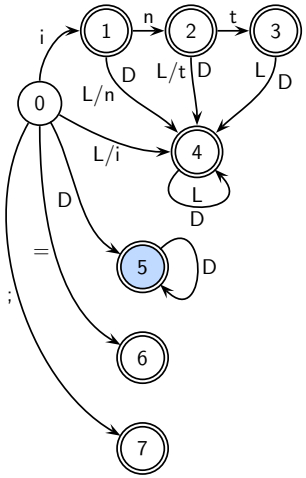
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |
| 9 | 3 | int | int32=5;↩ | 3 | 3 | 3 | |
| 10 | 4 | int3 | int32=5;↩ | 2 | 4 | 4 | |
| 11 | 4 | int32 | int32=5;↩ | = | 4 | 5 | Found ID |
| 12 | 0 | | =5;↩ | = | | | |
| 13 | 6 | = | =5;↩ | 5 | 6 | 1 | Found = |
| 14 | 0 | | 5;↩ | 5 | | | |



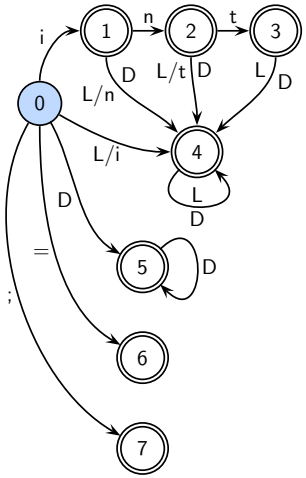
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |
| 9 | 3 | int | int32=5;↩ | 3 | 3 | 3 | |
| 10 | 4 | int3 | int32=5;↩ | 2 | 4 | 4 | |
| 11 | 4 | int32 | int32=5;↩ | = | 4 | 5 | Found ID |
| 12 | 0 | | =5;↩ | = | | | |
| 13 | 6 | = | =5;↩ | 5 | 6 | 1 | Found = |
| 14 | 0 | | 5;↩ | 5 | | | |
| 15 | 5 | 5 | 5;↩ | ; | 5 | 1 | Found NUM |



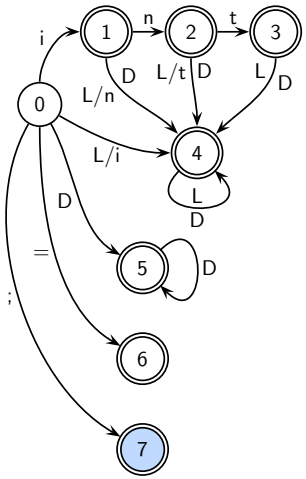
# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |
| 9 | 3 | int | int32=5;↩ | 3 | 3 | 3 | |
| 10 | 4 | int3 | int32=5;↩ | 2 | 4 | 4 | |
| 11 | 4 | int32 | int32=5;↩ | = | 4 | 5 | Found ID |
| 12 | 0 | | =5;↩ | = | | | |
| 13 | 6 | = | =5;↩ | 5 | 6 | 1 | Found = |
| 14 | 0 | | 5;↩ | 5 | | | |
| 15 | 5 | 5 | 5;↩ | ; | 5 | 1 | Found NUM |
| 16 | 0 | | ;↩ | ; | | | |



# Scanning the Input "int int32=5;↩"




| SNo | S | MS | Buffer | NC | LFS | MP | Action |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | int␣int32=5;↩ | i | | | |
| 2 | 1 | i | int␣int32=5;↩ | n | 1 | 1 | |
| 3 | 2 | in | int␣int32=5;↩ | t | 2 | 2 | |
| 4 | 3 | int | int␣int32=5;↩ | ␣ | 3 | 3 | Found INT |
| 5 | 0 | | ␣int32=5;↩ | ␣ | | | Discard ␣ |
| 6 | 0 | | int32=5;↩ | i | | | |
| 7 | 1 | i | int32=5;↩ | n | 1 | 1 | |
| 8 | 2 | in | int32=5;↩ | t | 2 | 2 | |
| 9 | 3 | int | int32=5;↩ | 3 | 3 | 3 | |
| 10 | 4 | int3 | int32=5;↩ | 2 | 4 | 4 | |
| 11 | 4 | int32 | int32=5;↩ | = | 4 | 5 | Found ID |
| 12 | 0 | | =5;↩ | = | | | |
| 13 | 6 | = | =5;↩ | 5 | 6 | 1 | Found = |
| 14 | 0 | | 5;↩ | 5 | | | |
| 15 | 5 | 5 | 5;↩ | ; | 5 | 1 | Found NUM |
| 16 | 0 | | ;↩ | ; | | | |
| 17 | 7 | ; | ↩ | ↩ | 7 | | Found ; |

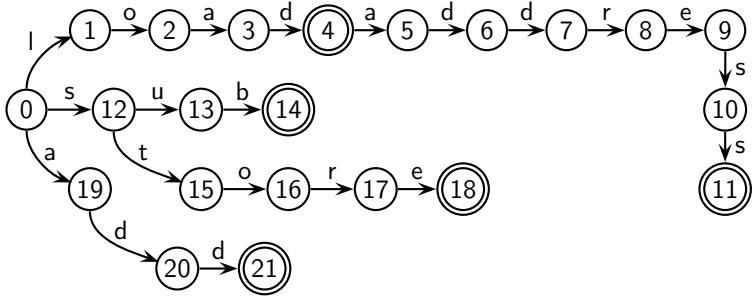


# Tutorial Problem On Scanning

- Find the occurrences of following substrings in a given input string

  load, loadaddress, add, sub, store

- Use the following automata

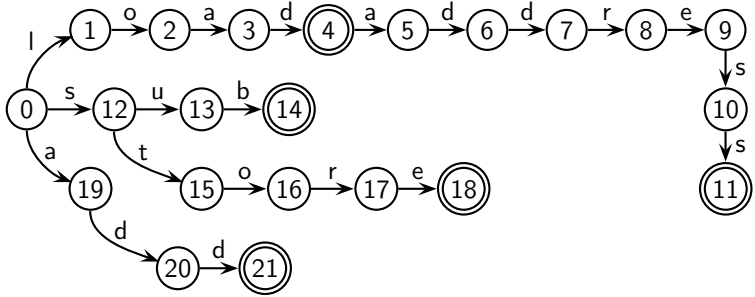



- Scan two input strings loadsubadd↩ and loadaddsub↩



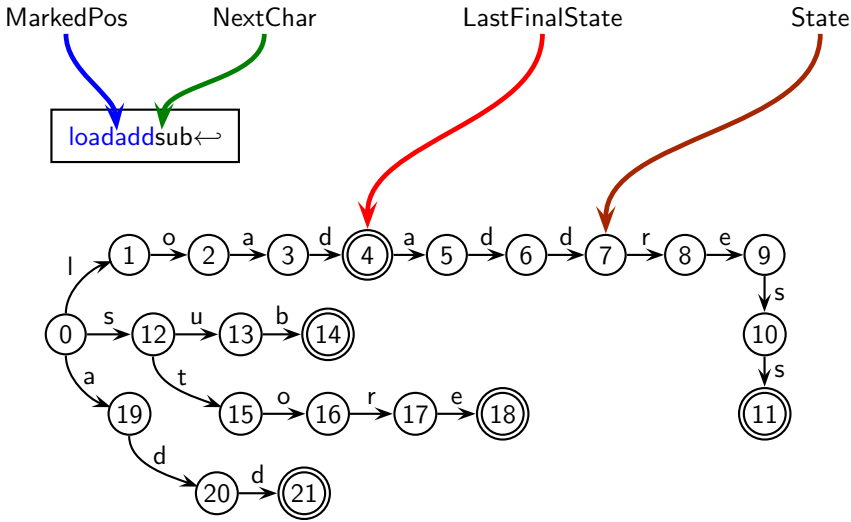
# The Role of MarkedPos

Observe the role of MarkedPos for the input loadaddsub⟲



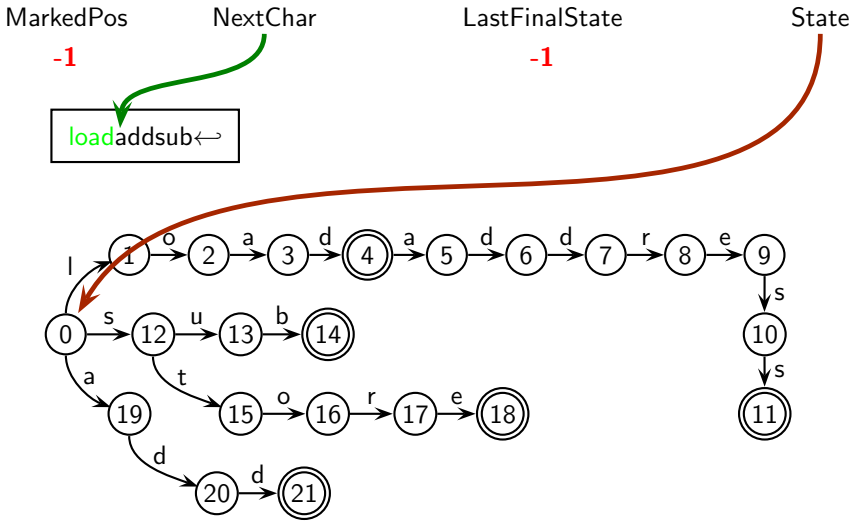


# The Role of MarkedPos





# The Role of MarkedPos





# Demo of Scan Trace



# Constructing DFAs



# Constructing DFA for Multiple Patterns

- Join multiple DFAs/NFAs using $\epsilon$ transition

  Transition without consuming any input symbol
- This creates an NFA (Non-deterministic Finite Automaton)
  - Possible transition without consuming any input symbol
  - Possibly multiple transitions on the same input symbol
- Make the NFA deterministic by subset construction
  - Each state in the resulting DFA is a set of "similar" states of the NFA
  - The start state of the DFA is a union of all original start states (of multiple patterns)
  - Subsequent states are identified by finding out the sets of states of the NFA for each possible input symbol



# Constructing NFA for a Regular Expression

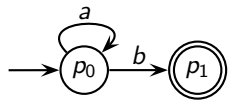
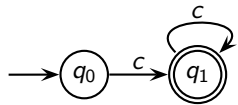
Consider a regular expression $R$. Apply steps 1 to 4 to construct an NFA for $R$ inductively:

1. If $R$ is a letter in the alphabet $\Sigma$, create a two state NFA that accepts the letter (single transition from the start state to a single final state on the letter)
2. If $R$ is $R_1 \cdot R_2$ , create an NFA by joining the two NFAs $N_1$ and $N_2$ by adding an epsilon transition from every final state of $N_1$ to the start state of $N_2$.
3. If the $R$ is $R_1 \mid R_2$, create an NFA by joining the two NFAs $N_1$ and $N_2$ by creating a new start state $s_0$ and a new final state $s_f$. Add an epsilon transition from $s_0$ the start state of $R_1$ and similarly for $R_2$. Add an epsilon transition from every final state of $N_1$ to $s_f$ and similarly for $N_2$.
4. If $R$ is $R_1$*, create an NFA by adding an epslion transition from every final state of $R_1$ to the start state of $R_1$

   Alternatively, we can create a new start state $s_0$ with an epsilon transition to the start state of $R_1$ and a new final state $s_f$ with epsilon transitions from the final states of $R_1$, and then add an espilon transition from $s_f$ to $s_0$.

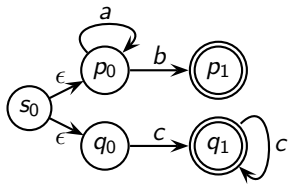


# Constructing DFA for Multiple Patterns: Example 1

| Pattern | DFA |
|---|---|
| $a^*b$ |  |
| $c^+$ |  |



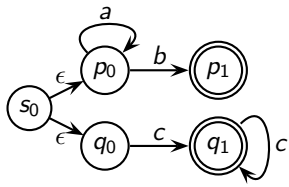
# Constructing DFA for Multiple Patterns: Example 1




| State | *Transition* | | |
|---|---|---|---|
| | *a* | *b* | *c* |
| | | | |
| | | | |
| | | | |
| | | | |



# Constructing DFA for Multiple Patterns: Example 1

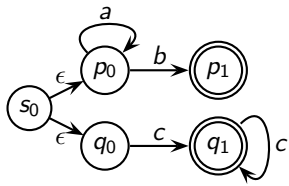



| State | *Transition* | | |
|---|---|---|---|
| | *a* | *b* | *c* |
| $\{s_0, p_0, q_0\}$ | | | |
| | | | |
| | | | |
| | | | |

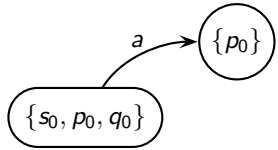
$\{s_0, p_0, q_0\}$



# Constructing DFA for Multiple Patterns: Example 1

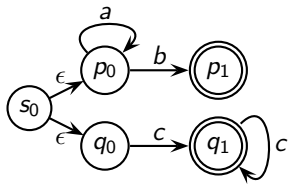



| State | Transition | | |
|---|---|---|---|
| | a | b | c |
| $\{s_0, p_0, q_0\}$ | $\{p_0\}$ | | |
| $\{p_0\}$ | | | |
| | | | |
| | | | |

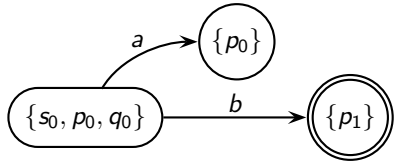




# Constructing DFA for Multiple Patterns: Example 1

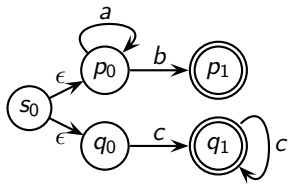



| State | Transition | | |
|---|---|---|---|
| | a | b | c |
| $\{s_0, p_0, q_0\}$ | $\{p_0\}$ | $\{p_1\}$ | |
| $\{p_0\}$ | | | |
| $\{p_1\}$ | | | |
| | | | |

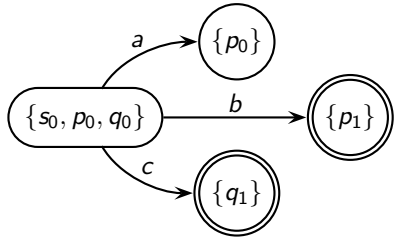




# Constructing DFA for Multiple Patterns: Example 1

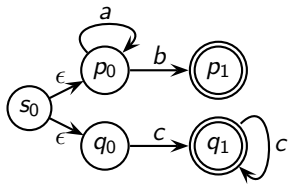



| State | *Transition* | | |
|---|---|---|---|
| | *a* | *b* | *c* |
| $\{s_0, p_0, q_0\}$ | $\{p_0\}$ | $\{p_1\}$ | $\{q_1\}$ |
| $\{p_0\}$ | | | |
| $\{p_1\}$ | | | |
| $\{q_1\}$ | | | |

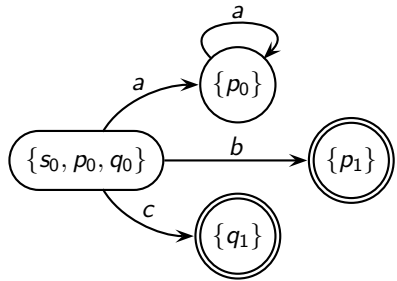




# Constructing DFA for Multiple Patterns: Example 1

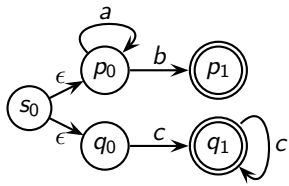



| State | *Transition* | | |
|---|---|---|---|
| | *a* | *b* | *c* |
| $\{s_0, p_0, q_0\}$ | $\{p_0\}$ | $\{p_1\}$ | $\{q_1\}$ |
| $\{p_0\}$ | $\{p_0\}$ | | |
| $\{p_1\}$ | | | |
| $\{q_1\}$ | | | |

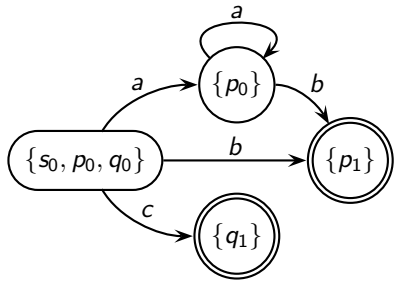




# Constructing DFA for Multiple Patterns: Example 1

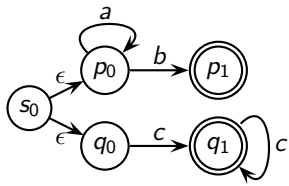



| State | *Transition* | | |
|---|---|---|---|
| | *a* | *b* | *c* |
| $\{s_0, p_0, q_0\}$ | $\{p_0\}$ | $\{p_1\}$ | $\{q_1\}$ |
| $\{p_0\}$ | $\{p_0\}$ | $\{p_1\}$ | |
| $\{p_1\}$ | | | |
| $\{q_1\}$ | | | |

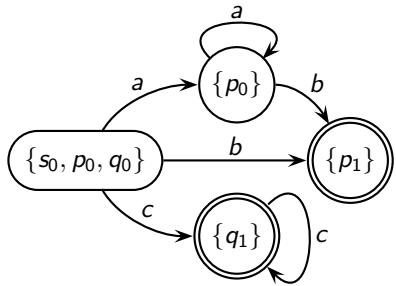




# Constructing DFA for Multiple Patterns: Example 1




| State | Transition | | |
|---|---|---|---|
| | a | b | c |
| $\{s_0, p_0, q_0\}$ | $\{p_0\}$ | $\{p_1\}$ | $\{q_1\}$ |
| $\{p_0\}$ | $\{p_0\}$ | $\{p_1\}$ | |
| $\{p_1\}$ | | | |
| $\{q_1\}$ | | | $\{q_1\}$ |





# Constructing DFA for Multiple Patterns: Example 2

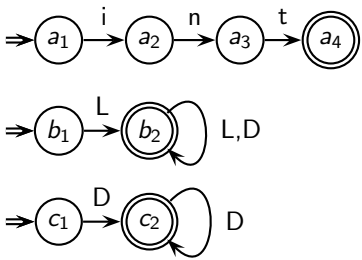
Let L and D denote the set of all letters and digits, respectively

| Pattern | Token |
|---|---|
| int | INT |
| $L(L\|D)^*$ | ID |
| $D^+$ | NUM |
| = | = |
| ; | ; |

For convenience, we will ignore the last two patterns that are completely independent



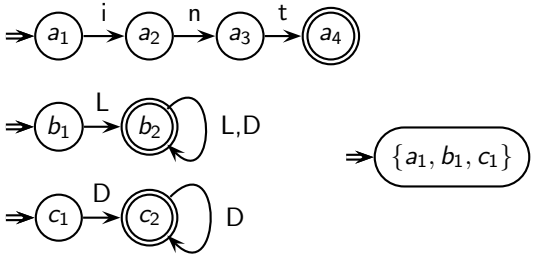
# Constructing DFA for Multiple Patterns: Example 2




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |



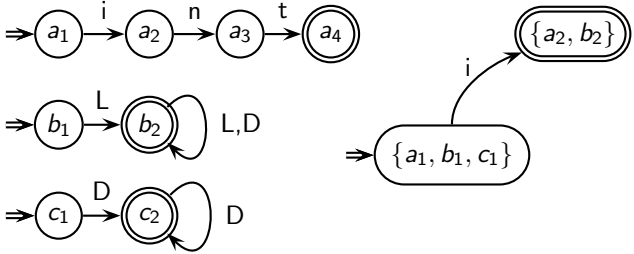
# Constructing DFA for Multiple Patterns: Example 2




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |



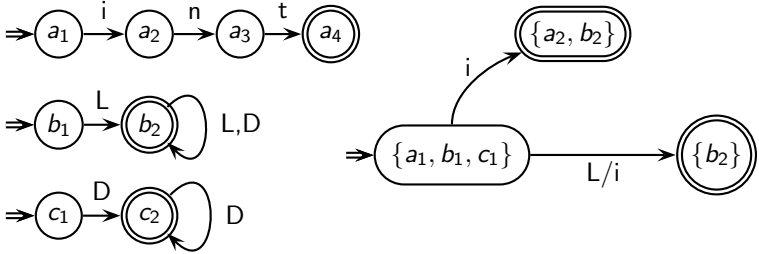
# Constructing DFA for Multiple Patterns: Example 2




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | | | | |
| $\{a_2, b_2\}$ | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |



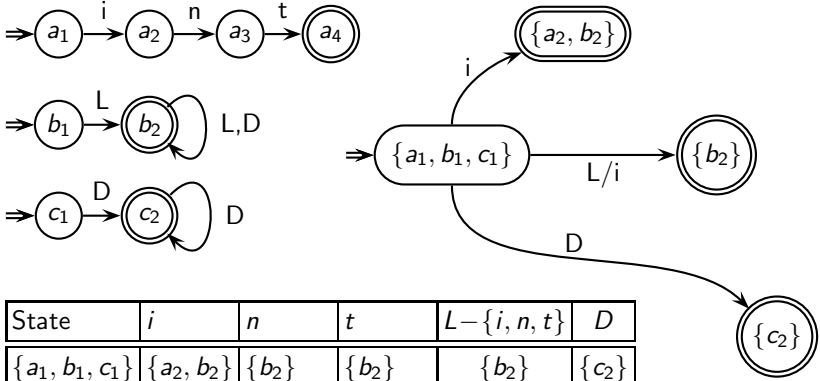
# Constructing DFA for Multiple Patterns: Example 2




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | |
| $\{a_2, b_2\}$ | | | | | |
| $\{b_2\}$ | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |



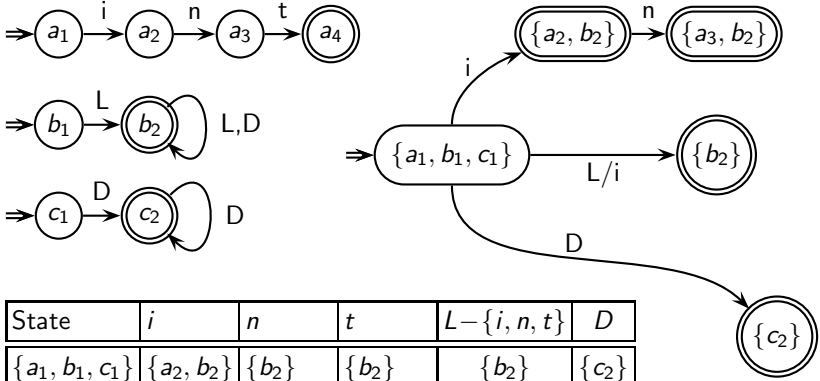
# Constructing DFA for Multiple Patterns: Example 2




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{c_2\}$ |
| $\{a_2, b_2\}$ | | | | | |
| $\{b_2\}$ | | | | | |
| $\{c_2\}$ | | | | | |
| | | | | | |
| | | | | | |

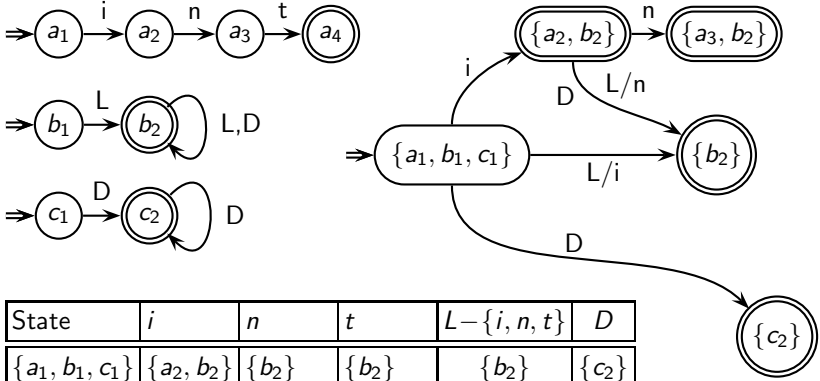


# Constructing DFA for Multiple Patterns: Example 2




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{c_2\}$ |
| $\{a_2, b_2\}$ | | $\{a_3, b_2\}$ | | | |
| $\{b_2\}$ | | | | | |
| $\{c_2\}$ | | | | | |
| | | | | | |
| | | | | | |

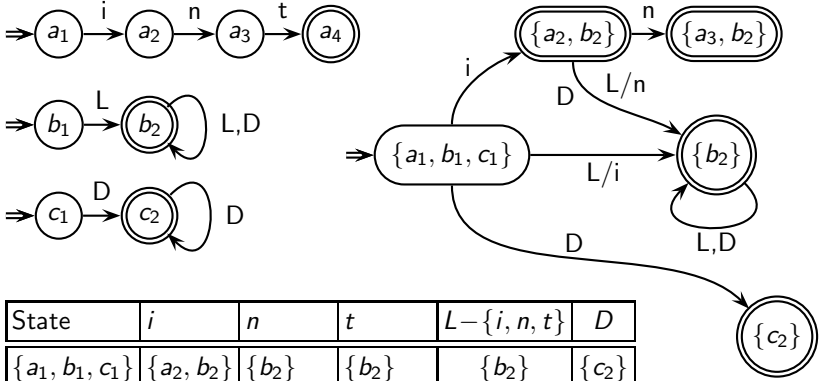
# Constructing DFA for Multiple Patterns: Example 2




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{c_2\}$ |
| $\{a_2, b_2\}$ | $\{b_2\}$ | $\{a_3, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{b_2\}$ | | | | | |
| $\{c_2\}$ | | | | | |
| $\{a_3, b_2\}$ | | | | | |
| | | | | | |



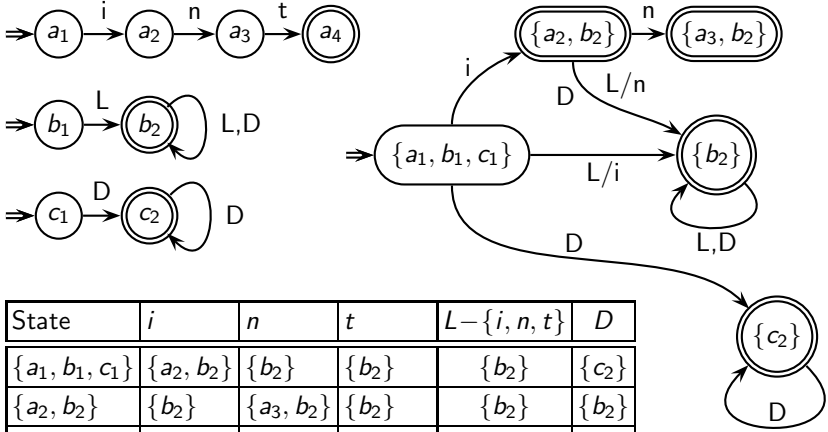
# Constructing DFA for Multiple Patterns: Example 2




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{c_2\}$ |
| $\{a_2, b_2\}$ | $\{b_2\}$ | $\{a_3, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{c_2\}$ | | | | | |
| $\{a_3, b_2\}$ | | | | | |
| | | | | | |

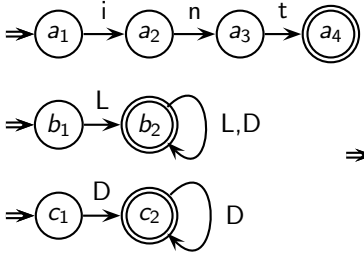


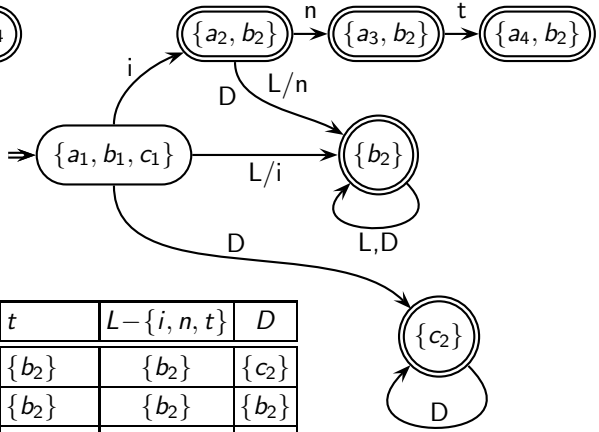
# Constructing DFA for Multiple Patterns: Example 2




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{c_2\}$ |
| $\{a_2, b_2\}$ | $\{b_2\}$ | $\{a_3, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{c_2\}$ | | | | | $\{c_2\}$ |
| $\{a_3, b_2\}$ | | | | | |
| | | | | | |

# Constructing DFA for Multiple Patterns: Example 2

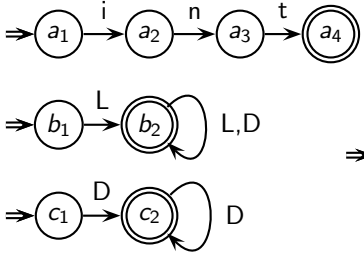


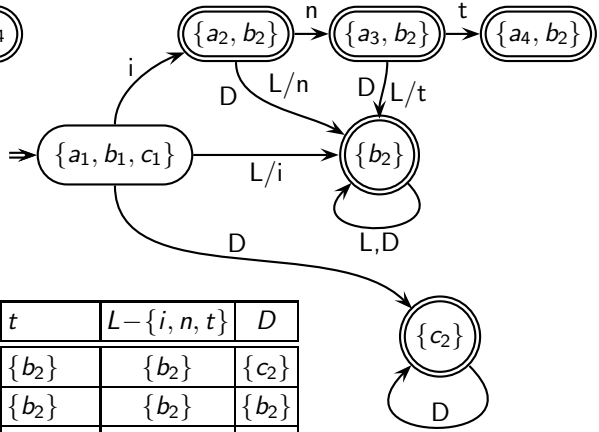




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{c_2\}$ |
| $\{a_2, b_2\}$ | $\{b_2\}$ | $\{a_3, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{c_2\}$ | | | | | $\{c_2\}$ |
| $\{a_3, b_2\}$ | | | $\{a_4, b_2\}$ | | |
| $\{a_4, b_2\}$ | | | | | |



# Constructing DFA for Multiple Patterns: Example 2

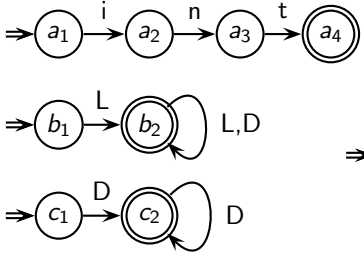


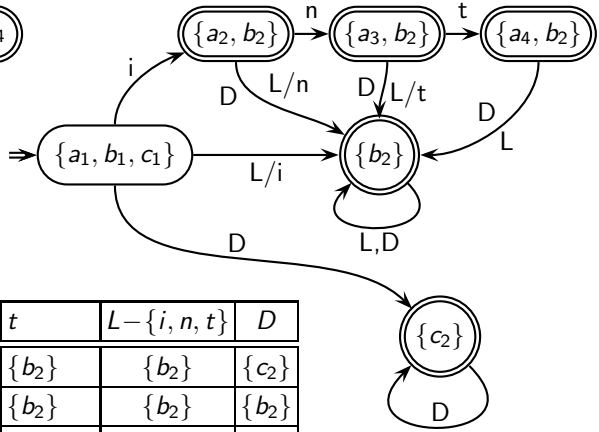




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{c_2\}$ |
| $\{a_2, b_2\}$ | $\{b_2\}$ | $\{a_3, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{c_2\}$ | | | | | $\{c_2\}$ |
| $\{a_3, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{a_4, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{a_4, b_2\}$ | | | | | |



# Constructing DFA for Multiple Patterns: Example 2

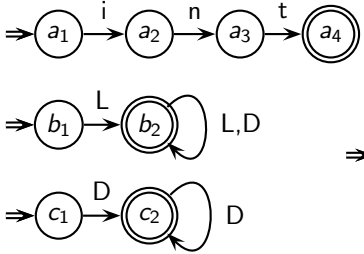


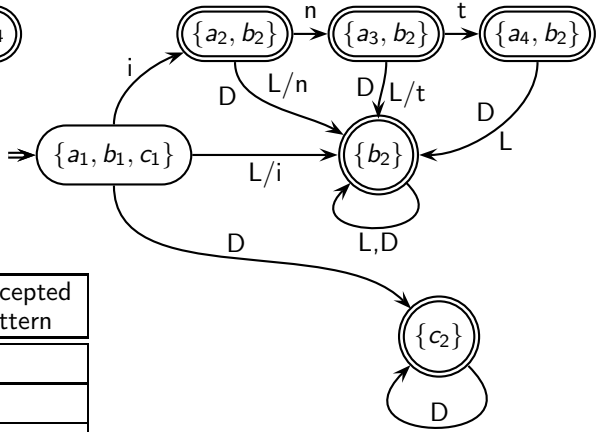




| State | $i$ | $n$ | $t$ | $L-\{i,n,t\}$ | $D$ |
|---|---|---|---|---|---|
| $\{a_1, b_1, c_1\}$ | $\{a_2, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{c_2\}$ |
| $\{a_2, b_2\}$ | $\{b_2\}$ | $\{a_3, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{c_2\}$ | | | | | $\{c_2\}$ |
| $\{a_3, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{a_4, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |
| $\{a_4, b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ | $\{b_2\}$ |



# Constructing DFA for Multiple Patterns: Example 2

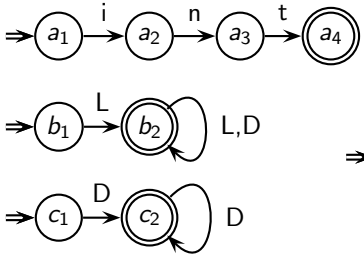


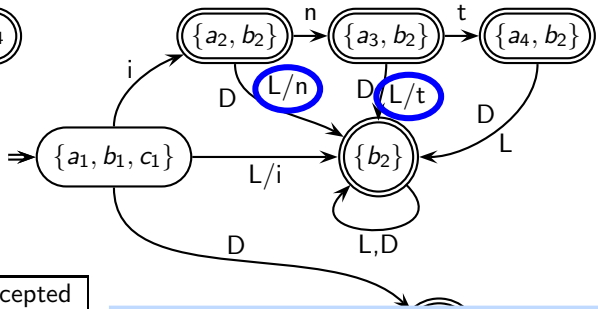




| State | Possible Patterns | Accepted Pattern |
|---|---|---|
| $\{a_1, b_1, c_1\}$ | | |
| $\{a_2, b_2\}$ | ID | ID |
| $\{b_2\}$ | ID | ID |
| $\{c_2\}$ | NUM | NUM |
| $\{a_3, b_2\}$ | ID | ID |
| $\{a_4, b_2\}$ | INT, ID | INT |



# Constructing DFA for Multiple Patterns: Example 2




| State | Possible Patterns | Accepted Pattern |
|---|---|---|
| $\{a_1, b_1, c_1\}$ | | |
| $\{a_2, b_2\}$ | ID | ID |
| $\{b_2\}$ | ID | ID |
| $\{c_2\}$ | NUM | NUM |
| $\{a_3, b_2\}$ | ID | ID |
| $\{a_4, b_2\}$ | INT, ID | INT |

*Longest match.* Lexeme "int" reaches state $\{a_4, b_2\}$ whereas lexeme "integer" reaches the state $\{b_2\}$

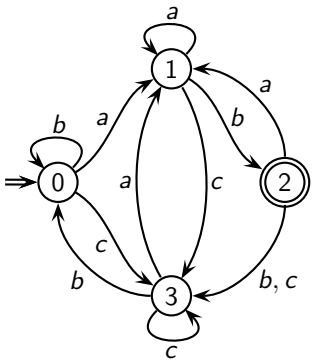
*First maching rule preferred.* Transitions L/n and L/t to state $\{b_2\}$ ensure that INT is prefered over ID for the lexeme "int"



# Representing DFAs Using Four Arrays

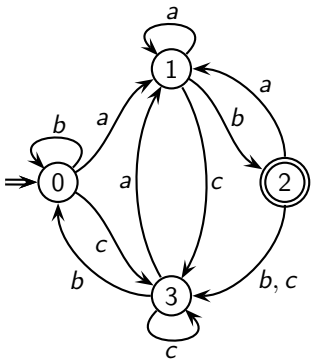


# DFA to be Represented Using Four Arrays: Example 1





# DFA to be Represented Using Four Arrays: Example 1



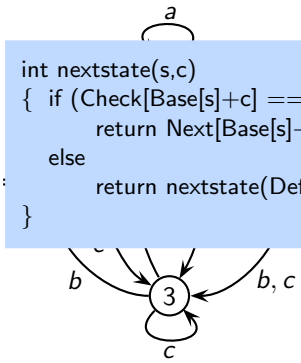

| | a | b | c |
|---|---|---|---|
| 0 | 1 | 0 | 3 |
| 1 | 1 | 2 | 3 |
| 2 | 1 | 3 | 3 |
| 3 | 1 | 0 | 3 |



# DFA to be Represented Using Four Arrays: Example 1

```
int nextstate(s,c)
{  if (Check[Base[s]+c] == s)
        return Next[Base[s]+c];
   else
        return nextstate(Default[s],c);
}
```

States 0 and 3 have identical transitions. Transitions in states 1 and 2 differ from them only on b.




| Char | Code |
|---|---|
| a | 0 |
| b | 1 |
| c | 2 |

| | a | b | c |
|---|---|---|---|
| 0 | 1 | 0 | 3 |
| 1 | 1 | 2 | 3 |
| 2 | 1 | 3 | 3 |
| 3 | 1 | 0 | 3 |

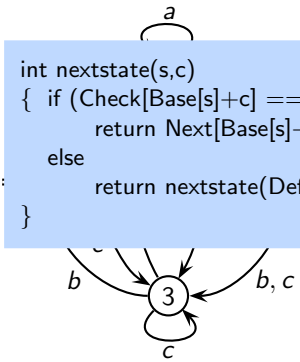
| State | Default | Base |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |

| | Next | Check |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |

# DFA to be Represented Using Four Arrays: Example 1

```
int nextstate(s,c)
{  if (Check[Base[s]+c] == s)
        return Next[Base[s]+c];
   else
        return nextstate(Default[s],c);
}
```

We choose to fill the entries for state 0 first (state 3 could also have been used)




| Char | Code |
|---|---|
| a | 0 |
| b | 1 |
| c | 2 |

| | a | b | c |
|---|---|---|---|
| 0 | 1 | 0 | 3 |
| 1 | 1 | 2 | 3 |
| 2 | 1 | 3 | 3 |
| 3 | 1 | 0 | 3 |

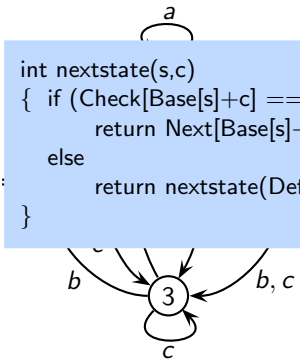
| State | Default | Base |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |

| | Next | Check |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |

# DFA to be Represented Using Four Arrays: Example 1

```
int nextstate(s,c)
{  if (Check[Base[s]+c] == s)
        return Next[Base[s]+c];
   else
        return nextstate(Default[s],c);
}
```

The Check array contains 0 to confirm that the corresponding entries in the next array are for state 0




| Char | Code |
|---|---|
| a | 0 |
| b | 1 |
| c | 2 |

| | a | b | c |
|---|---|---|---|
| 0 | 1 | 0 | 3 |
| 1 | 1 | 2 | 3 |
| 2 | 1 | 3 | 3 |
| 3 | 1 | 0 | 3 |

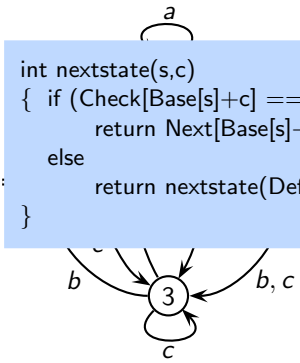
| State | Default | Base |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |

| | Next | Check |
|---|---|---|
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 2 | 3 | 0 |
| 3 | | |
| 4 | | |
| 5 | | |

# DFA to be Represented Using Four Arrays: Example 1

```
int nextstate(s,c)
{  if (Check[Base[s]+c] == s)
        return Next[Base[s]+c];
   else
        return nextstate(Default[s],c);
}
```

The Check array contains 0 to confirm that the corresponding entries in the next array are for state 0




| Char | Code |
|---|---|
| a | 0 |
| b | 1 |
| c | 2 |

| | a | b | c |
|---|---|---|---|
| 0 | 1 | 0 | 3 |
| 1 | 1 | 2 | 3 |
| 2 | 1 | 3 | 3 |
| 3 | 1 | 0 | 3 |

| State | Default | Base |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |

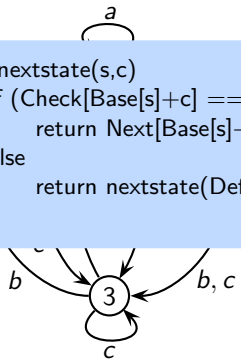
| | Next | Check |
|---|---|---|
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 2 | 3 | 0 |
| 3 | | |
| 4 | | |
| 5 | | |



# DFA to be Represented Using Four Arrays: Example 1

```
int nextstate(s,c)
{  if (Check[Base[s]+c] ==
        return Next[Base[s]+
   else
        return nextstate(Default[s],c);
}
```

For state 1, we reuse the transitions on a and c from state 0 but need to enter transition on b explicitly. We do this using the next free entry (index 3) in the next array and back calculating the base of state 1.




| Char | Code |
|---|---|
| a | 0 |
| b | 1 |
| c | 2 |

| | a | b | c |
|---|---|---|---|
| 0 | 1 | 0 | 3 |
| 1 | 1 | 2 | 3 |
| 2 | 1 | 3 | 3 |
| 3 | 1 | 0 | 3 |

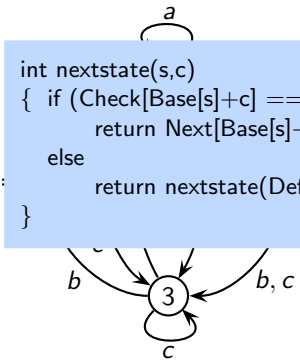
| State | Default | Base |
|---|---|---|
| 0 | | |
| 1 | 0 | |
| 2 | | |
| 3 | | |

| | Next | Check |
|---|---|---|
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 2 | 3 | 0 |
| 3 | 2 | 1 |
| 4 | | |
| 5 | | |

# DFA to be Represented Using Four Arrays: Example 1

```
int nextstate(s,c)
{  if (Check[Base[s]+c] == s
        return Next[Base[s]+c
   else
        return nextstate(Default[s],c);
}
```

The variation in state 2 is similar to that for state 1. We reuse the transitions on a and c from state 0 but enter transition on b explicitly in the next free entry (index 4) in the next array and back-calculate the base of state 2.




| Char | Code |
|---|---|
| a | 0 |
| b | 1 |
| c | 2 |

| | a | b | c |
|---|---|---|---|
| 0 | 1 | 0 | 3 |
| 1 | 1 | 2 | 3 |
| 2 | 1 | 3 | 3 |
| 3 | 1 | 0 | 3 |

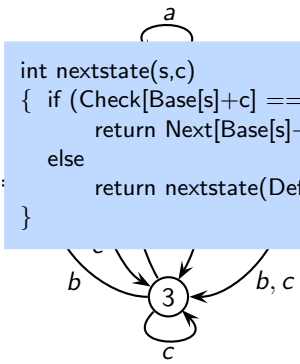
| State | Default | Base |
|---|---|---|
| 0 | | |
| 1 | 0 | |
| 2 | 0 | |
| 3 | | |

| | Next | Check |
|---|---|---|
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 2 | 3 | 0 |
| 3 | 2 | 1 |
| 4 | 3 | 2 |
| 5 | | |

# DFA to be Represented Using Four Arrays: Example 1

```
int nextstate(s,c)
{  if (Check[Base[s]+c] == s
        return Next[Base[s]+c
   else
        return nextstate(Default[s],c);
}
```

State 3 is identical to state 0. We have shown here its base as same as for state 0.
(In practice, lex begins the entries from index 1 and keeps index 0 free for such entries. We have ignored it because it is a matter of details.)




| Char | Code |
|---|---|
| a | 0 |
| b | 1 |
| c | 2 |

| | a | b | c |
|---|---|---|---|
| 0 | 1 | 0 | 3 |
| 1 | 1 | 2 | 3 |
| 2 | 1 | 3 | 3 |
| 3 | 1 | 0 | 3 |

| State | Default | Base |
|---|---|---|
| 0 | | |
| 1 | 0 | |
| 2 | 0 | |
| 3 | 0 | |

| | Next | Check |
|---|---|---|
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 2 | 3 | 0 |
| 3 | 2 | 1 |
| 4 | 3 | 2 |
| 5 | | |



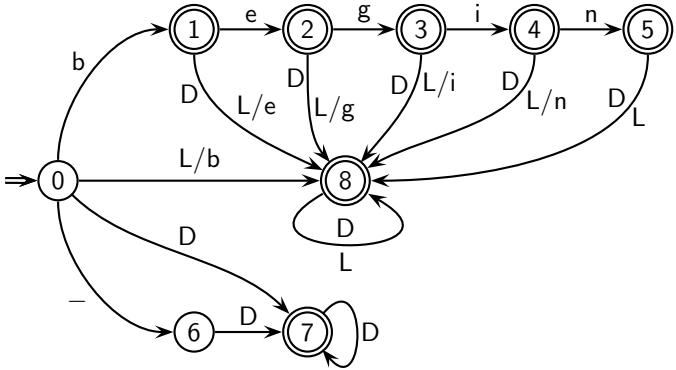
# The Intuition Behind Four Array Representation

How to find the appropriate space in Next array for a state?

- View the entries (in the row of the state) that are required to be stored as "pins" separated by the entries that are not required to be stored
- View the positions in the Next array that do not contain a transiton as "holes"
- Try to match the pattern (i.e. separation) of pins with that of the available holes



# DFA to be Represented Using Four Arrays: Example 2




| Set | Characters |
|---|---|
| L | a to z |
| D | 0 to 9 |

| Pattern | Token |
|---|---|
| begin | BEGIN |
| L(L\|D)* | ID |
| (-\|$\epsilon$)D$^+$ | NUM |



# Table Representation for Example 2

In the following, L denotes any letter from a to z other than b, e, g, i, n because these letters are listed seperately

| | b | e | g | i | n | L | D | - |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |

| Character | Code |
|---|---|
| a - z | 0 - 25 |
| 0 - 9 | 26 - 35 |
| - | 36 |



# Choice of Default States for Example 2

- States 8 and 6 are represented independently
- State 6 is the default state for state 7
- State 8 is the default state for all other states



# Four Arrays Representation for Example 2

S: State
D: Default
B: Base
N: Next
C: Check

| S | D | B |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

| | N | C |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |
| 11 | | |
| 12 | | |
| 13 | | |
| 14 | | |
| 15 | | |
| 16 | | |
| 17 | | |
| 18 | | |
| 19 | | |

| | N | C |
|---|---|---|
| 20 | | |
| 21 | | |
| 22 | | |
| 23 | | |
| 24 | | |
| 25 | | |
| 26 | | |
| 27 | | |
| 28 | | |
| 29 | | |
| 30 | | |
| 31 | | |
| 32 | | |
| 33 | | |
| 34 | | |
| 35 | | |
| 36 | | |
| 37 | | |
| 38 | | |
| 39 | | |

| | N | C |
|---|---|---|
| 40 | | |
| 41 | | |
| 42 | | |
| 43 | | |
| 44 | | |
| 45 | | |
| 46 | | |
| 47 | | |
| 48 | | |
| 49 | | |
| 50 | | |
| 51 | | |
| 52 | | |
| 53 | | |
| 54 | | |
| 55 | | |
| 56 | | |
| 57 | | |
| 58 | | |
| 59 | | |

| | N | C |
|---|---|---|
| 60 | | |
| 61 | | |
| 62 | | |
| 63 | | |
| 64 | | |
| 65 | | |
| 66 | | |
| 67 | | |
| 68 | | |
| 69 | | |
| 70 | | |
| 71 | | |
| 72 | | |
| 73 | | |
| 74 | | |
| 75 | | |
| 76 | | |
| 77 | | |
| 78 | | |
| 79 | | |



# Four Arrays Representation for Example 2

S: State
D: Default
B: Base
N: Next
C: Check

| S | D | B |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

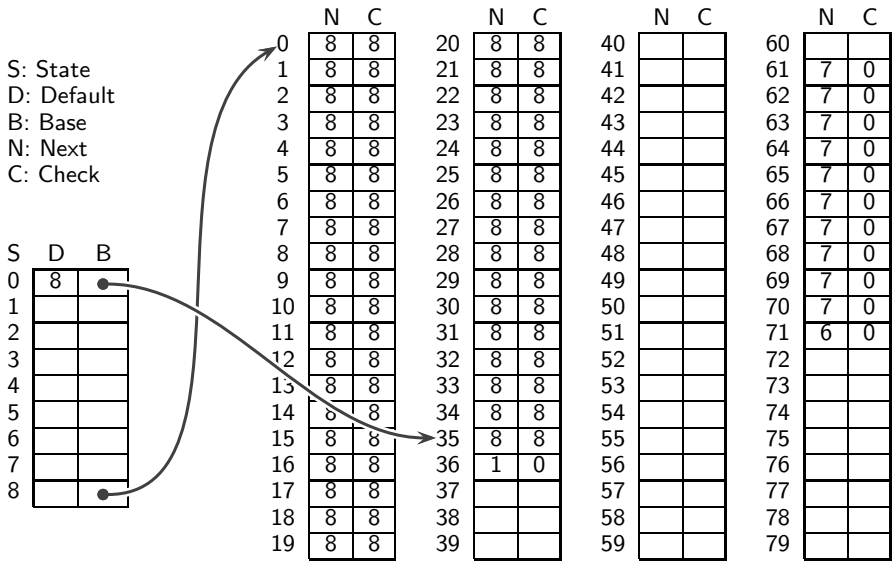
| | N | C |
|---|---|---|
| 0 | 8 | 8 |
| 1 | 8 | 8 |
| 2 | 8 | 8 |
| 3 | 8 | 8 |
| 4 | 8 | 8 |
| 5 | 8 | 8 |
| 6 | 8 | 8 |
| 7 | 8 | 8 |
| 8 | 8 | 8 |
| 9 | 8 | 8 |
| 10 | 8 | 8 |
| 11 | 8 | 8 |
| 12 | 8 | 8 |
| 13 | 8 | 8 |
| 14 | 8 | 8 |
| 15 | 8 | 8 |
| 16 | 8 | 8 |
| 17 | 8 | 8 |
| 18 | 8 | 8 |
| 19 | 8 | 8 |

| | N | C |
|---|---|---|
| 20 | 8 | 8 |
| 21 | 8 | 8 |
| 22 | 8 | 8 |
| 23 | 8 | 8 |
| 24 | 8 | 8 |
| 25 | 8 | 8 |
| 26 | 8 | 8 |
| 27 | 8 | 8 |
| 28 | 8 | 8 |
| 29 | 8 | 8 |
| 30 | 8 | 8 |
| 31 | 8 | 8 |
| 32 | 8 | 8 |
| 33 | 8 | 8 |
| 34 | 8 | 8 |
| 35 | 8 | 8 |
| 36 | | |
| 37 | | |
| 38 | | |
| 39 | | |

| | N | C |
|---|---|---|
| 40 | | |
| 41 | | |
| 42 | | |
| 43 | | |
| 44 | | |
| 45 | | |
| 46 | | |
| 47 | | |
| 48 | | |
| 49 | | |
| 50 | | |
| 51 | | |
| 52 | | |
| 53 | | |
| 54 | | |
| 55 | | |
| 56 | | |
| 57 | | |
| 58 | | |
| 59 | | |

| | N | C |
|---|---|---|
| 60 | | |
| 61 | | |
| 62 | | |
| 63 | | |
| 64 | | |
| 65 | | |
| 66 | | |
| 67 | | |
| 68 | | |
| 69 | | |
| 70 | | |
| 71 | | |
| 72 | | |
| 73 | | |
| 74 | | |
| 75 | | |
| 76 | | |
| 77 | | |
| 78 | | |
| 79 | | |

# Four Arrays Representation for Example 2





# Four Arrays Representation for Example 2

S: State
D: Default
B: Base
N: Next
C: Check

| S | D | B |
|---|---|---|
| 0 | 8 | |
| 1 | 8 | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

| | N | C |
|---|---|---|
| 0 | 8 | 8 |
| 1 | 8 | 8 |
| 2 | 8 | 8 |
| 3 | 8 | 8 |
| 4 | 8 | 8 |
| 5 | 8 | 8 |
| 6 | 8 | 8 |
| 7 | 8 | 8 |
| 8 | 8 | 8 |
| 9 | 8 | 8 |
| 10 | 8 | 8 |
| 11 | 8 | 8 |
| 12 | 8 | 8 |
| 13 | 8 | 8 |
| 14 | 8 | 8 |
| 15 | 8 | 8 |
| 16 | 8 | 8 |
| 17 | 8 | 8 |
| 18 | 8 | 8 |
| 19 | 8 | 8 |

| | N | C |
|---|---|---|
| 20 | 8 | 8 |
| 21 | 8 | 8 |
| 22 | 8 | 8 |
| 23 | 8 | 8 |
| 24 | 8 | 8 |
| 25 | 8 | 8 |
| 26 | 8 | 8 |
| 27 | 8 | 8 |
| 28 | 8 | 8 |
| 29 | 8 | 8 |
| 30 | 8 | 8 |
| 31 | 8 | 8 |
| 32 | 8 | 8 |
| 33 | 8 | 8 |
| 34 | 8 | 8 |
| 35 | 8 | 8 |
| 36 | 1 | 0 |
| 37 | 2 | 1 |
| 38 | | |
| 39 | | |

| | N | C |
|---|---|---|
| 40 | | |
| 41 | | |
| 42 | | |
| 43 | | |
| 44 | | |
| 45 | | |
| 46 | | |
| 47 | | |
| 48 | | |
| 49 | | |
| 50 | | |
| 51 | | |
| 52 | | |
| 53 | | |
| 54 | | |
| 55 | | |
| 56 | | |
| 57 | | |
| 58 | | |
| 59 | | |

| | N | C |
|---|---|---|
| 60 | | |
| 61 | 7 | 0 |
| 62 | 7 | 0 |
| 63 | 7 | 0 |
| 64 | 7 | 0 |
| 65 | 7 | 0 |
| 66 | 7 | 0 |
| 67 | 7 | 0 |
| 68 | 7 | 0 |
| 69 | 7 | 0 |
| 70 | 7 | 0 |
| 71 | 6 | 0 |
| 72 | | |
| 73 | | |
| 74 | | |
| 75 | | |
| 76 | | |
| 77 | | |
| 78 | | |
| 79 | | |



# Four Arrays Representation for Example 2

S: State
D: Default
B: Base
N: Next
C: Check

| S | D | B |
|---|---|---|
| 0 | 8 | |
| 1 | 8 | |
| 2 | 8 | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

| | N | C |
|---|---|---|
| 0 | 8 | 8 |
| 1 | 8 | 8 |
| 2 | 8 | 8 |
| 3 | 8 | 8 |
| 4 | 8 | 8 |
| 5 | 8 | 8 |
| 6 | 8 | 8 |
| 7 | 8 | 8 |
| 8 | 8 | 8 |
| 9 | 8 | 8 |
| 10 | 8 | 8 |
| 11 | 8 | 8 |
| 12 | 8 | 8 |
| 13 | 8 | 8 |
| 14 | 8 | 8 |
| 15 | 8 | 8 |
| 16 | 8 | 8 |
| 17 | 8 | 8 |
| 18 | 8 | 8 |
| 19 | 8 | 8 |

| | N | C |
|---|---|---|
| 20 | 8 | 8 |
| 21 | 8 | 8 |
| 22 | 8 | 8 |
| 23 | 8 | 8 |
| 24 | 8 | 8 |
| 25 | 8 | 8 |
| 26 | 8 | 8 |
| 27 | 8 | 8 |
| 28 | 8 | 8 |
| 29 | 8 | 8 |
| 30 | 8 | 8 |
| 31 | 8 | 8 |
| 32 | 8 | 8 |
| 33 | 8 | 8 |
| 34 | 8 | 8 |
| 35 | 8 | 8 |
| 36 | 1 | 0 |
| 37 | 2 | 1 |
| 38 | 3 | 2 |
| 39 | | |

| | N | C |
|---|---|---|
| 40 | | |
| 41 | | |
| 42 | | |
| 43 | | |
| 44 | | |
| 45 | | |
| 46 | | |
| 47 | | |
| 48 | | |
| 49 | | |
| 50 | | |
| 51 | | |
| 52 | | |
| 53 | | |
| 54 | | |
| 55 | | |
| 56 | | |
| 57 | | |
| 58 | | |
| 59 | | |

| | N | C |
|---|---|---|
| 60 | | |
| 61 | 7 | 0 |
| 62 | 7 | 0 |
| 63 | 7 | 0 |
| 64 | 7 | 0 |
| 65 | 7 | 0 |
| 66 | 7 | 0 |
| 67 | 7 | 0 |
| 68 | 7 | 0 |
| 69 | 7 | 0 |
| 70 | 7 | 0 |
| 71 | 6 | 0 |
| 72 | | |
| 73 | | |
| 74 | | |
| 75 | | |
| 76 | | |
| 77 | | |
| 78 | | |
| 79 | | |



# Four Arrays Representation for Example 2

S: State
D: Default
B: Base
N: Next
C: Check

| S | D | B |
|---|---|---|
| 0 | 8 | |
| 1 | 8 | |
| 2 | 8 | |
| 3 | 8 | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

| | N | C |
|---|---|---|
| 0 | 8 | 8 |
| 1 | 8 | 8 |
| 2 | 8 | 8 |
| 3 | 8 | 8 |
| 4 | 8 | 8 |
| 5 | 8 | 8 |
| 6 | 8 | 8 |
| 7 | 8 | 8 |
| 8 | 8 | 8 |
| 9 | 8 | 8 |
| 10 | 8 | 8 |
| 11 | 8 | 8 |
| 12 | 8 | 8 |
| 13 | 8 | 8 |
| 14 | 8 | 8 |
| 15 | 8 | 8 |
| 16 | 8 | 8 |
| 17 | 8 | 8 |
| 18 | 8 | 8 |
| 19 | 8 | 8 |

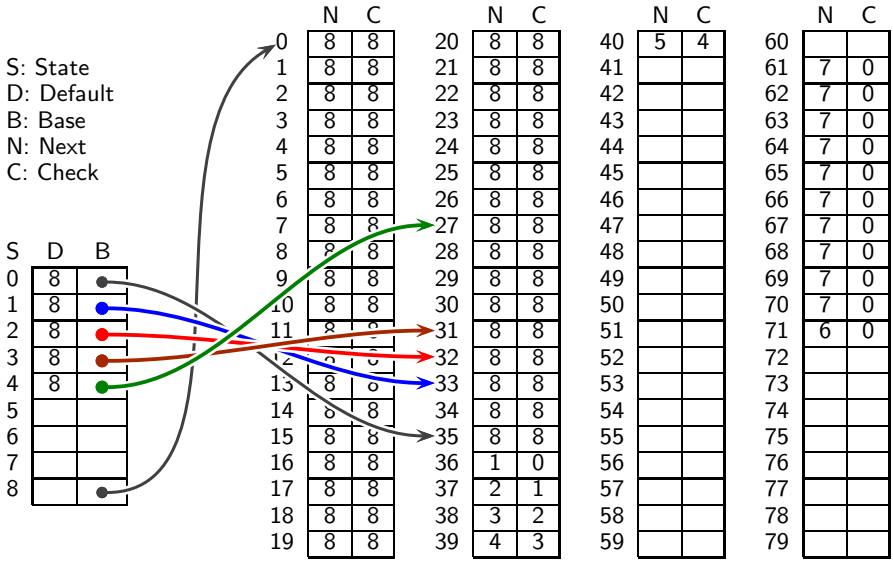
| | N | C |
|---|---|---|
| 20 | 8 | 8 |
| 21 | 8 | 8 |
| 22 | 8 | 8 |
| 23 | 8 | 8 |
| 24 | 8 | 8 |
| 25 | 8 | 8 |
| 26 | 8 | 8 |
| 27 | 8 | 8 |
| 28 | 8 | 8 |
| 29 | 8 | 8 |
| 30 | 8 | 8 |
| 31 | 8 | 8 |
| 32 | 8 | 8 |
| 33 | 8 | 8 |
| 34 | 8 | 8 |
| 35 | 8 | 8 |
| 36 | 1 | 0 |
| 37 | 2 | 1 |
| 38 | 3 | 2 |
| 39 | 4 | 3 |

| | N | C |
|---|---|---|
| 40 | | |
| 41 | | |
| 42 | | |
| 43 | | |
| 44 | | |
| 45 | | |
| 46 | | |
| 47 | | |
| 48 | | |
| 49 | | |
| 50 | | |
| 51 | | |
| 52 | | |
| 53 | | |
| 54 | | |
| 55 | | |
| 56 | | |
| 57 | | |
| 58 | | |
| 59 | | |

| | N | C |
|---|---|---|
| 60 | | |
| 61 | 7 | 0 |
| 62 | 7 | 0 |
| 63 | 7 | 0 |
| 64 | 7 | 0 |
| 65 | 7 | 0 |
| 66 | 7 | 0 |
| 67 | 7 | 0 |
| 68 | 7 | 0 |
| 69 | 7 | 0 |
| 70 | 7 | 0 |
| 71 | 6 | 0 |
| 72 | | |
| 73 | | |
| 74 | | |
| 75 | | |
| 76 | | |
| 77 | | |
| 78 | | |
| 79 | | |



# Four Arrays Representation for Example 2





# Four Arrays Representation for Example 2

S: State
D: Default
B: Base
N: Next
C: Check

| S | D | B |
|---|---|---|
| 0 | 8 | |
| 1 | 8 | |
| 2 | 8 | |
| 3 | 8 | |
| 4 | 8 | |
| 5 | 8 | |
| 6 | | |
| 7 | | |
| 8 | | |

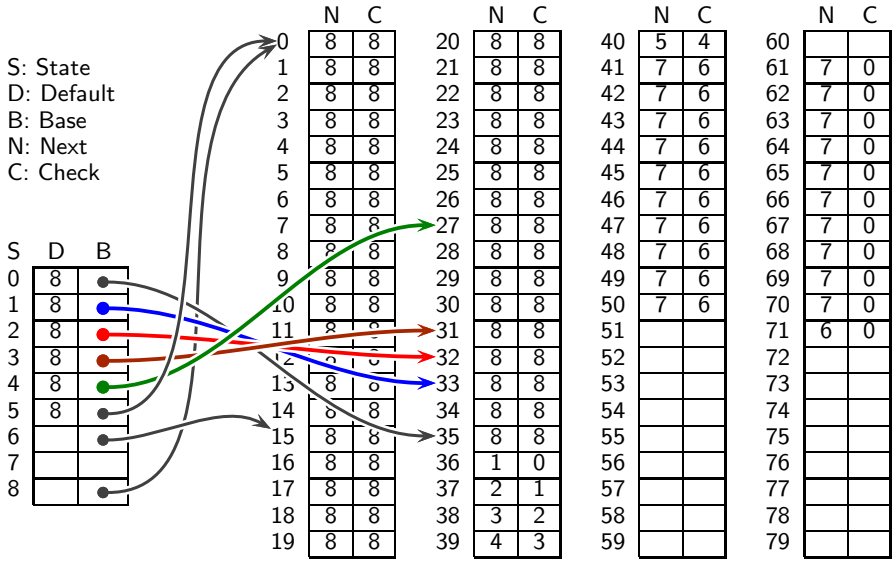
| | N | C |
|---|---|---|
| 0 | 8 | 8 |
| 1 | 8 | 8 |
| 2 | 8 | 8 |
| 3 | 8 | 8 |
| 4 | 8 | 8 |
| 5 | 8 | 8 |
| 6 | 8 | 8 |
| 7 | 8 | 8 |
| 8 | 8 | 8 |
| 9 | 8 | 8 |
| 10 | 8 | 8 |
| 11 | 8 | 8 |
| 12 | 8 | 8 |
| 13 | 8 | 8 |
| 14 | 8 | 8 |
| 15 | 8 | 8 |
| 16 | 8 | 8 |
| 17 | 8 | 8 |
| 18 | 8 | 8 |
| 19 | 8 | 8 |

| | N | C |
|---|---|---|
| 20 | 8 | 8 |
| 21 | 8 | 8 |
| 22 | 8 | 8 |
| 23 | 8 | 8 |
| 24 | 8 | 8 |
| 25 | 8 | 8 |
| 26 | 8 | 8 |
| 27 | 8 | 8 |
| 28 | 8 | 8 |
| 29 | 8 | 8 |
| 30 | 8 | 8 |
| 31 | 8 | 8 |
| 32 | 8 | 8 |
| 33 | 8 | 8 |
| 34 | 8 | 8 |
| 35 | 8 | 8 |
| 36 | 1 | 0 |
| 37 | 2 | 1 |
| 38 | 3 | 2 |
| 39 | 4 | 3 |

| | N | C |
|---|---|---|
| 40 | 5 | 4 |
| 41 | | |
| 42 | | |
| 43 | | |
| 44 | | |
| 45 | | |
| 46 | | |
| 47 | | |
| 48 | | |
| 49 | | |
| 50 | | |
| 51 | | |
| 52 | | |
| 53 | | |
| 54 | | |
| 55 | | |
| 56 | | |
| 57 | | |
| 58 | | |
| 59 | | |

| | N | C |
|---|---|---|
| 60 | | |
| 61 | 7 | 0 |
| 62 | 7 | 0 |
| 63 | 7 | 0 |
| 64 | 7 | 0 |
| 65 | 7 | 0 |
| 66 | 7 | 0 |
| 67 | 7 | 0 |
| 68 | 7 | 0 |
| 69 | 7 | 0 |
| 70 | 7 | 0 |
| 71 | 6 | 0 |
| 72 | | |
| 73 | | |
| 74 | | |
| 75 | | |
| 76 | | |
| 77 | | |
| 78 | | |
| 79 | | |

# Four Arrays Representation for Example 2





# Four Arrays Representation for Example 2

S: State
D: Default
B: Base
N: Next
C: Check

| S | D | B |
|---|---|---|
| 0 | 8 | |
| 1 | 8 | |
| 2 | 8 | |
| 3 | 8 | |
| 4 | 8 | |
| 5 | 8 | |
| 6 | | |
| 7 | 6 | |
| 8 | | |

| | N | C |
|---|---|---|
| 0 | 8 | 8 |
| 1 | 8 | 8 |
| 2 | 8 | 8 |
| 3 | 8 | 8 |
| 4 | 8 | 8 |
| 5 | 8 | 8 |
| 6 | 8 | 8 |
| 7 | 8 | 8 |
| 8 | 8 | 8 |
| 9 | 8 | 8 |
| 10 | 8 | 8 |
| 11 | 8 | 8 |
| 12 | 8 | 8 |
| 13 | 8 | 8 |
| 14 | 8 | 8 |
| 15 | 8 | 8 |
| 16 | 8 | 8 |
| 17 | 8 | 8 |
| 18 | 8 | 8 |
| 19 | 8 | 8 |

| | N | C |
|---|---|---|
| 20 | 8 | 8 |
| 21 | 8 | 8 |
| 22 | 8 | 8 |
| 23 | 8 | 8 |
| 24 | 8 | 8 |
| 25 | 8 | 8 |
| 26 | 8 | 8 |
| 27 | 8 | 8 |
| 28 | 8 | 8 |
| 29 | 8 | 8 |
| 30 | 8 | 8 |
| 31 | 8 | 8 |
| 32 | 8 | 8 |
| 33 | 8 | 8 |
| 34 | 8 | 8 |
| 35 | 8 | 8 |
| 36 | 1 | 0 |
| 37 | 2 | 1 |
| 38 | 3 | 2 |
| 39 | 4 | 3 |

| | N | C |
|---|---|---|
| 40 | 5 | 4 |
| 41 | 7 | 6 |
| 42 | 7 | 6 |
| 43 | 7 | 6 |
| 44 | 7 | 6 |
| 45 | 7 | 6 |
| 46 | 7 | 6 |
| 47 | 7 | 6 |
| 48 | 7 | 6 |
| 49 | 7 | 6 |
| 50 | 7 | 6 |
| 51 | | |
| 52 | | |
| 53 | | |
| 54 | | |
| 55 | | |
| 56 | | |
| 57 | | |
| 58 | | |
| 59 | | |

| | N | C |
|---|---|---|
| 60 | | |
| 61 | 7 | 0 |
| 62 | 7 | 0 |
| 63 | 7 | 0 |
| 64 | 7 | 0 |
| 65 | 7 | 0 |
| 66 | 7 | 0 |
| 67 | 7 | 0 |
| 68 | 7 | 0 |
| 69 | 7 | 0 |
| 70 | 7 | 0 |
| 71 | 6 | 0 |
| 72 | | |
| 73 | | |
| 74 | | |
| 75 | | |
| 76 | | |
| 77 | | |
| 78 | | |
| 79 | | |



# Size Comparison for Example 2

- Space for a 2 dimensional table

$$\text{rows} \times \text{columns} = 9 \times 36 = 324$$

- Space for four arrays representation

| Array | Size |
|---|---|
| Next | 71 |
| Check | 71 |
| Default | 9 |
| Base | 9 |
| Total | 160 |

- If a large graph seen as adjacency matrix is stored using four arrays, it would have the need of pointers and dynamic memory allocation

  This would imply good cache behaviour



# Further Compression Using Equivalence Classes

- The four arrays handle similarity in the rows of the 2-D table
- Several columns could have a lot of similarity too
- We can define equivalence classes of characters that have identical transitions
  Identical columns are collapsed into a single column
- The equivalence classes are given contiguous codes thereby eliminating several "holes" in the Next and Check arrays



# Further Compression Using Equivalence Classes for Example 2

| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |

```
int nextstate(s,c)
{  if (Check[Base[s]+c] == s)
        return Next[Base[s]+c];
   else
        return nextstate(Default[s],c);
}
```

Now c represents the class of a character instead of the character

# Four Arrays Representation Using Equivalence Classes for Example 2

| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |

S: State
D: Default
B: Base
N: Next
C: Check

| S | D | B |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

| | N | C |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |
| 11 | | |
| 12 | | |
| 13 | | |
| 14 | | |
| 15 | | |
| 16 | | |



# Four Arrays Representation Using Equivalence Classes for Example 2

| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |

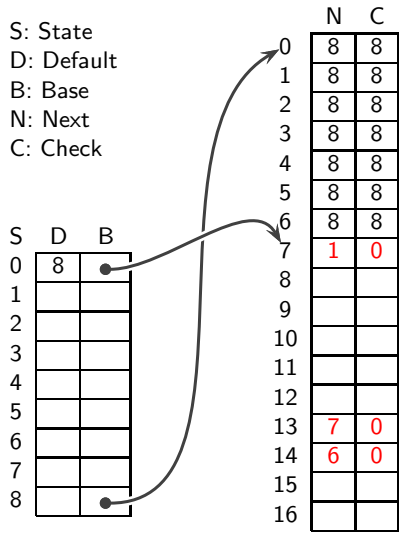
S: State
D: Default
B: Base
N: Next
C: Check

| S | D | B |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

| | N | C |
|---|---|---|
| 0 | 8 | 8 |
| 1 | 8 | 8 |
| 2 | 8 | 8 |
| 3 | 8 | 8 |
| 4 | 8 | 8 |
| 5 | 8 | 8 |
| 6 | 8 | 8 |
| 7 | | |
| 8 | | |
| 9 | | |
| 10 | | |
| 11 | | |
| 12 | | |
| 13 | | |
| 14 | | |
| 15 | | |
| 16 | | |

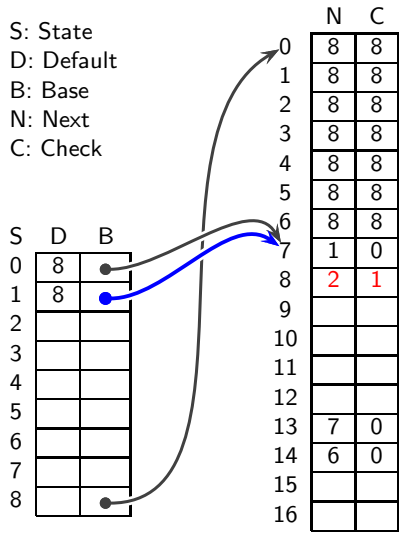
# Four Arrays Representation Using Equivalence Classes for Example 2

| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |



# Four Arrays Representation Using Equivalence Classes for Example 2

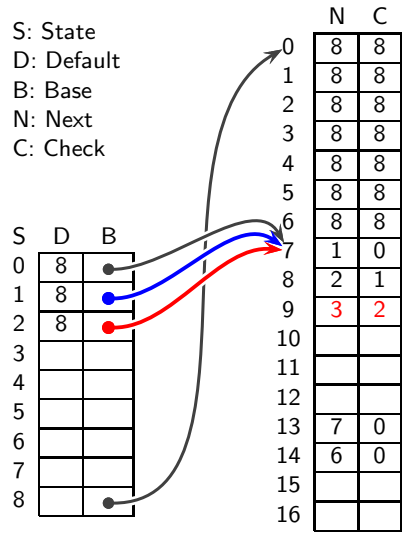
| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |





# Four Arrays Representation Using Equivalence Classes for Example 2

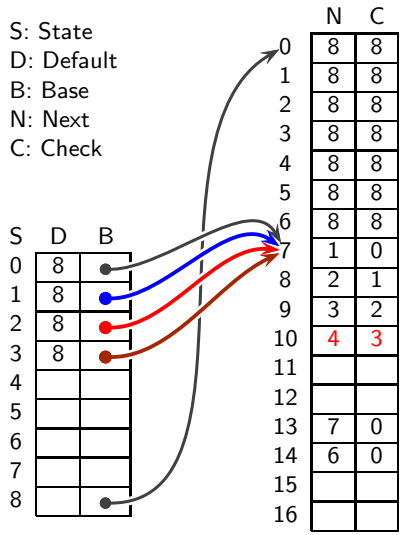
| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |





# Four Arrays Representation Using Equivalence Classes for Example 2

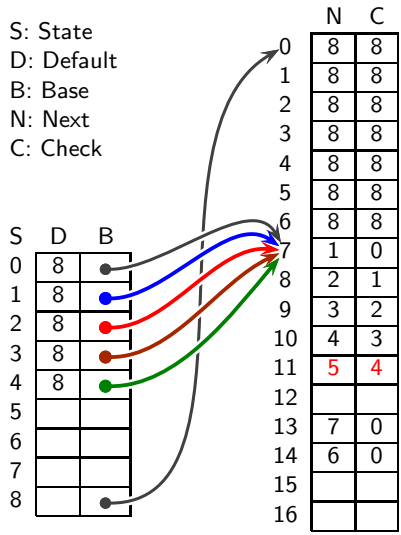
| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |





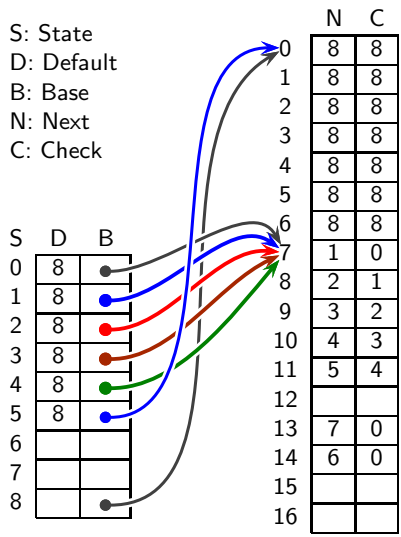
# Four Arrays Representation Using Equivalence Classes for Example 2

| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |



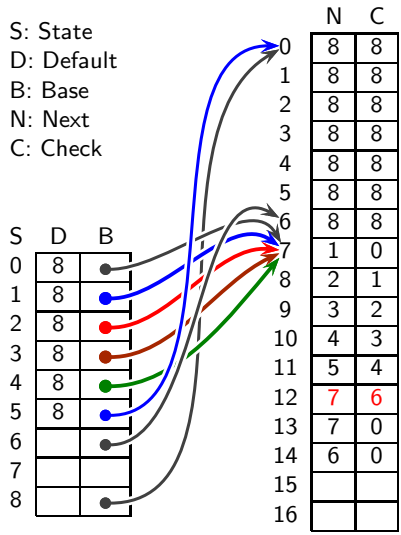
# Four Arrays Representation Using Equivalence Classes for Example 2

| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |



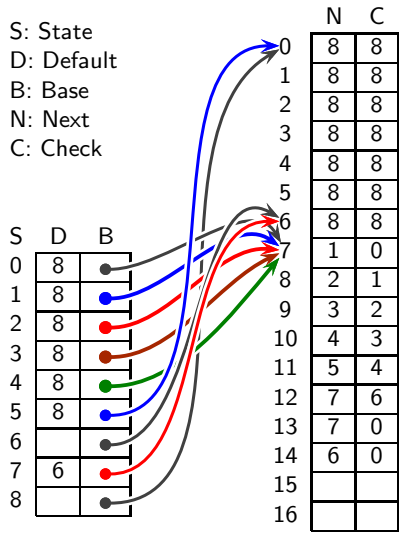
# Four Arrays Representation Using Equivalence Classes for Example 2

| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |



# Four Arrays Representation Using Equivalence Classes for Example 2

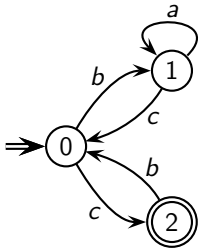
| EC → | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | b | e | g | i | n | L | D | - |
| 0 | 1 | 8 | 8 | 8 | 8 | 8 | 7 | 6 |
| 1 | 8 | 2 | 8 | 8 | 8 | 8 | 8 | |
| 2 | 8 | 8 | 3 | 8 | 8 | 8 | 8 | |
| 3 | 8 | 8 | 8 | 4 | 8 | 8 | 8 | |
| 4 | 8 | 8 | 8 | 8 | 5 | 8 | 8 | |
| 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |
| 6 | | | | | | | 7 | |
| 7 | | | | | | | 7 | |
| 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | |





# Tutorial Problem

Represent the following DFA using 4-arrays notation as compactly as possible

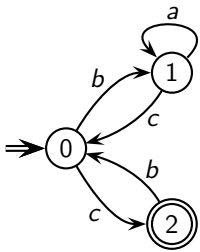



| Character | Code |
|---|---|
| *a* | 0 |
| *b* | 1 |
| *c* | 2 |



# Tutorial Problem

Represent the following DFA using 4-arrays notation as compactly as possible




| Character | Code |
|---|---|
| *a* | 0 |
| *b* | 1 |
| *c* | 2 |

| State | Base | Default |
|---|---|---|
| 0 | 2 | |
| 1 | 0 | |
| 2 | 0 | |

| | Next | Check |
|---|---|---|
| 0 | 1 | 1 |
| 1 | 0 | 2 |
| 2 | 0 | 1 |
| 3 | 1 | 0 |
| 4 | 2 | 0 |
| 5 | | |



# Minimizing DFAs



# Minimizing DFAs

Prof. Sanyal's slides (scanning-slides-sanyal-part3.pdf)