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Finite Automata



Deterministic Finite Automata (DFA)

- In computer science, we study different types of computer languages, such as Basic, Pascal, and C++.
- We will discuss a type of a language that can be recognized by special types of machines.



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Deterministic Finite Automata (DFA)

- A deterministic finite automaton (pl. automata) is a mathematical model of a machine that accepts languages of some alphabet.

prepared by Razana Alwee

- Deterministic Finite Automaton is a quintuple

$$M = \{ S, I, q_0, f_s, F \}$$

where,

S is a finite nonempty set of states

I is the input alphabet (a finite nonempty set of symbols)

q_0 is the initial state

f_s is the state transition function

F is the set of final states, subset of S .



- Let $M = \{ \{q_0, q_1, q_2\}, \{0, 1\}, q_0, f_s, \{q_2\} \}$

where f_s is defined as follows:

$$f_s(q_0, 0) = q_1, \quad f_s(q_1, 1) = q_2$$

$$f_s(q_0, 1) = q_0, \quad f_s(q_2, 0) = q_0$$

$$f_s(q_1, 0) = q_2, \quad f_s(q_2, 1) = q_1$$

- Note that for M :
 $S = \{q_0, q_1, q_2\}$, $I = \{0, 1\}$, $F = \{q_2\}$
 q_0 is the initial state

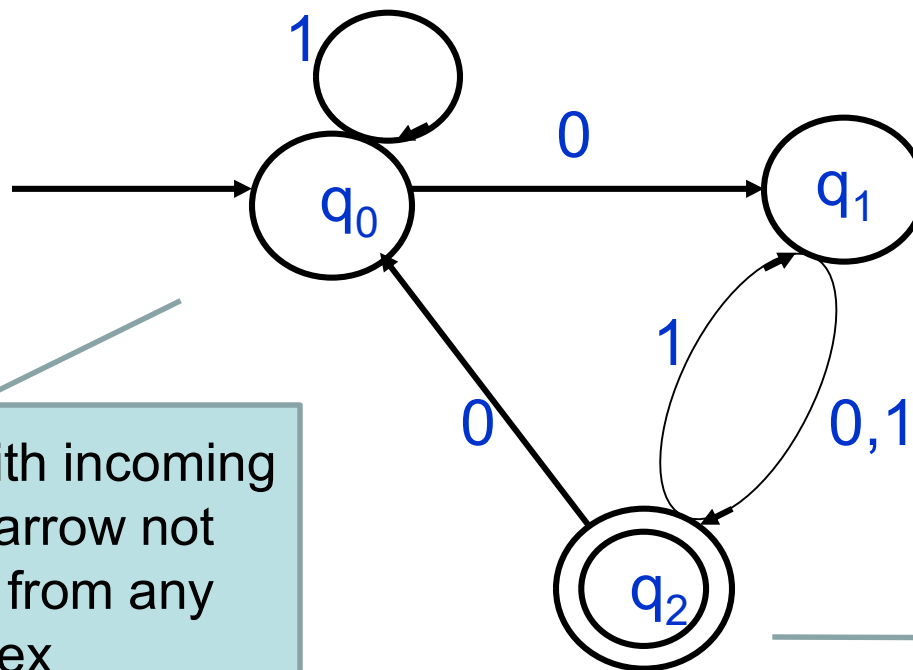


- The state transition function of a DFA is often described by means of a table, called a **transition table**.

f_s	0	1
q_0	q_1	q_0
q_1	q_2	q_2
q_2	q_0	q_1



- The transition diagram of this DFA is,



Each state represented by a small circle labeled with the state

Initial state with incoming unlabeled arrow not originating from any vertex

Final state with a double circle

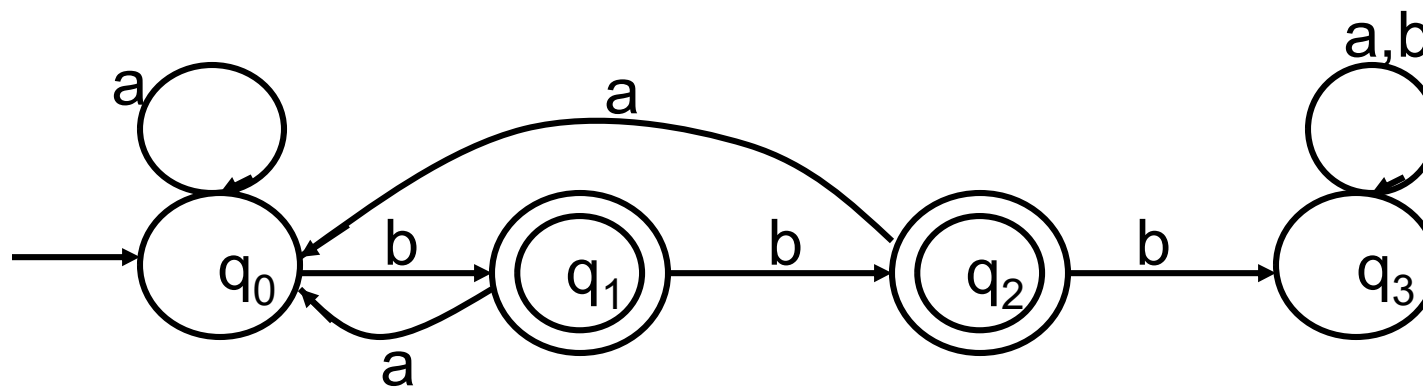
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Let $M = (\{q_0, q_1, q_2, q_3\}, \{a, b\}, q_0, f_s, \{q_1, q_2\})$
where f_s is given by the table

f_s	a	b
q_0	q_0	q_1
q_1	q_0	q_2
q_2	q_0	q_3
q_3	q_3	q_3

- The transition diagram of this DFA is,



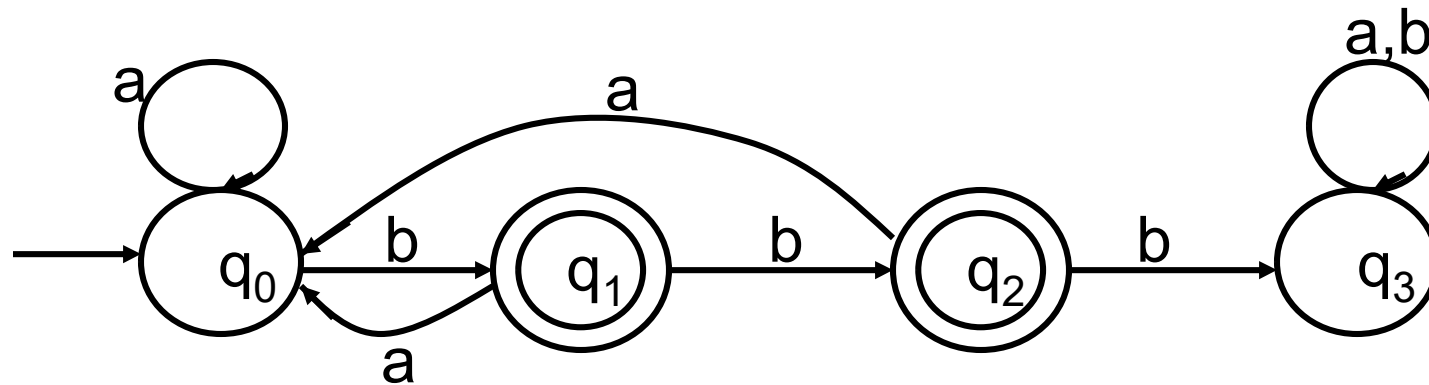
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Deterministic Finite Automata (DFA)

- Let $M = \{ S, I, q_0, f_s, F \}$ be a DFA and w is an input string,
- w is said to be accepted by M if
$$f_s^*(q_0, w) \in F$$
- f_s^* - extended transition function for M



example



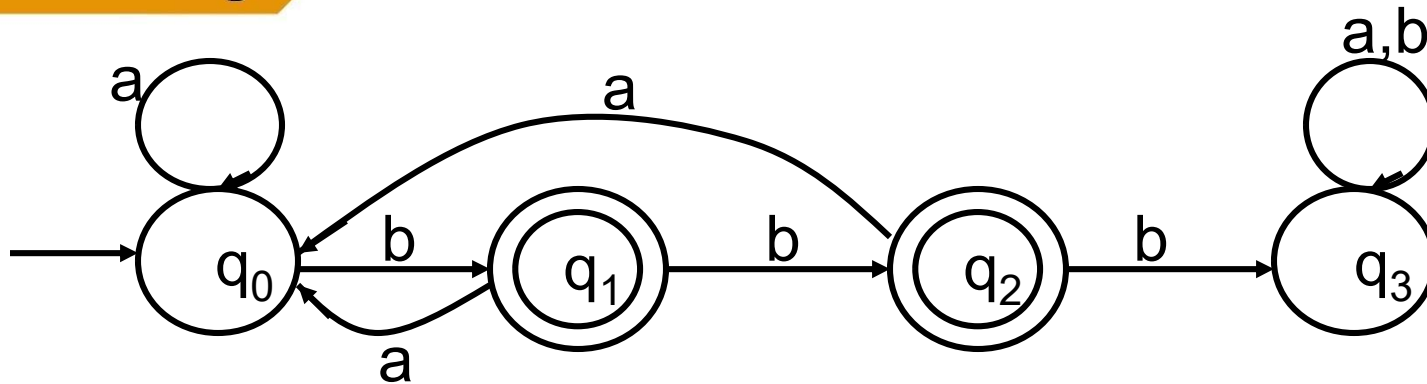
$w = abb$

$q_0 \xrightarrow{a} q_0 \xrightarrow{b} q_1 \xrightarrow{b} q_2$

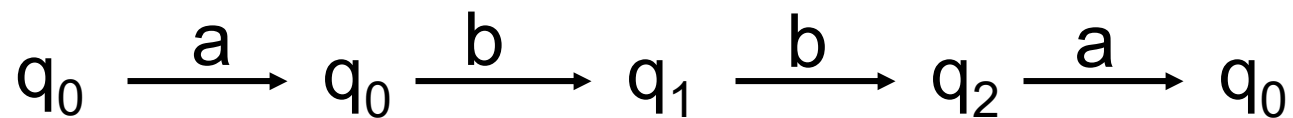
accepted
by M



example



w = abba

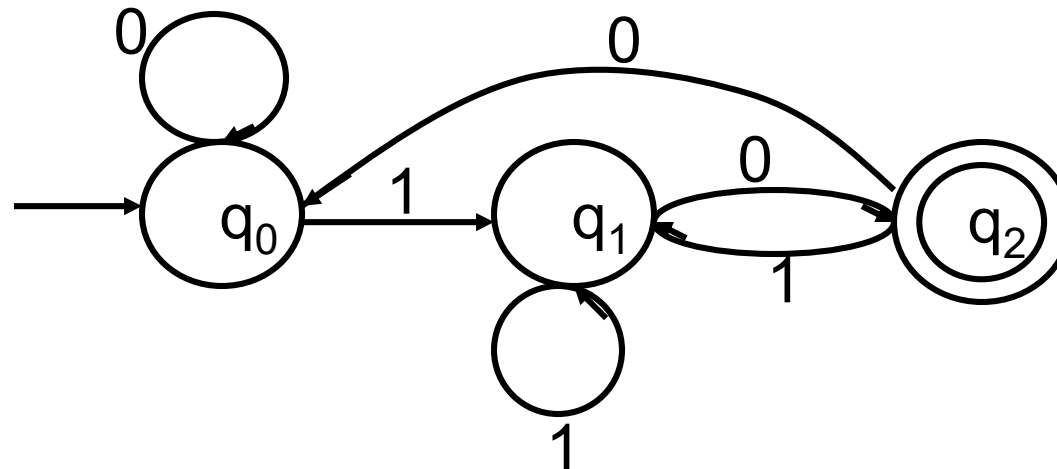


not accepted by M

prepared by Razana Alwee



example

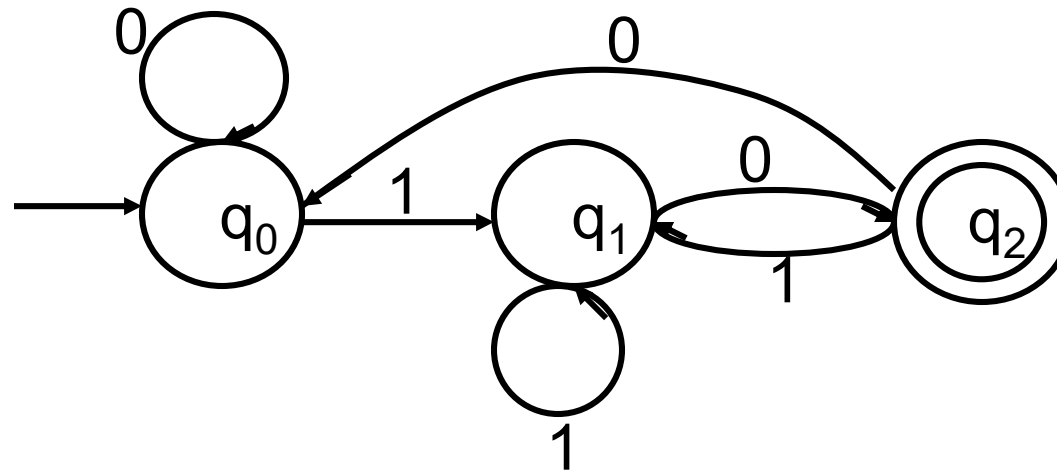


- What are the states of M? q_0, q_1, q_2
- Write the set of input symbols. $I = \{0, 1\}$
- Which is the initial state? q_0

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example



- Write the set of final states.

$$F = \{q_2\}$$

- Write the transition table for this DFA



The transition table, f_s

f_s	0	1
q_0	q_0	q_1
q_1	q_2	q_1
q_2	q_0	q_1

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example

Which of the strings are accepted by M?

0111010, 00111, 111010,

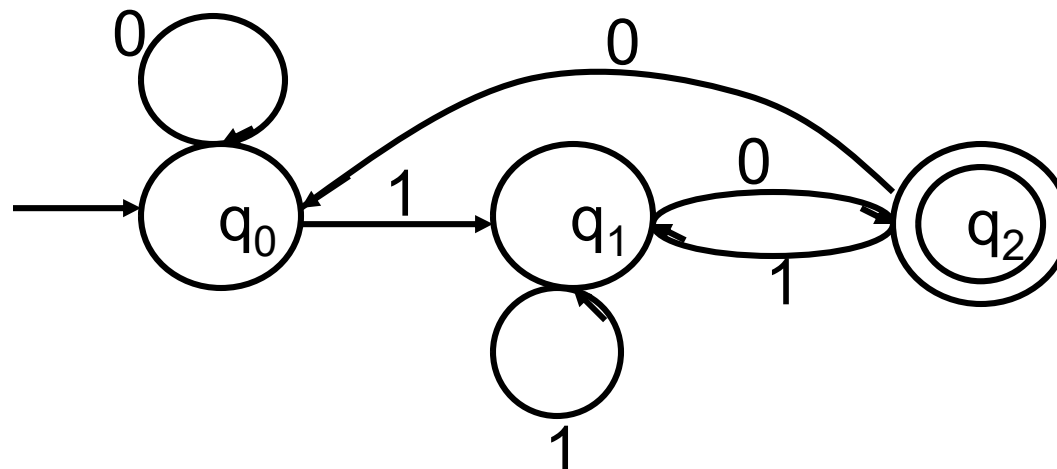
0100, 1110

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example

0111010



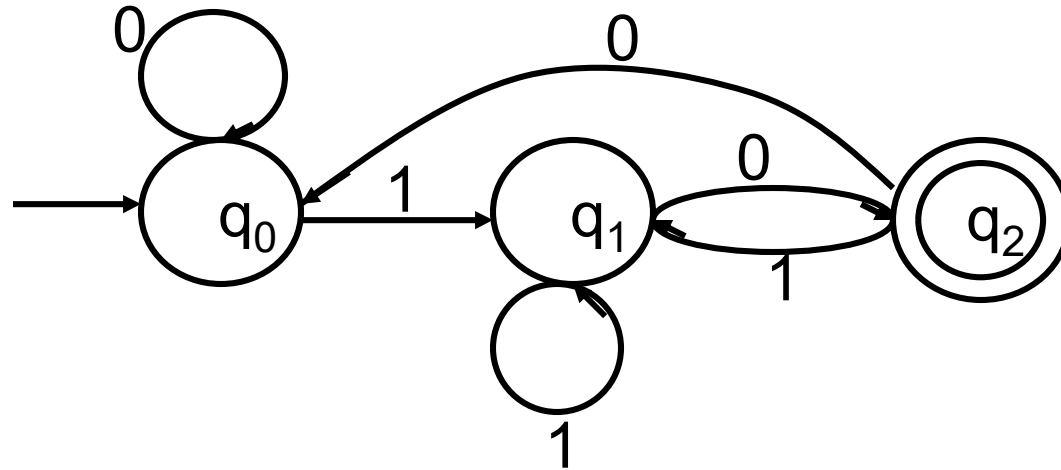
$q_0 \xrightarrow{0} q_0 \xrightarrow{1} q_1 \xrightarrow{1} q_1 \xrightarrow{0} q_2 \xrightarrow{1} q_1 \xrightarrow{0} q_2$

accepted by M



example

00111



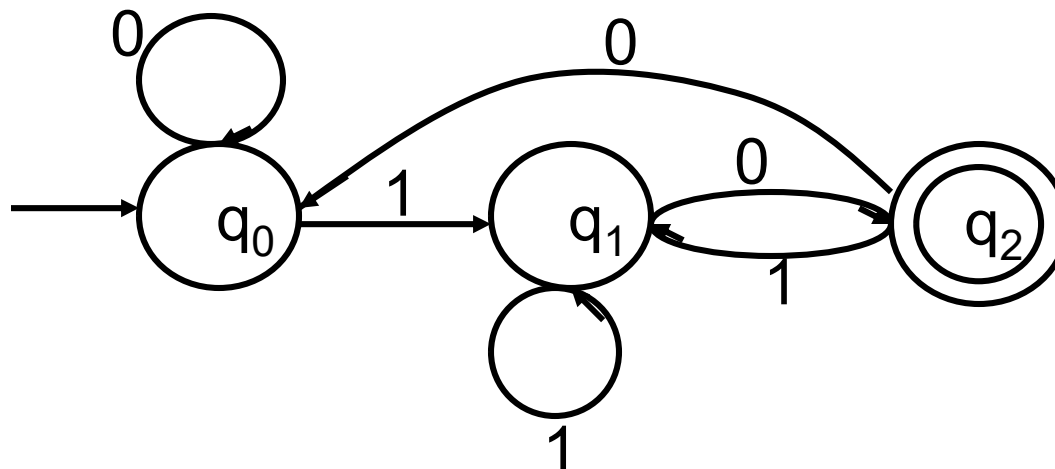
$q_0 \xrightarrow{0} q_0 \xrightarrow{0} q_0 \xrightarrow{1} q_1 \xrightarrow{1} q_1 \xrightarrow{1} q_1$

not accepted by M



example

111010



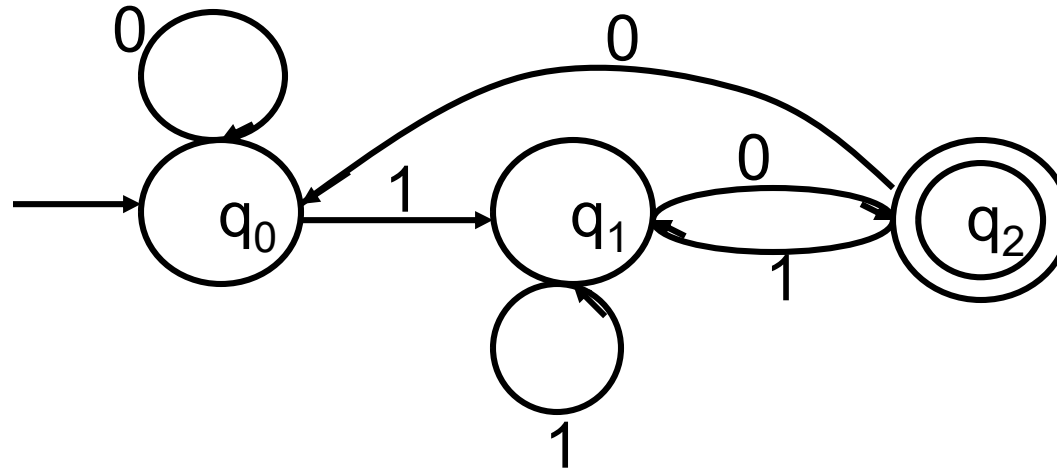
$q_0 \xrightarrow{1} q_1 \xrightarrow{1} q_1 \xrightarrow{1} q_1 \xrightarrow{0} q_2 \xrightarrow{1} q_1 \xrightarrow{0} q_2$

accepted by M



example

0100



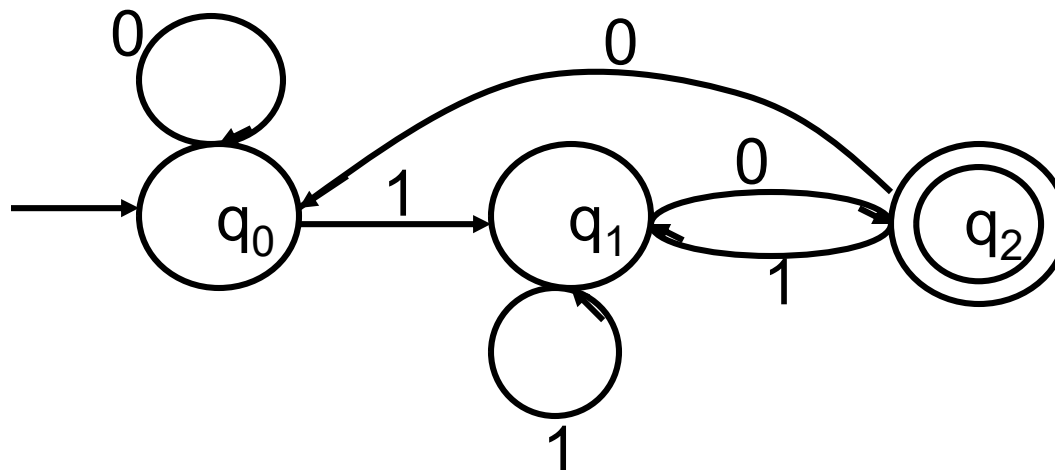
$q_0 \xrightarrow{0} q_0 \xrightarrow{1} q_1 \xrightarrow{0} q_2 \xrightarrow{0} q_0$

not accepted by M



example

1110



$q_0 \xrightarrow{1} q_1 \xrightarrow{1} q_1 \xrightarrow{1} q_1 \xrightarrow{0} q_2$

accepted by M



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example

Construct a state transition diagram of a DFA that accepts on $\{a,b\}$ that contain an even number of a's and an odd number of b's.

Example of accepted strings:

aab, baa, baaabba

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example

4 states,

q_0	even num. of a's & even num. of b's.
q_1	even num. of a's & odd num. of b's.
q_2	odd num. of a's & odd num. of b's.
q_3	odd num. of a's & even num. of b's.

$S = \{q_0, q_1, q_2, q_3\}$

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example

set of states, $S = \{q_0, q_1, q_2, q_3\}$

set of input symbols, $I = \{a, b\}$

initial state, q_0

final state, q_1

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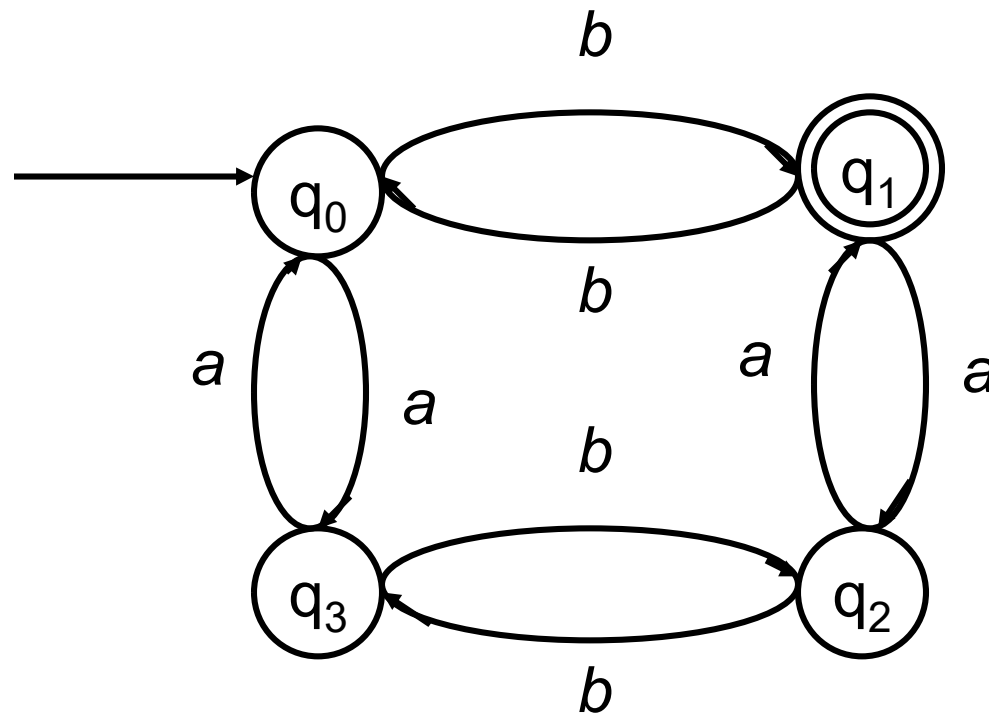
State transition function

f_s	a	b
q_0	q_3	q_1
q_1	q_2	q_0
q_2	q_1	q_3
q_3	q_0	q_2

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State transition diagram



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Let $M=(S, I, q_0, f_s, F)$ be the DFA such that $S=\{q_0, q_1, q_2\}$, $I=\{a, b\}$, $F=\{q_2\}$, q_0 =initial state, and f_s is given by,

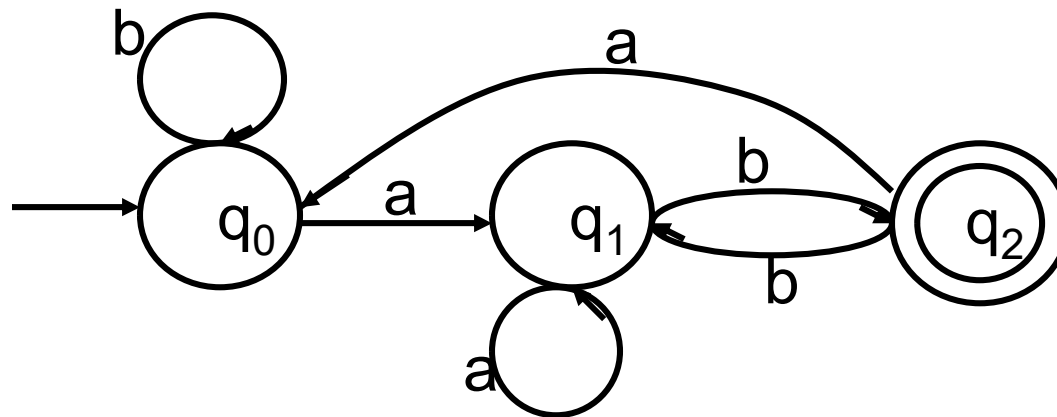
f_s	a	b
q_0	q_0	q_1
q_1	q_2	q_1
q_2	q_2	q_0

Draw the state diagram of M.

Which of the strings
**abaa, bbbabb, bbbaa dan
bababa**

are accepted by M?

The transition diagram of M is,



Construct the transition table of M.

Which of the strings

baba, baab, abab dan abaab

are accepted by M?

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exercise

- Construct a state transition diagram of a DFA M with the input set $\{0,1\}$ such that M accepts only the string 101.

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Exercise

- Construct a deterministic finite automaton (DFA) that accepts the set of all bit strings that contain string '0101'.

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Exercise

- Construct a deterministic finite automaton (DFA) that accepts all string over $\{a,b\}$ that contain ab and end in bbb

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Construct a state transition diagram of a DFA that accepts all string over $\{a, b, \dots, z, 0, 1, \dots, 9\}$ that start with a letter (a - z) and end with a digit (0 - 9).

Example of accepted strings are $a9$, $xy12$, $a1b2c3$ ect.

Finite State Machines (FSM)

- Automata with input as well as output.
- Every state has an input and corresponding to the input the state also has an output.
- These types of automata are commonly called **finite state machines**.

Finite State Machines (FSM)

- A finite state machine is a sextuple,
 $M = \{ S, I, O, q_0, f_s, f_o \}$
where,
 - S is a finite nonempty set of states
 - I is the input alphabet
 - O is the output alphabet
 - q_0 is the initial state
 - f_s is the state transition function
 - f_o is the output function.



- Let $M = \{ S, I, O, q_0, f_s, f_o \}$ be the FSM
- where,
 - $S = \{q_0, q_1, q_2\},$
 - $I = \{a, b\},$
 - $O = \{0, 1\},$
 - $q_0 =$ initial state,

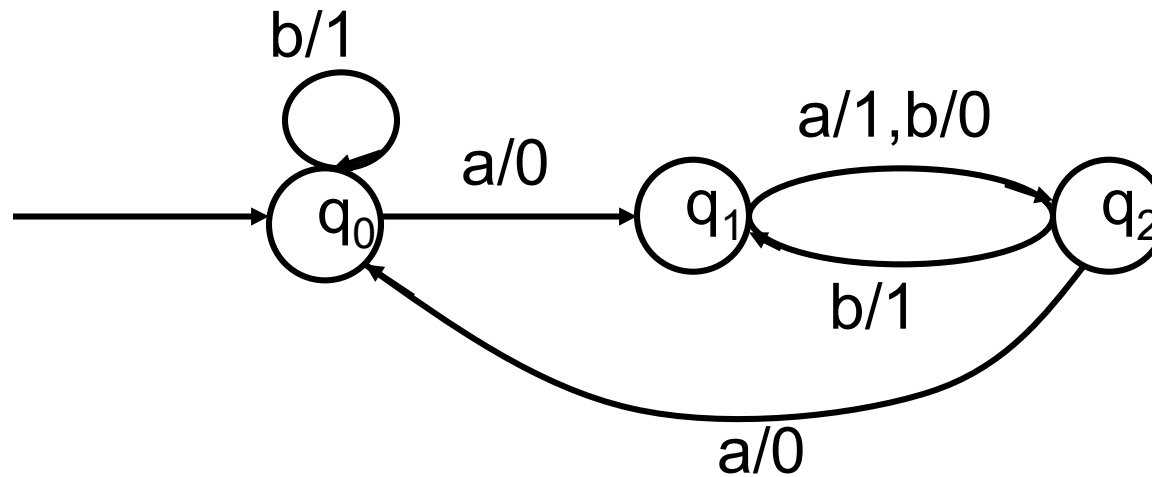


f_s and f_o

	f_s		f_o	
	a	b	a	b
q_0	q_1	q_0	0	1
q_1	q_2	q_2	1	0
q_2	q_0	q_1	0	1



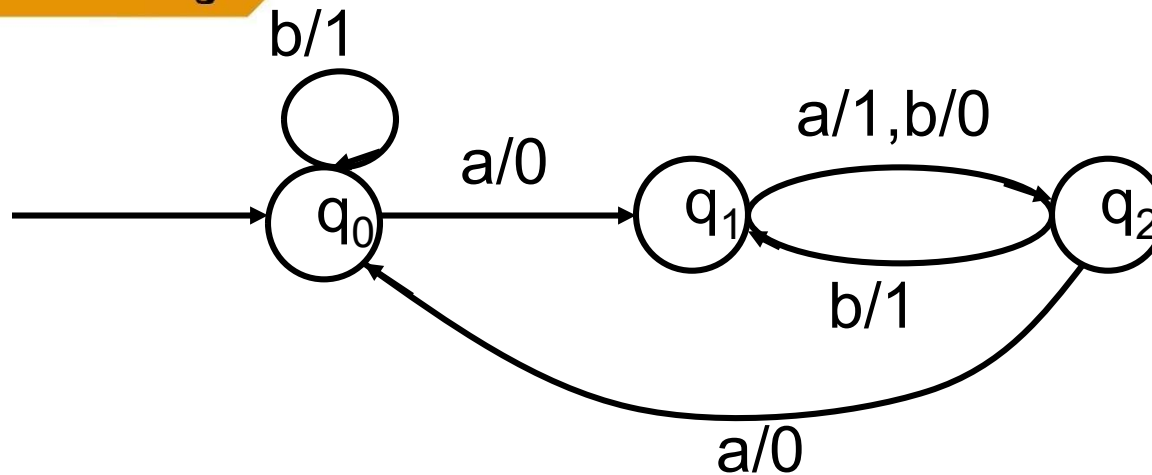
example



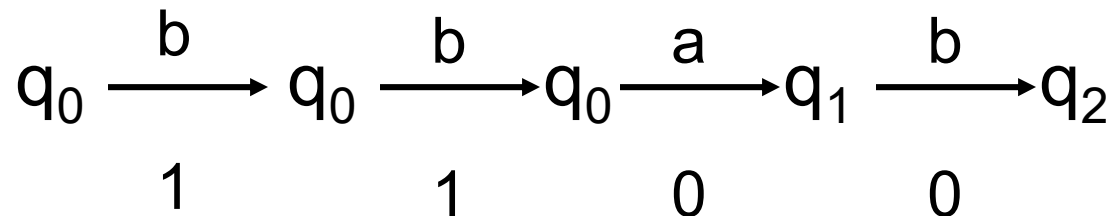
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example



Input string: bbab



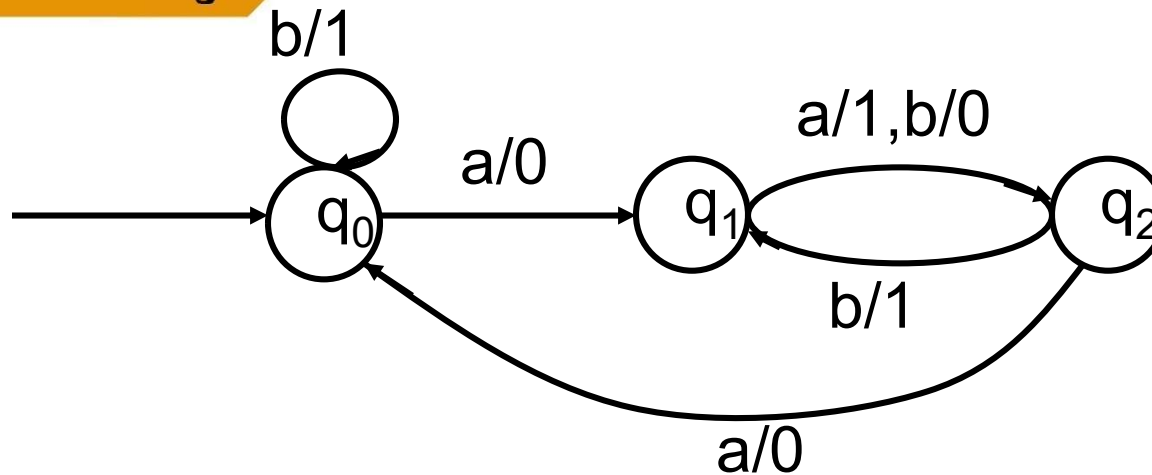
Output string: 1100

Output: 0

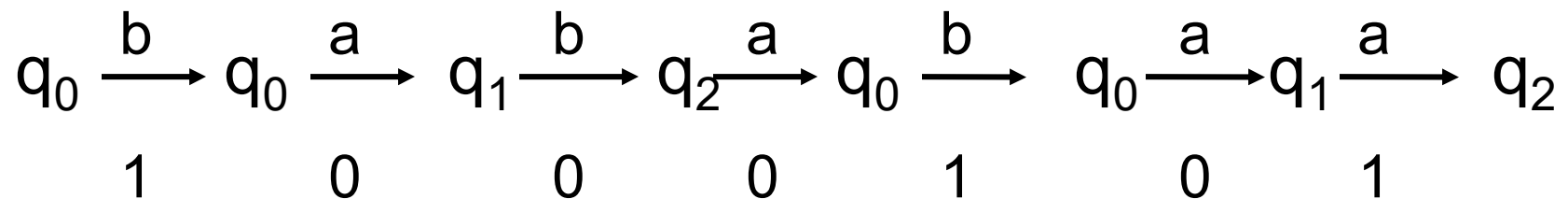
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example



Input string: bababaa



Output string: 1000101

Output: 1

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- Let $M = \{ S, I, O, q_0, f_s, f_o \}$ be the FSM
- where,
 $S = \{q_0, q_1, q_2, q_3\}$,
 $I = \{a, b\}$,
 $O = \{0, 1\}$,
 q_0 = initial state,



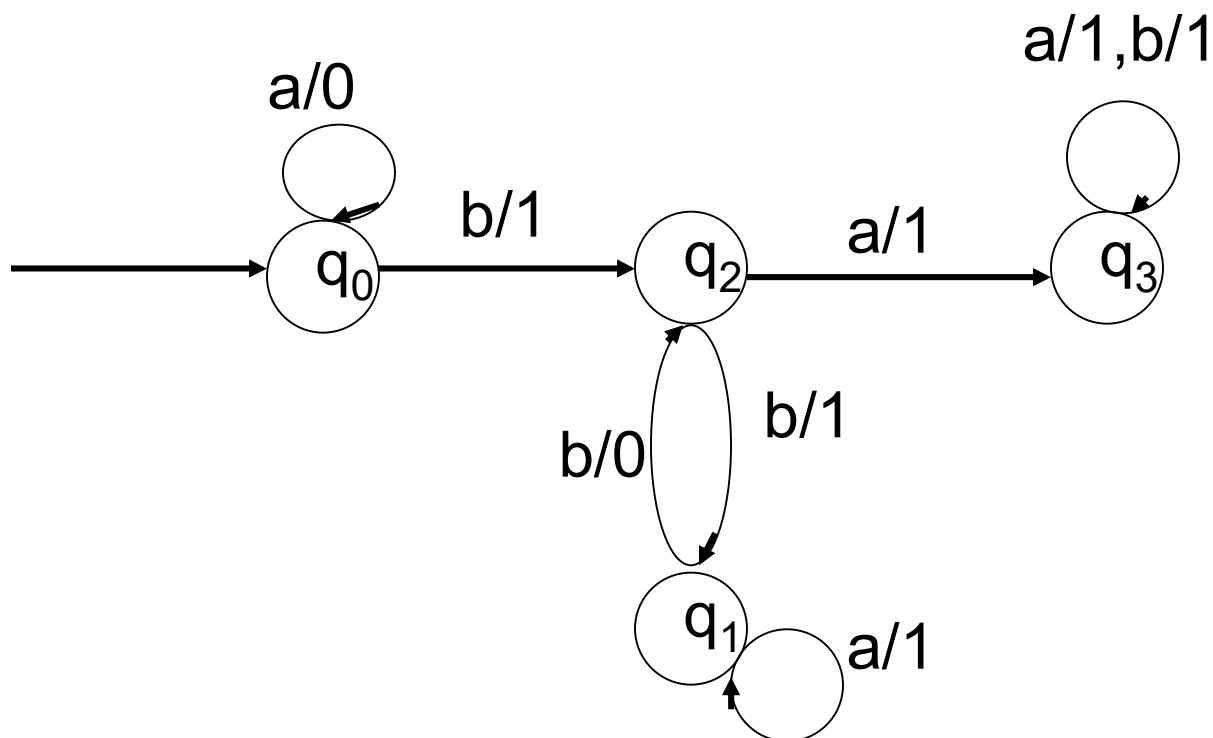
■ f_s and f_o

	f_s		f_o	
	a	b	a	b
q_0	q_0	q_2	0	1
q_1	q_1	q_2	1	0
q_2	q_3	q_1	1	1
q_3	q_3	q_3	1	1

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- Draw the transition diagram of M.



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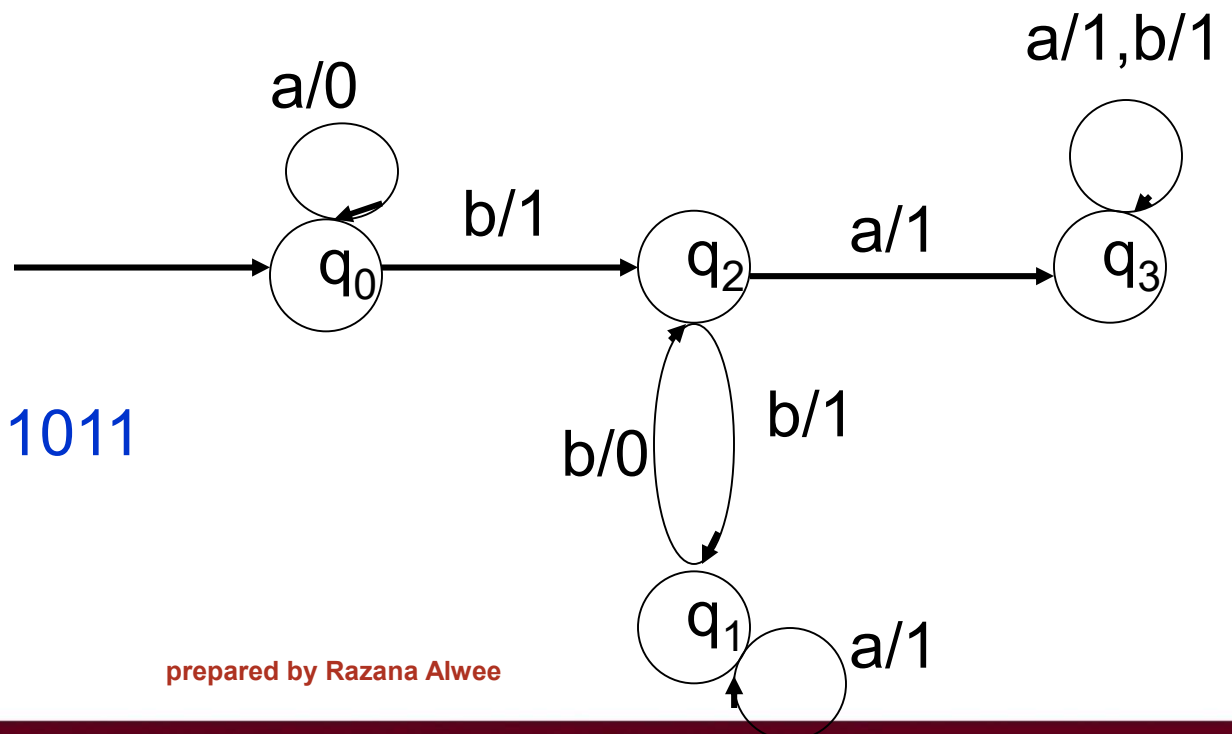
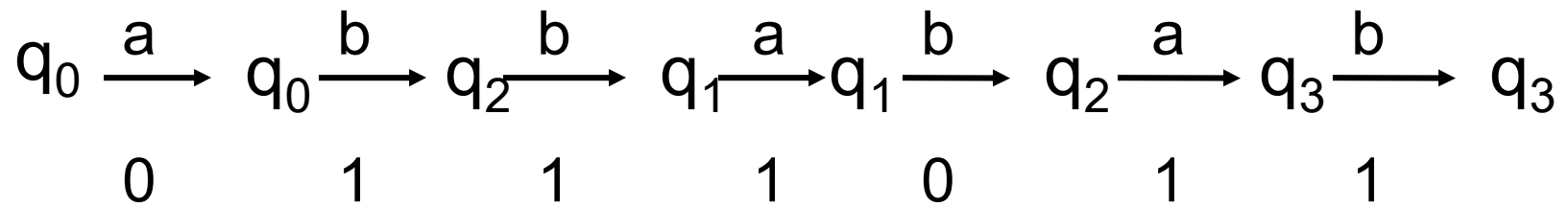
example

- What is the output string if the input string is *abbabab*?

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abbabab



Output string: 0111011

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example

- What is the output of *abbabab*?

Output: 1

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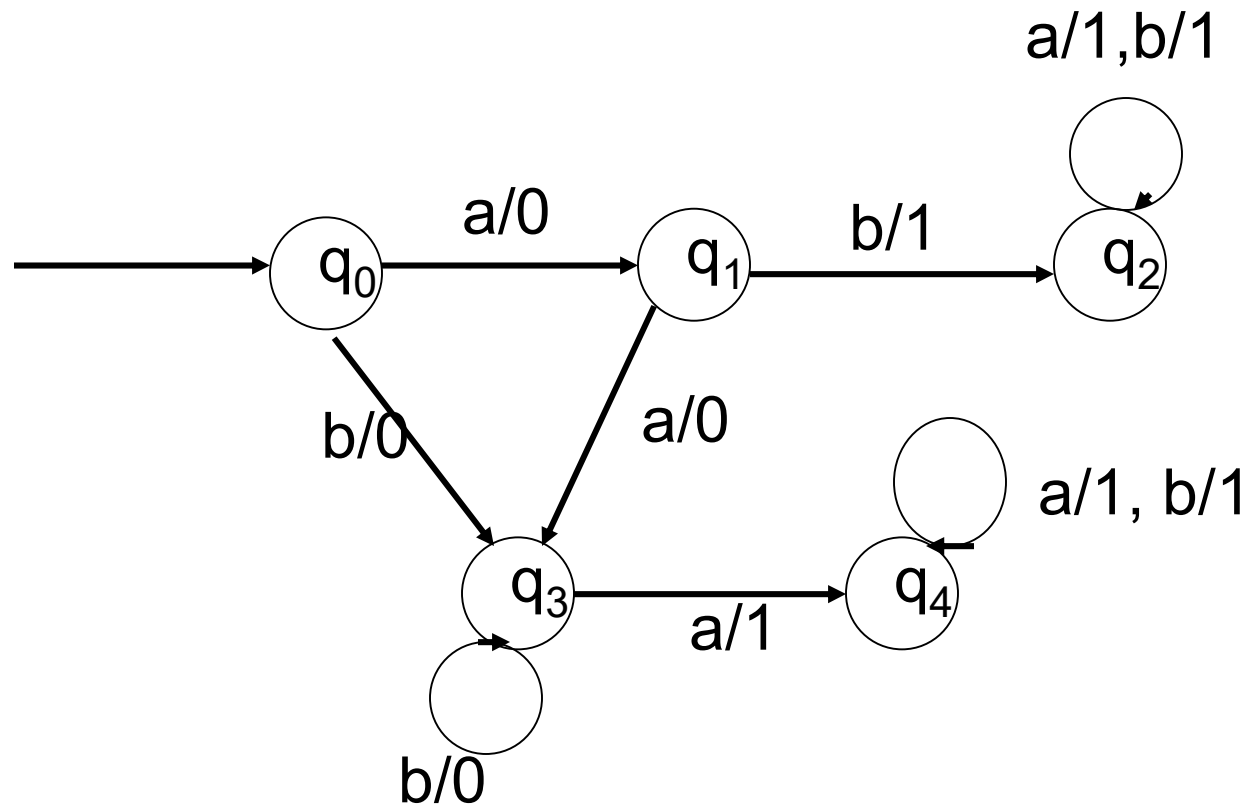
Finite State Machines (FSM)

- Let M be a FSM.
- Let x be a nonempty string in M .
- We say that x is accepted by M if and only if the output of x is 1.

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example



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example

- Write the transition table of M.
- What is the output string if the input string is *aaabbbb*?
- What is the output if the input string is *bbbbaaaa*?

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example

- Is the string *aaa* accepted by M?
- Which of the strings
ba, aabbba, bbbb, aaabbbb
are accepted by M?

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- The transition table of M.

	f_s		f_o	
	a	b	a	b
q_0	q_1	q_3	0	0
q_1	q_3	q_2	0	1
q_2	q_2	q_2	1	1
q_3	q_4	q_3	1	0
q_4	q_4	q_4	1	1

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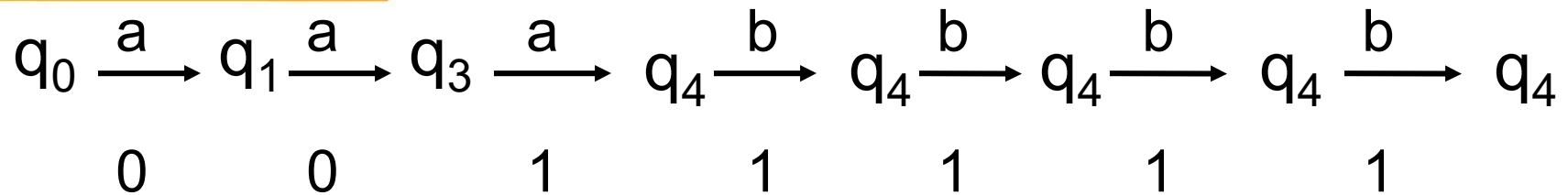
example

- What is the output string if the input string is *aaabbbb*?

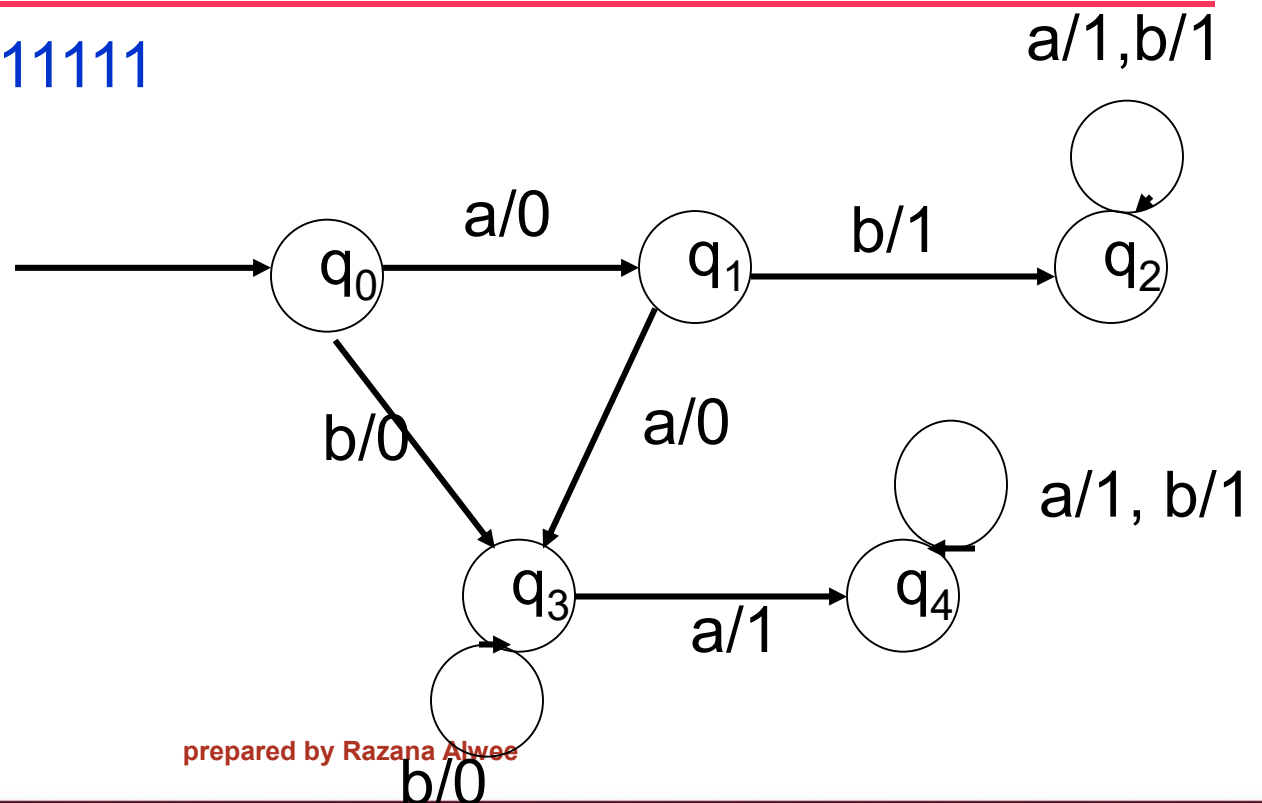
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aaabbbb



Output string: 0011111



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example

- What is the output if the input string is *bbbaaaa*?

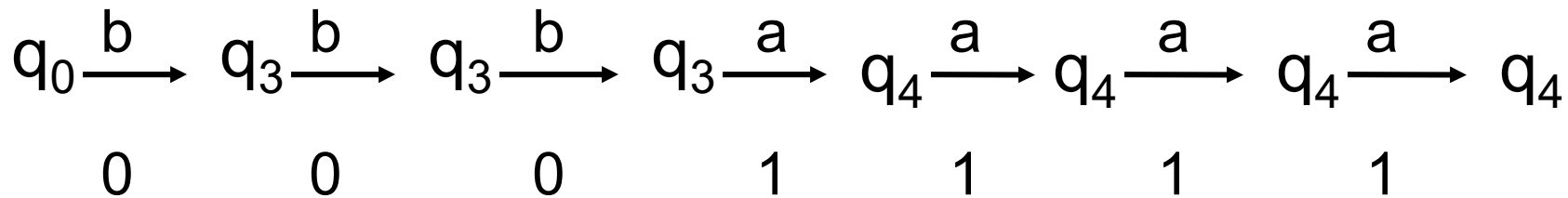
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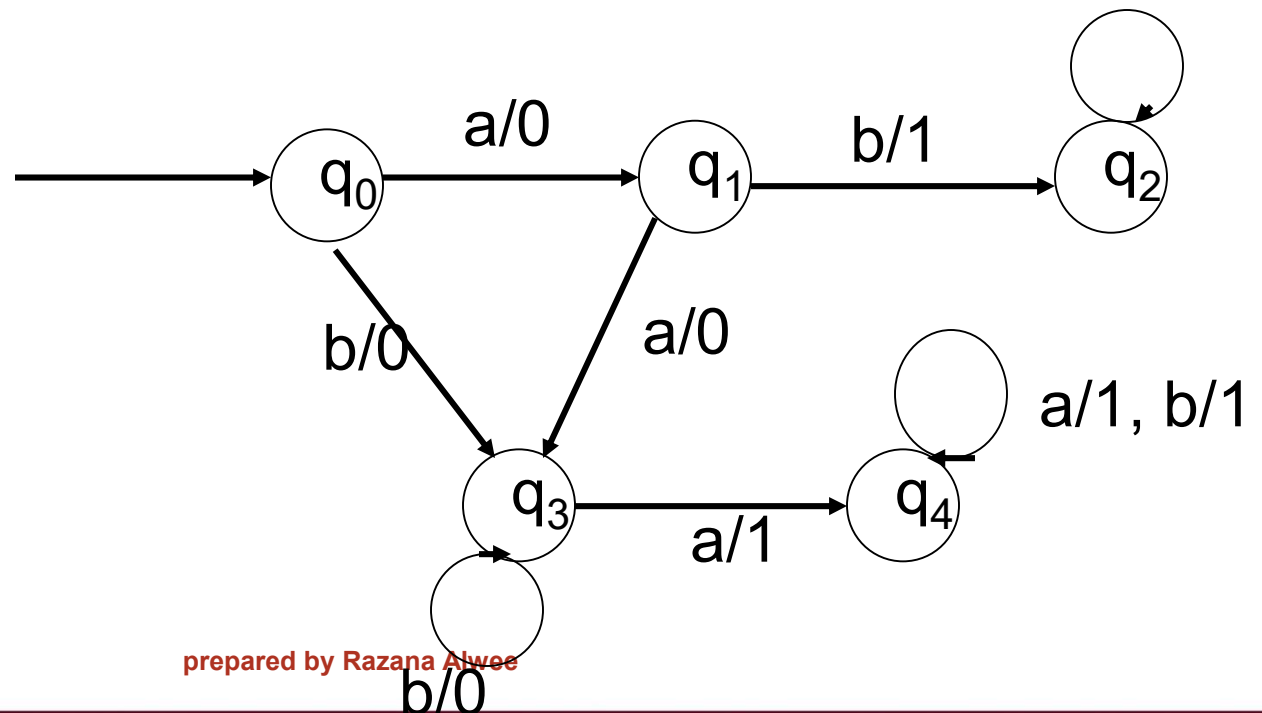
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bbbaaaa



a/1, b/1

Output: 1



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example

- Is the string *aaa* accepted by M?

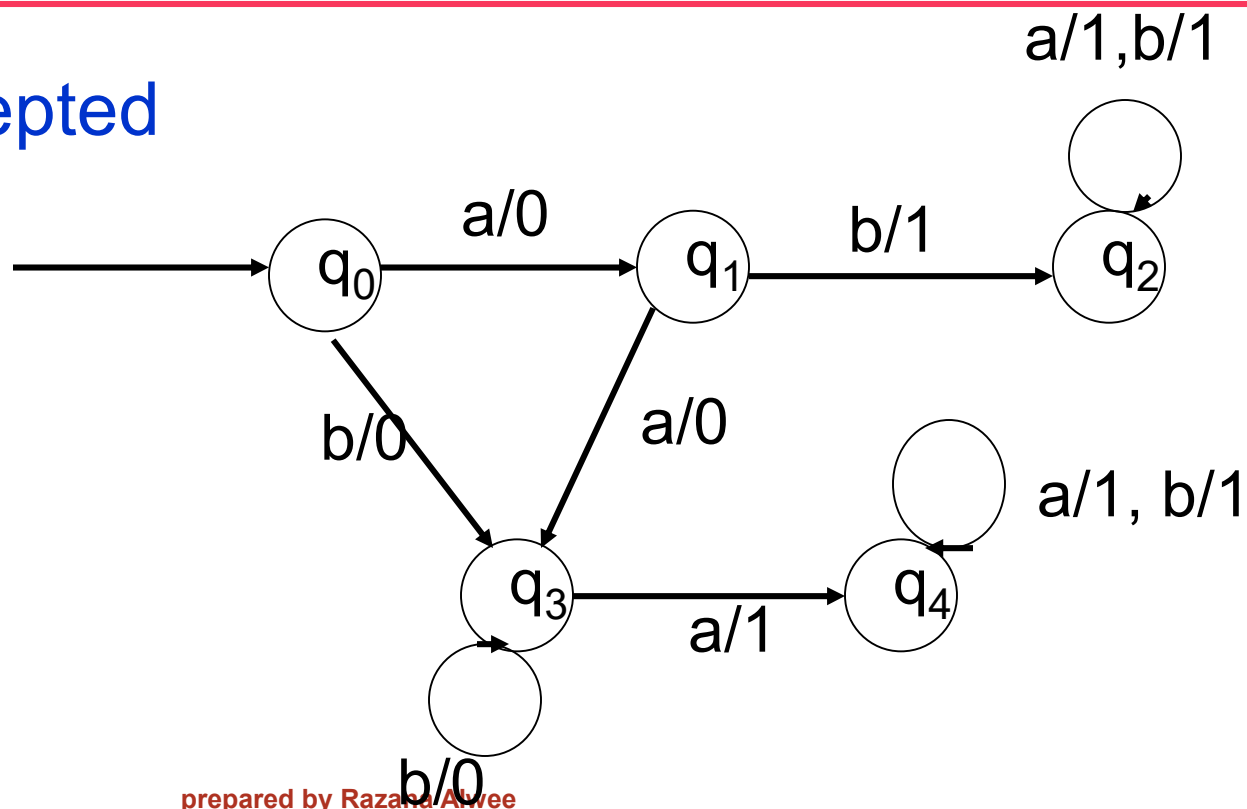
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aaa

$q_0 \xrightarrow[a]{a} q_1 \xrightarrow[a]{a} q_3 \xrightarrow[a]{a} q_4$

Output: 1, accepted



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example

- Which of the strings
ba, aabbba, bbbb, aaabbbb
are accepted by M?

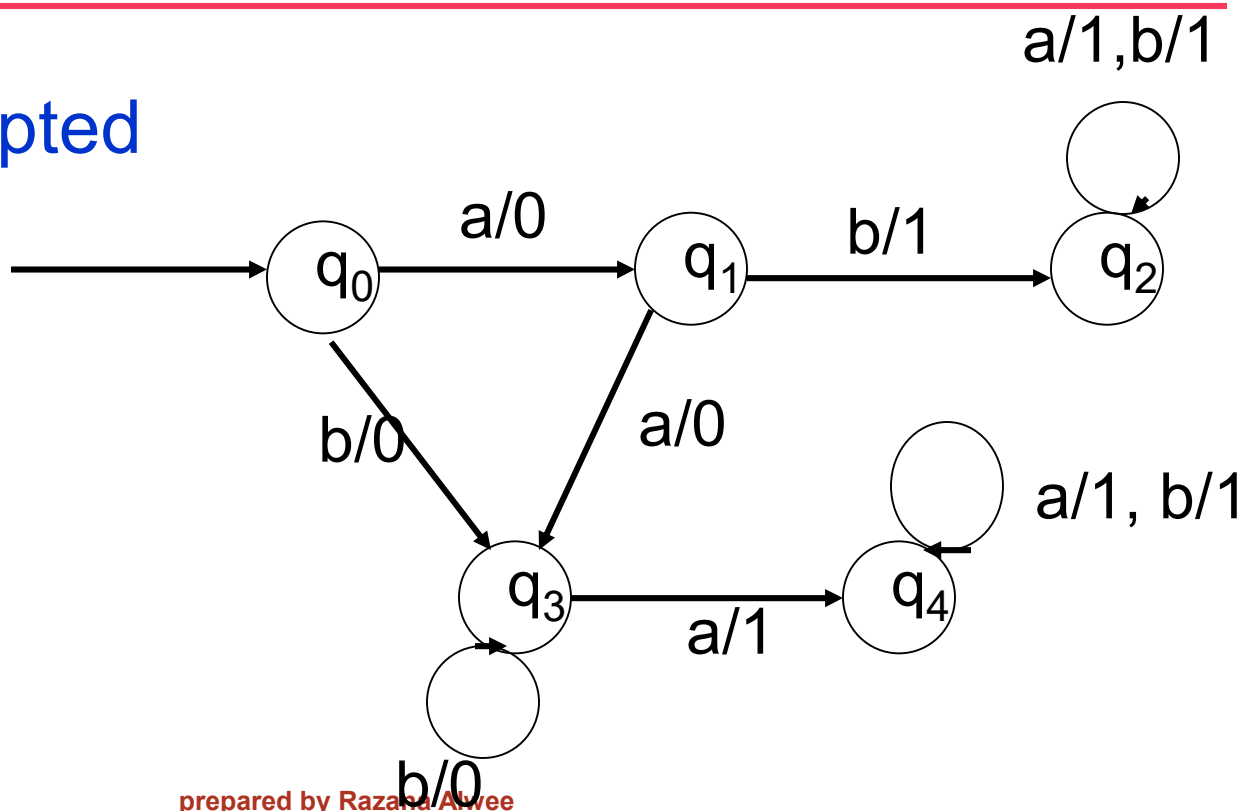
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ba

$$q_0 \xrightarrow[b]{b} q_3 \xrightarrow[1]{a} q_4$$

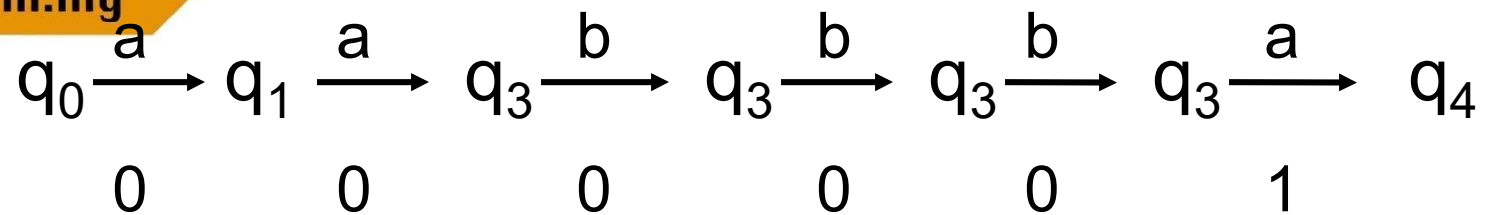
Output: 1, accepted



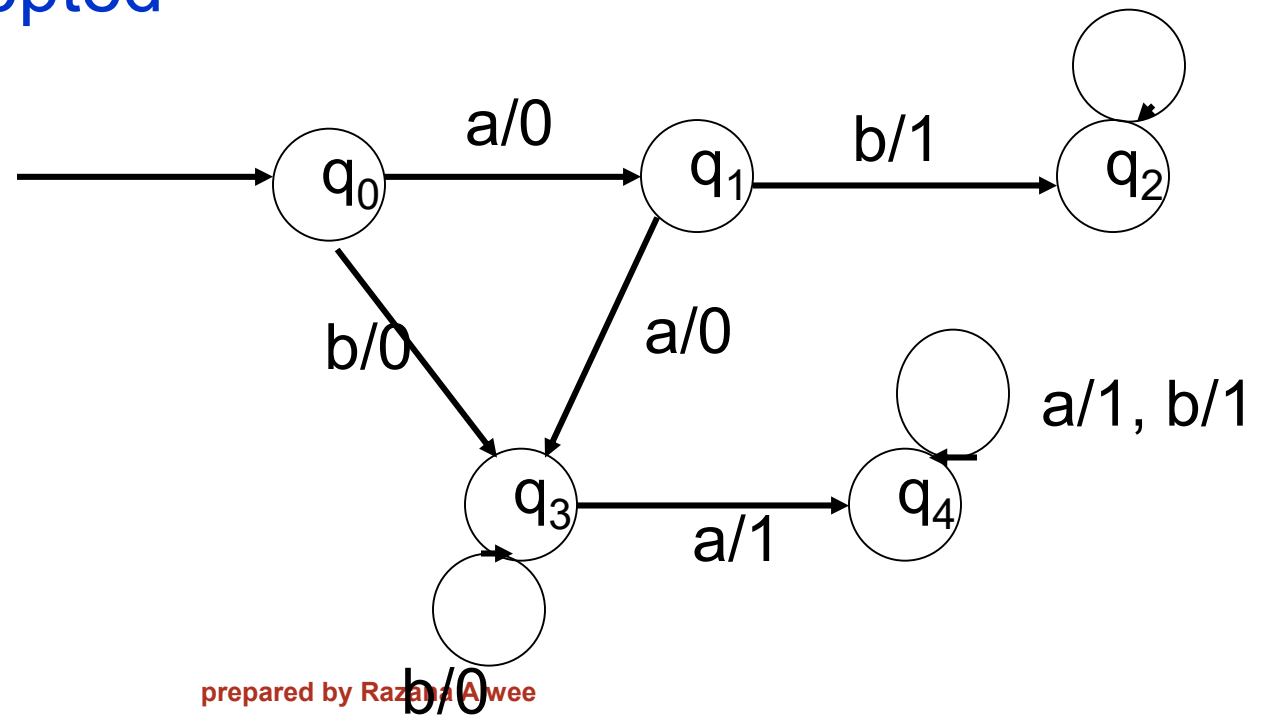
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aabbba



Output: 1, accepted

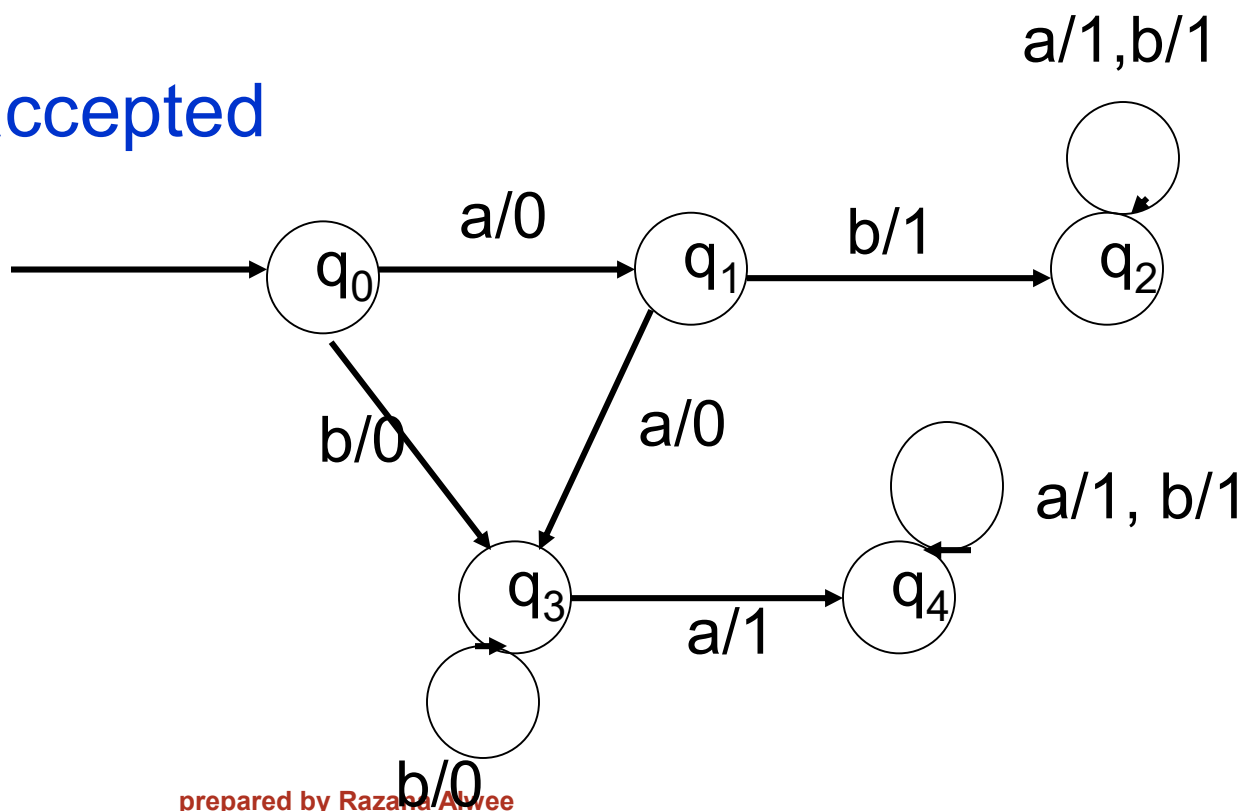




bbbb

$q_0 \xrightarrow[b]{b} q_3 \xrightarrow[b]{b} q_3 \xrightarrow[b]{b} q_3 \xrightarrow[b]{b} q_3$

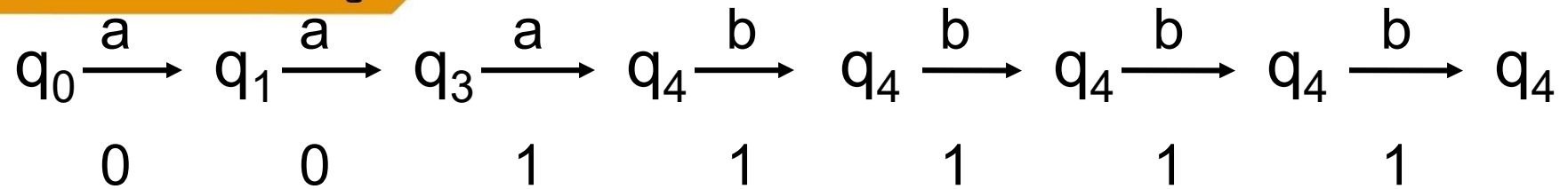
Output: 0, not accepted



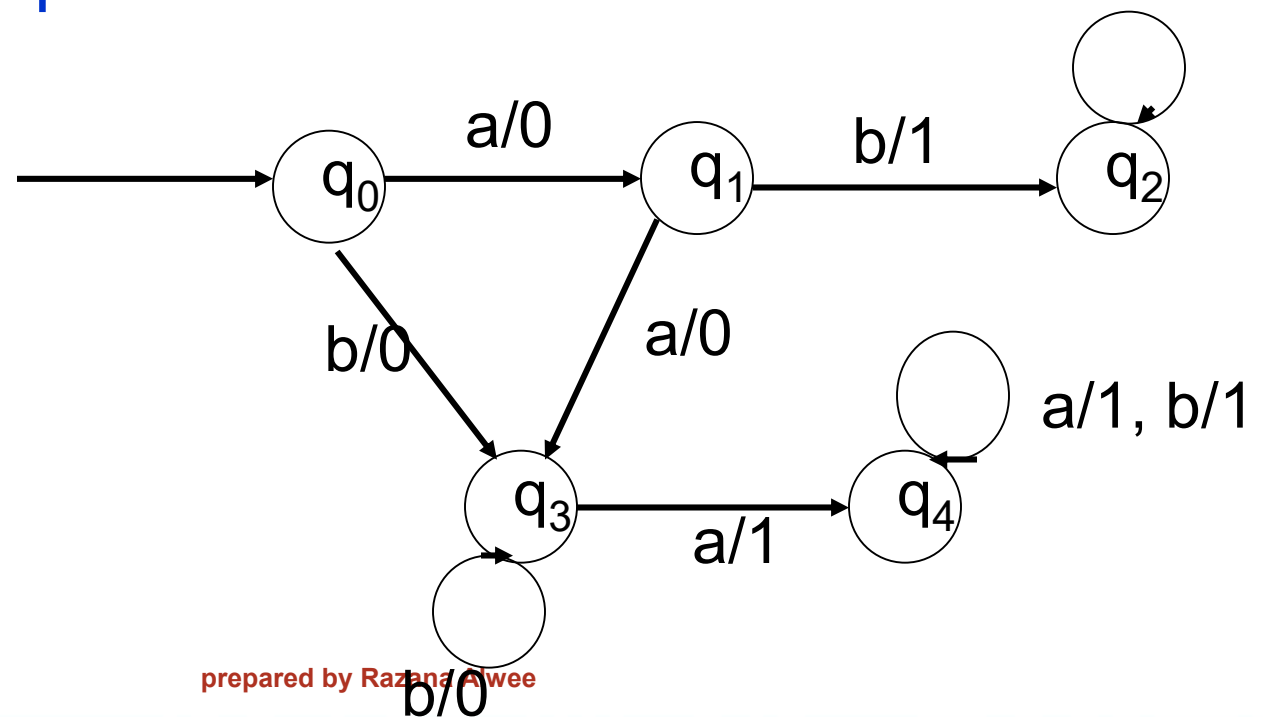
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aaabbbb



Output: 1, accepted



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example

- Consider a vending machine that sells candy and the cost of a candy is 50 cents.
- The machine accepts any sequence of 10-, 20-, or 50 cent coins.
- After inserting at least 50 cents, the customer can press the button to release the candy.

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example

- If the customer inputs more than 50 cents, the machine does not return the change.
- After selling the candy, the machine returns to initial state.
- Construct a finite state machine that models this vending machine.

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example

States,

q_0 , initial state (0)

q_1 , 10 cents

q_2 , 20 cents

q_3 , 30 cents

q_4 , 40 cents

q_5 , ≥ 50 cents

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example

$S = \{q_0, q_1, q_2, q_3, q_4, q_5\},$

$I = \{10, 20, 50, B\},$

$O = \{0, 1\},$

$q_0 = \text{initial state},$

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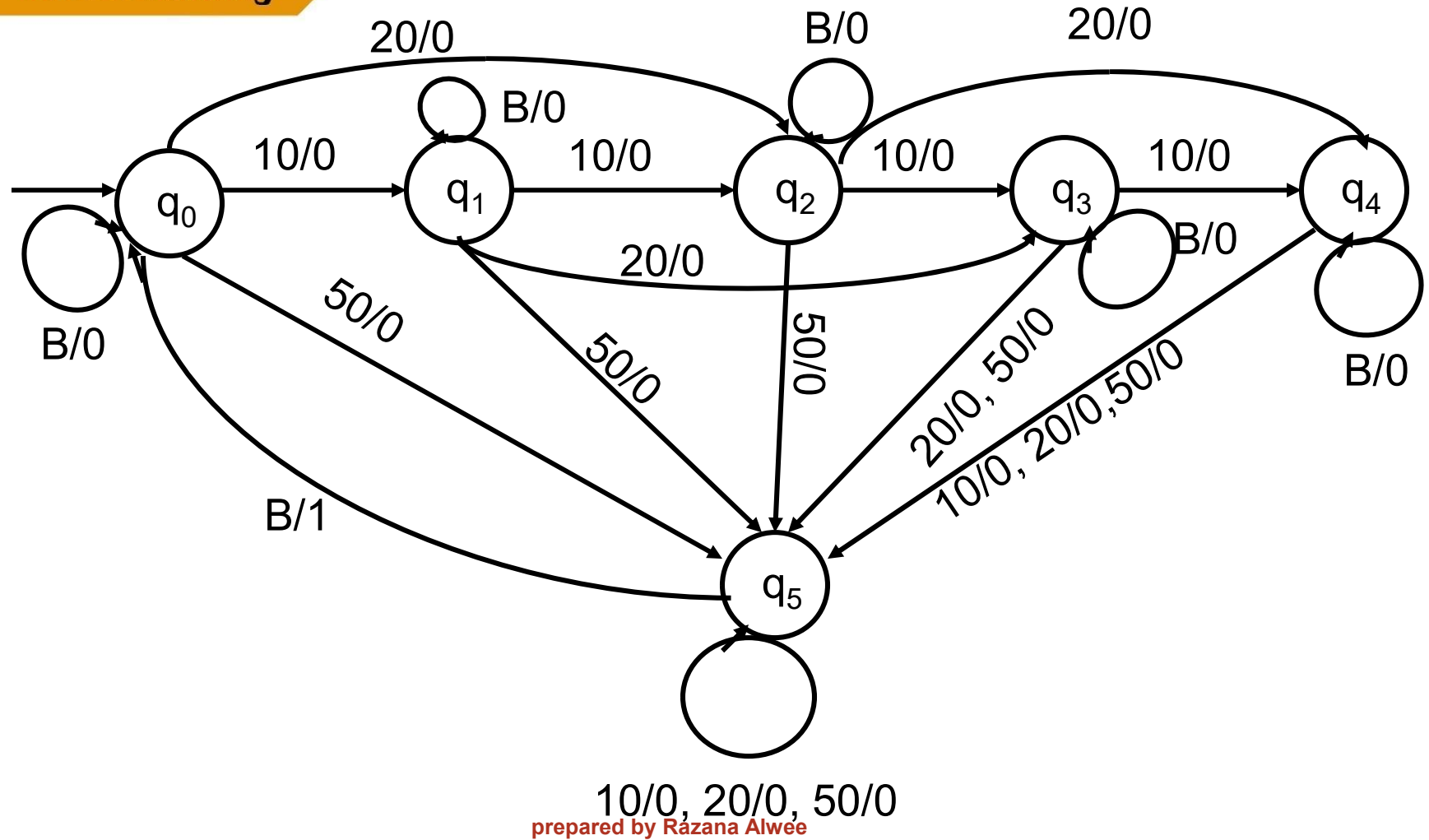
example

		f_s					f_o			
		10	20	50	B		10	20	50	B
q_0	q_1	q_2	q_5	q_0	0	0	0	0	0	0
q_1	q_2	q_3	q_5	q_1	0	0	0	0	0	0
q_2	q_3	q_4	q_5	q_2	0	0	0	0	0	0
q_3	q_4	q_5	q_5	q_3	0	0	0	0	0	0
q_4	q_5	q_5	q_5	q_4	0	0	0	0	0	0
q_5	q_5	q_5	q_5	q_0	0	0	0	0	1	1

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example





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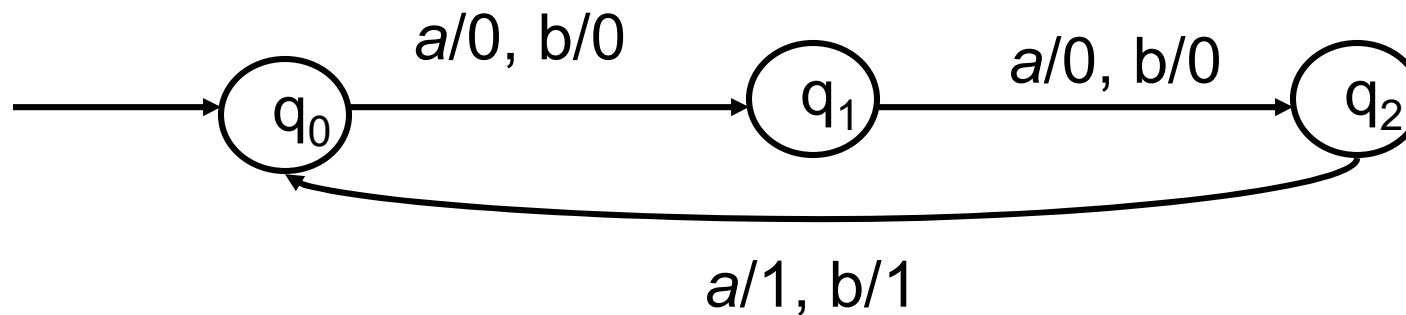
example

- Design a FSM, with input alphabet $I=\{a, b\}$, that outputs a 1 if the number of input symbols read so far is divisible by 3.

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example



prepared by Razana Alwee



Let $M = \{ S, I, O, q_0, f_s, f_o \}$ be a FSM

where,

$S = \{q_0, q_1, q_2\}$,

$I = \{a, b\}$,

$O = \{0, 1\}$,

q_0 = initial state,



f_s and f_o

	f_s		f_o	
	a	b	a	b
q_0	q_2	q_1	1	1
q_1	q_2	q_2	0	0
q_2	q_1	q_2	1	1

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exercise

- Draw the transition diagram of M.
- What is the output string if the input string is *aabbb*?
- What is the output string if the input string is *ababab*?
- What is the output if the input string is *abbbaba*?
- What is the output if the input string is *bbbababa*?

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exercise

- Design a FSM that accepts all string over $\{a,b\}$ that begin with aa.
- For example: aaab, aabba, aababab

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Exercise

- Design a FSM that accepts all string over $\{a,b\}$ that end with aba.
- For example: aaba, aababa, bbbaba

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Exercise

- Design a FSM that accepts all string over $\{a,b\}$ that contain bbb and end in ab

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In a standard washing machine operation, there are four phases which start with Idle/Stop, Wash, Rinse and Spin. When the start/stop button is pressed, the door will be automatically locked, timer will start and the washing machine will begin to wash. After the timer end, the washing machine starts the rinse phase and timer for rinsing phase will begin. After the timer is end, the spin phase will begin. At this point, the timer will start again and after it end, operation of the washing machine is finish and it returns to Idle/Stop condition. At any time during the operation, if the start/stop button is pressed again, the washing machine will stop the operation and return to Idle/Stop condition. The door will always remain locked during the operation unless it is in Idle/Stop condition.

Based on the above washing machine operation,

- a) define all the states, inputs and outputs.
- b) construct a transition diagram.