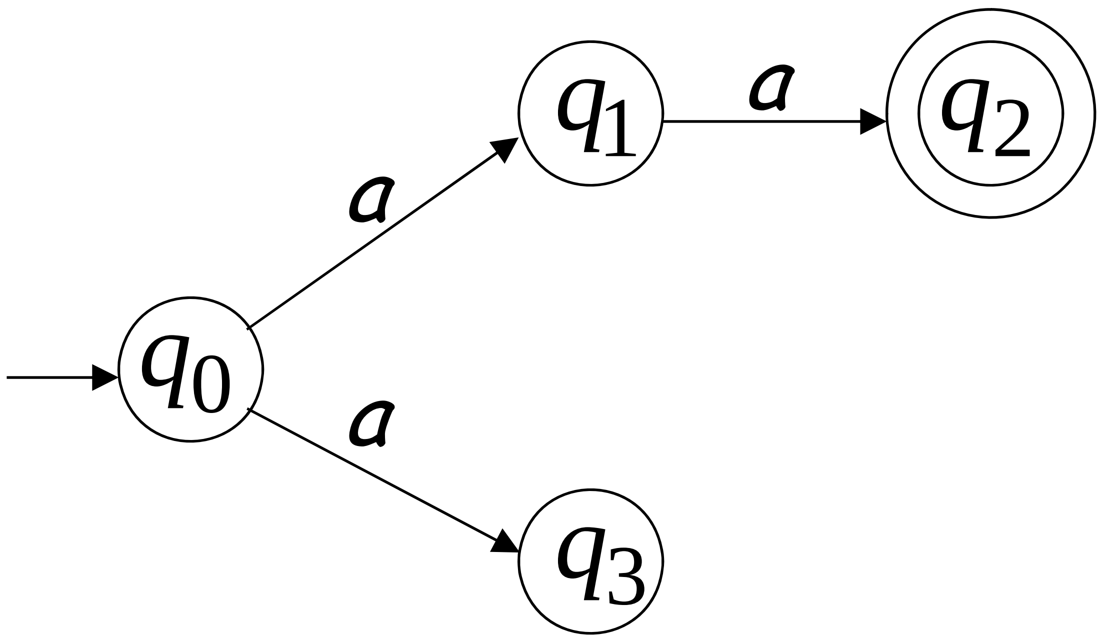
Non Deterministic Automata

Nondeterministic Finite Accepter (NFA)

Alphabet = $\{a\}$



Nondeterministic Finite Accepter (NFA)

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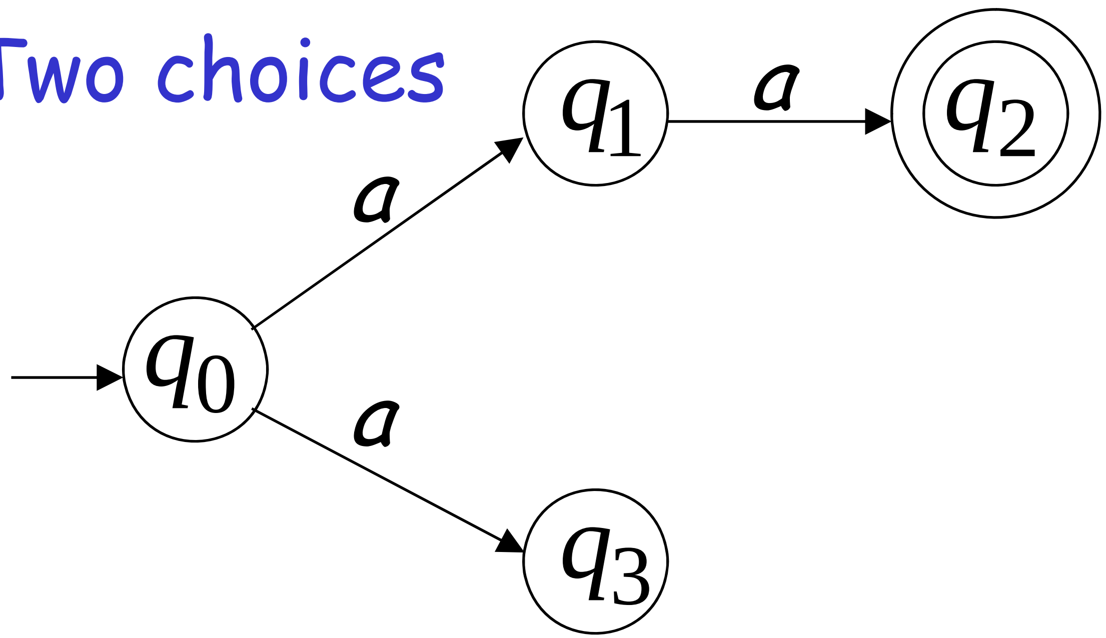

Nondeterministic Finite Accepter (NFA)

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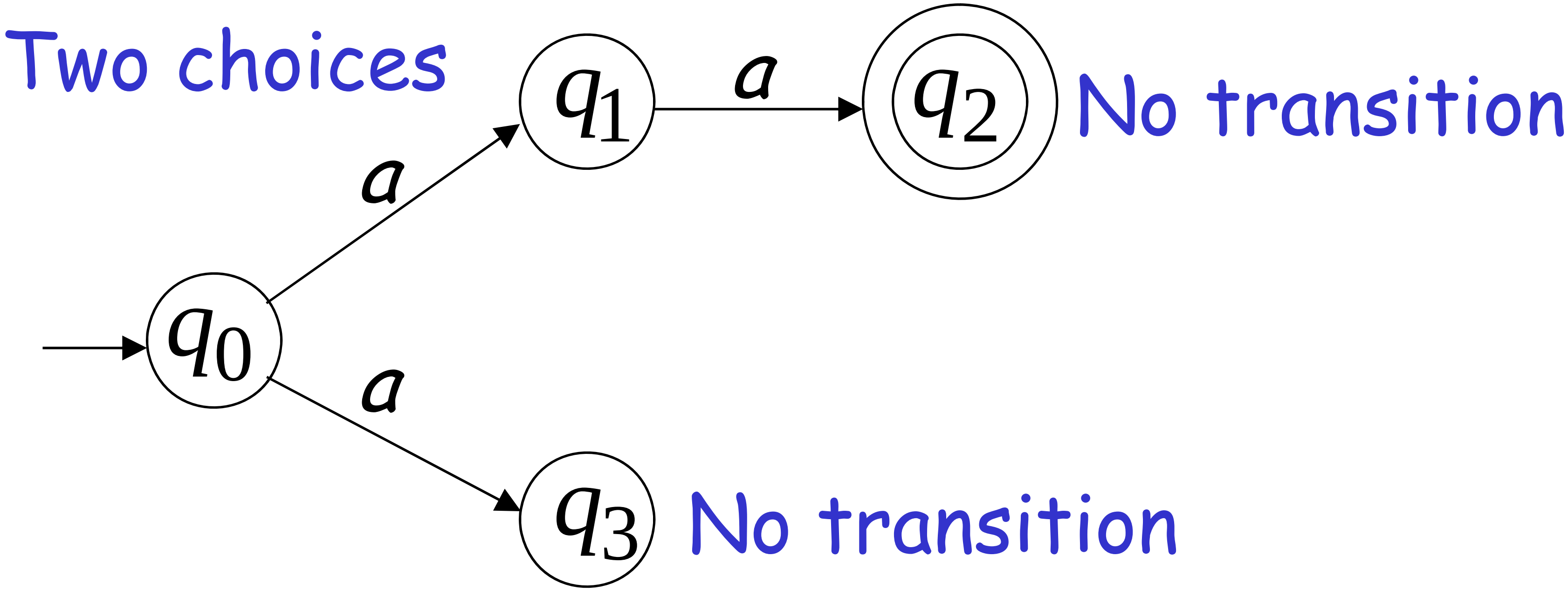
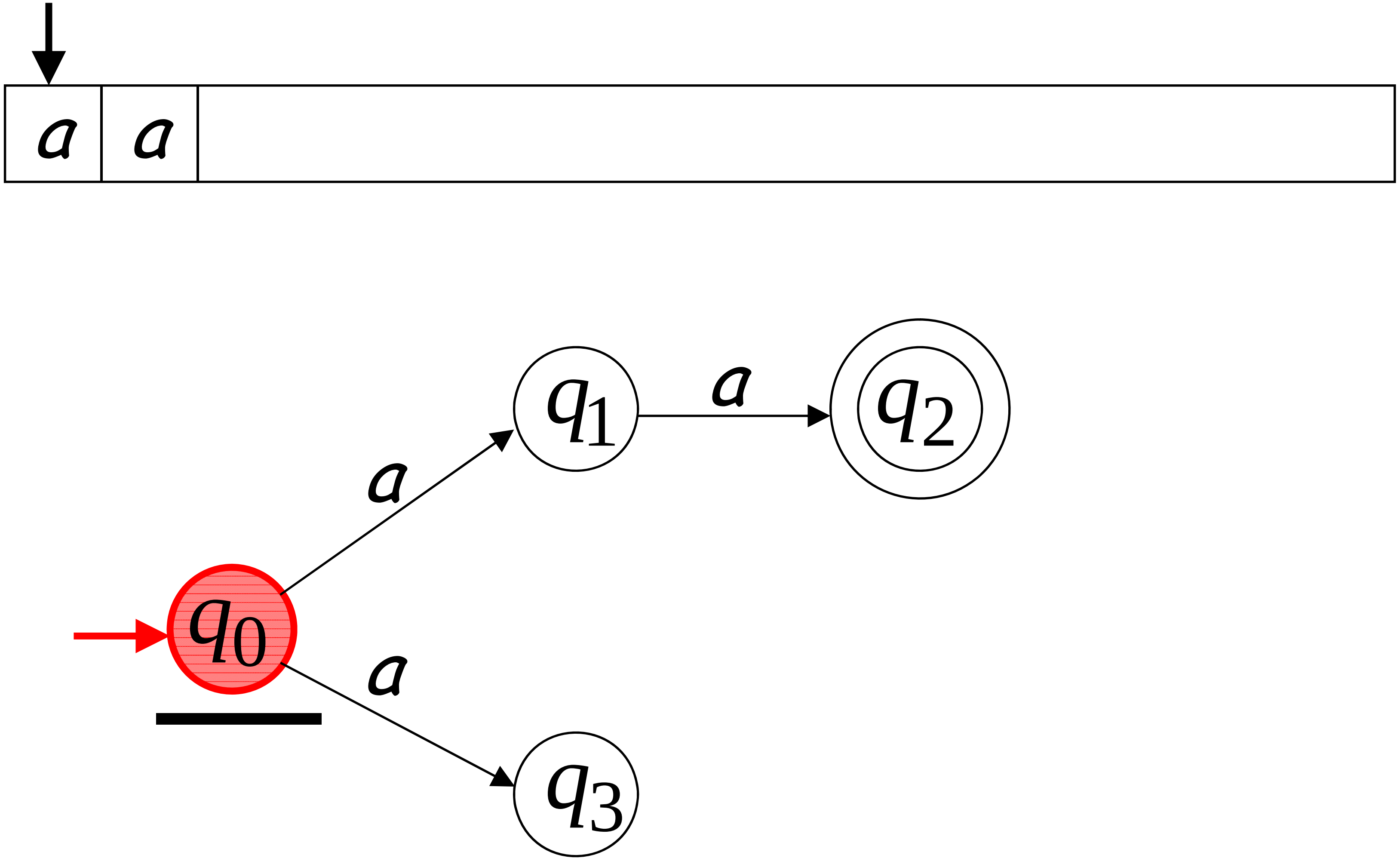
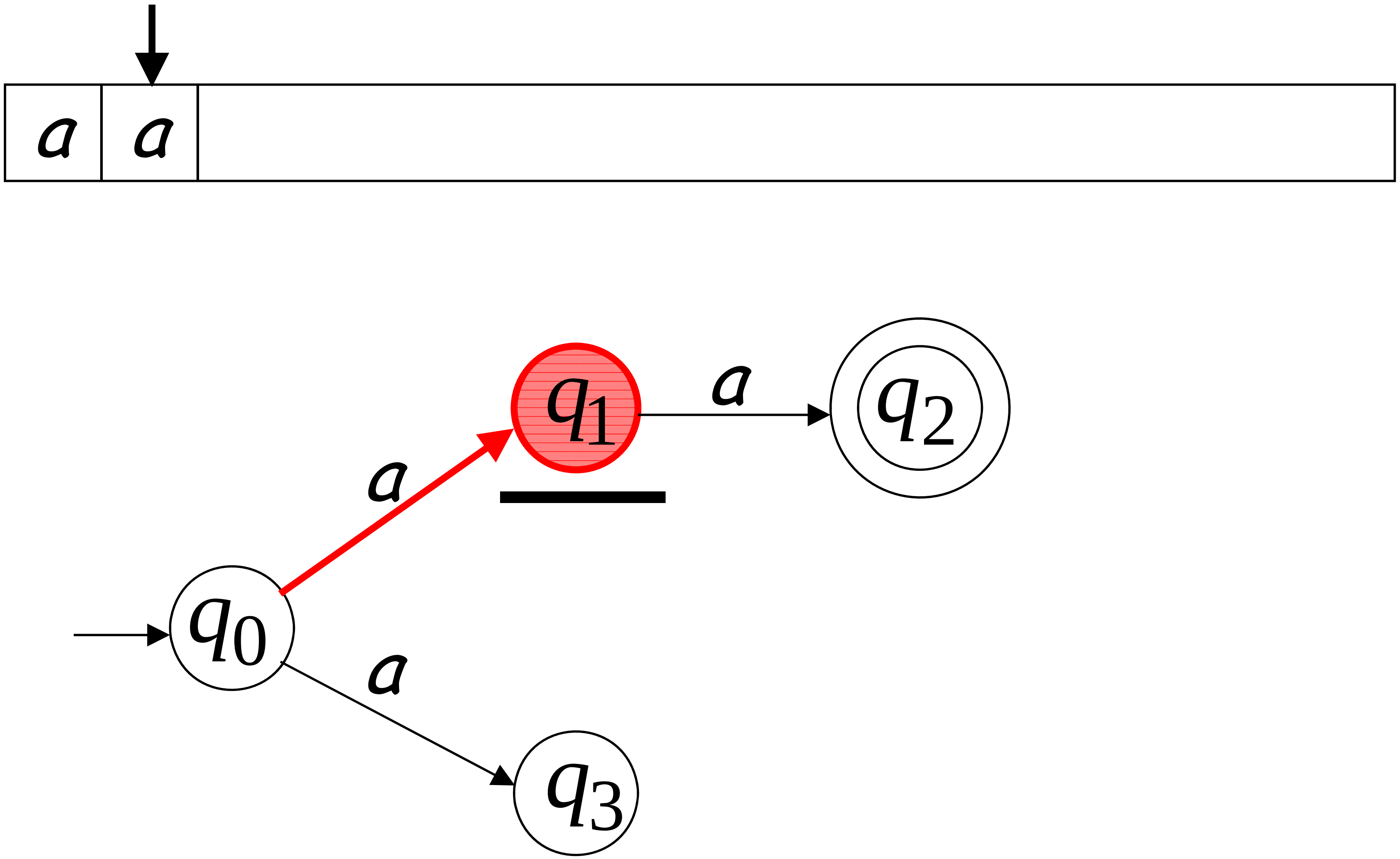


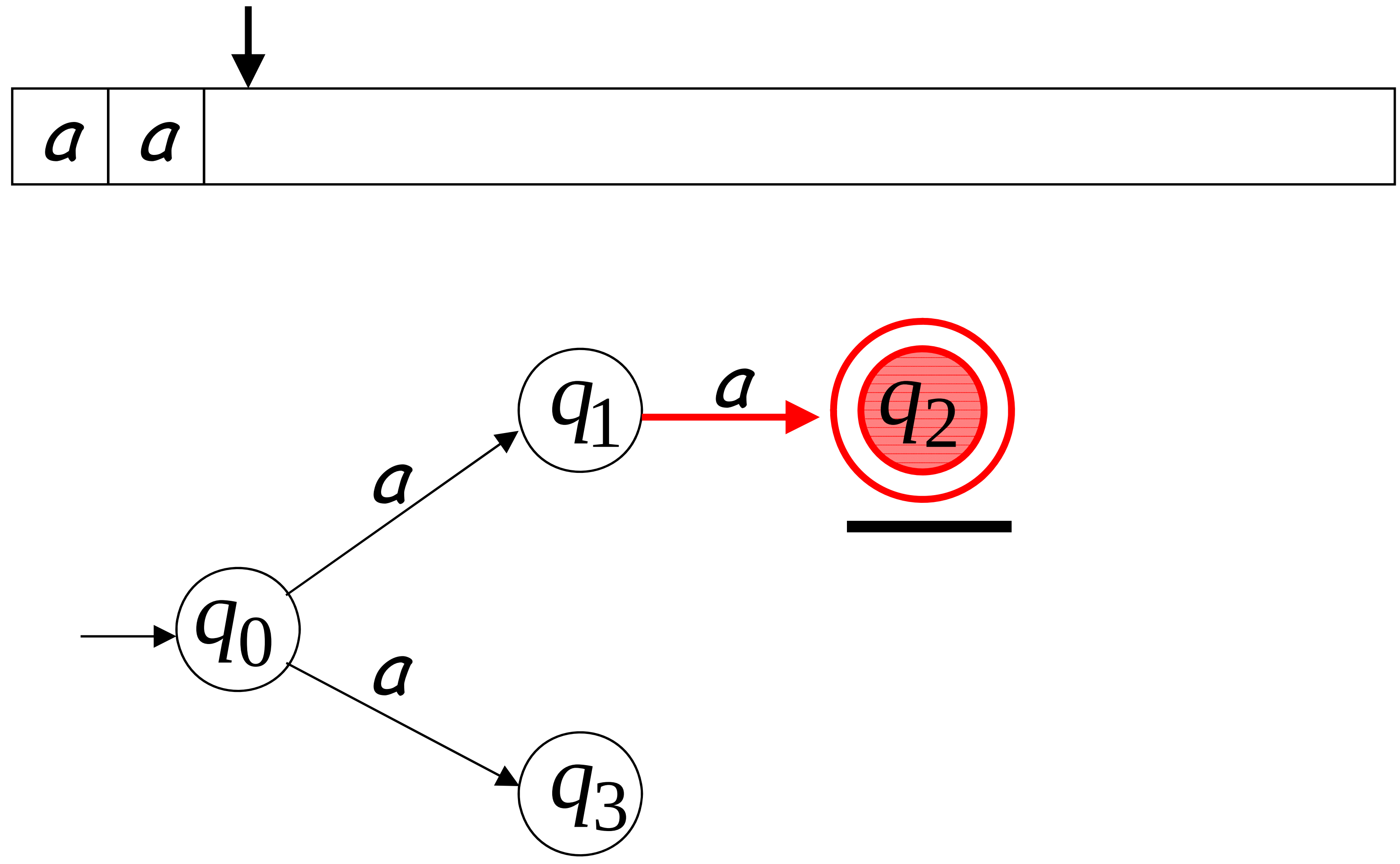
First Choice



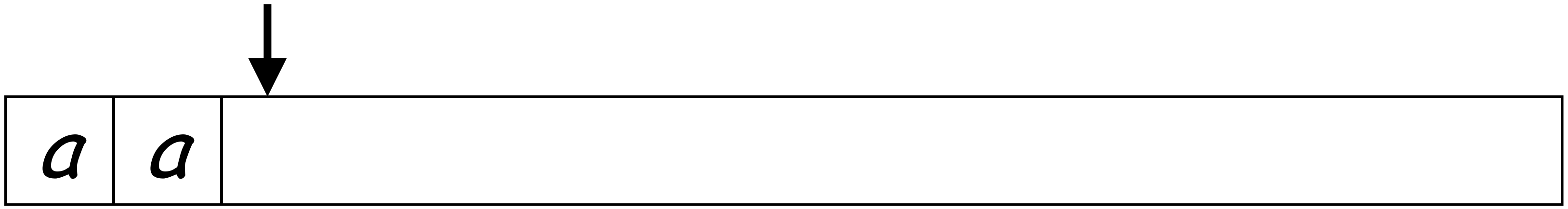
First Choice

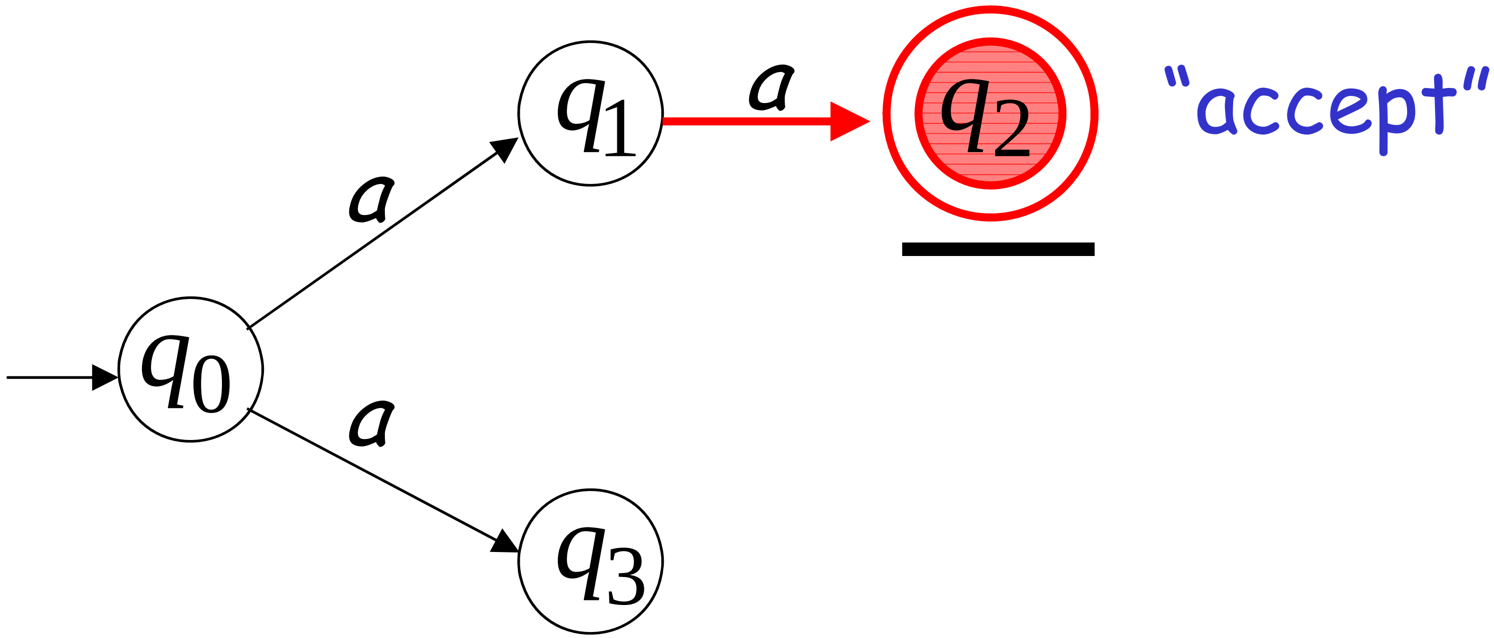


First Choice

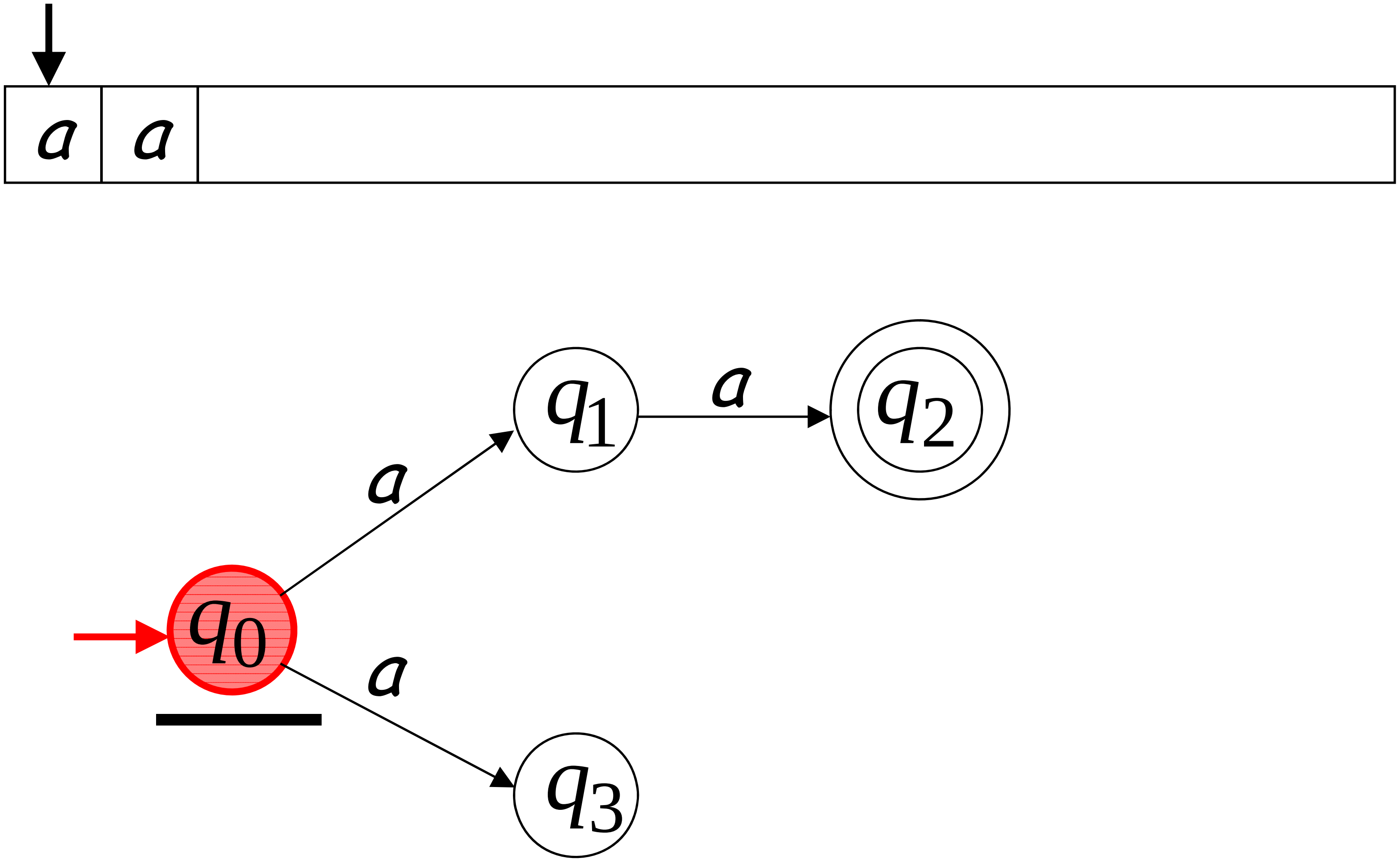


First Choice

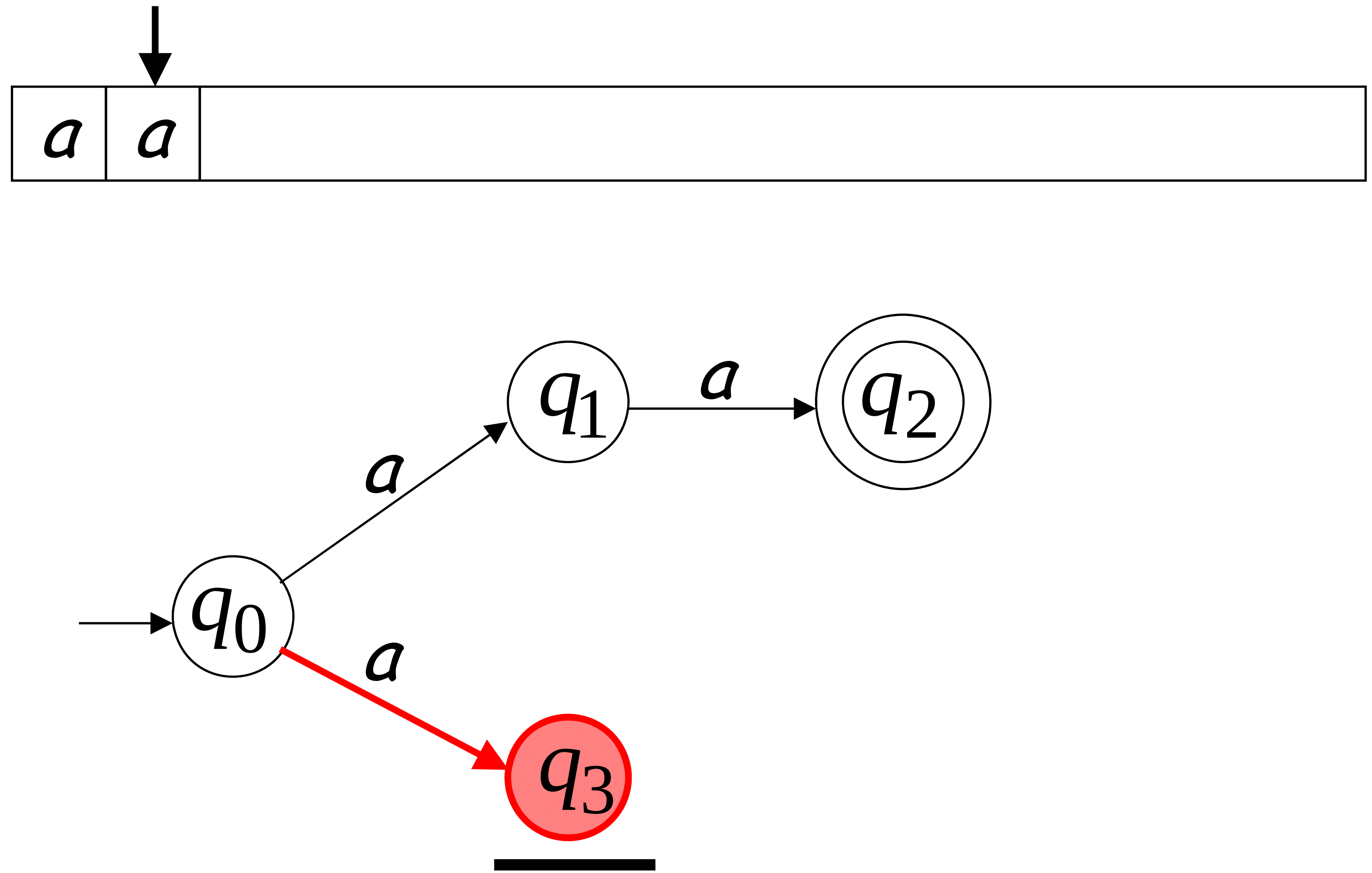




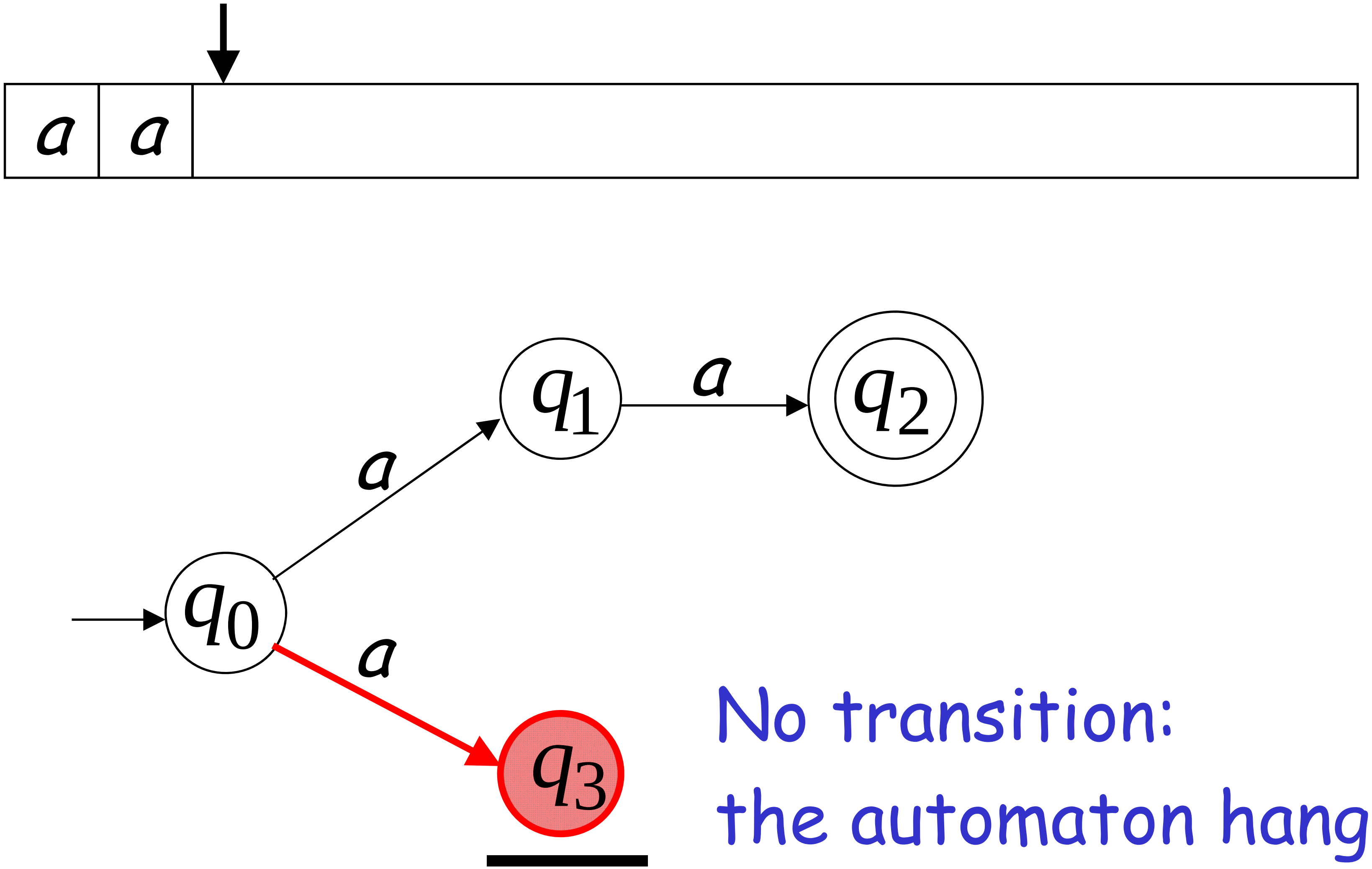
Second Choice



Second Choice

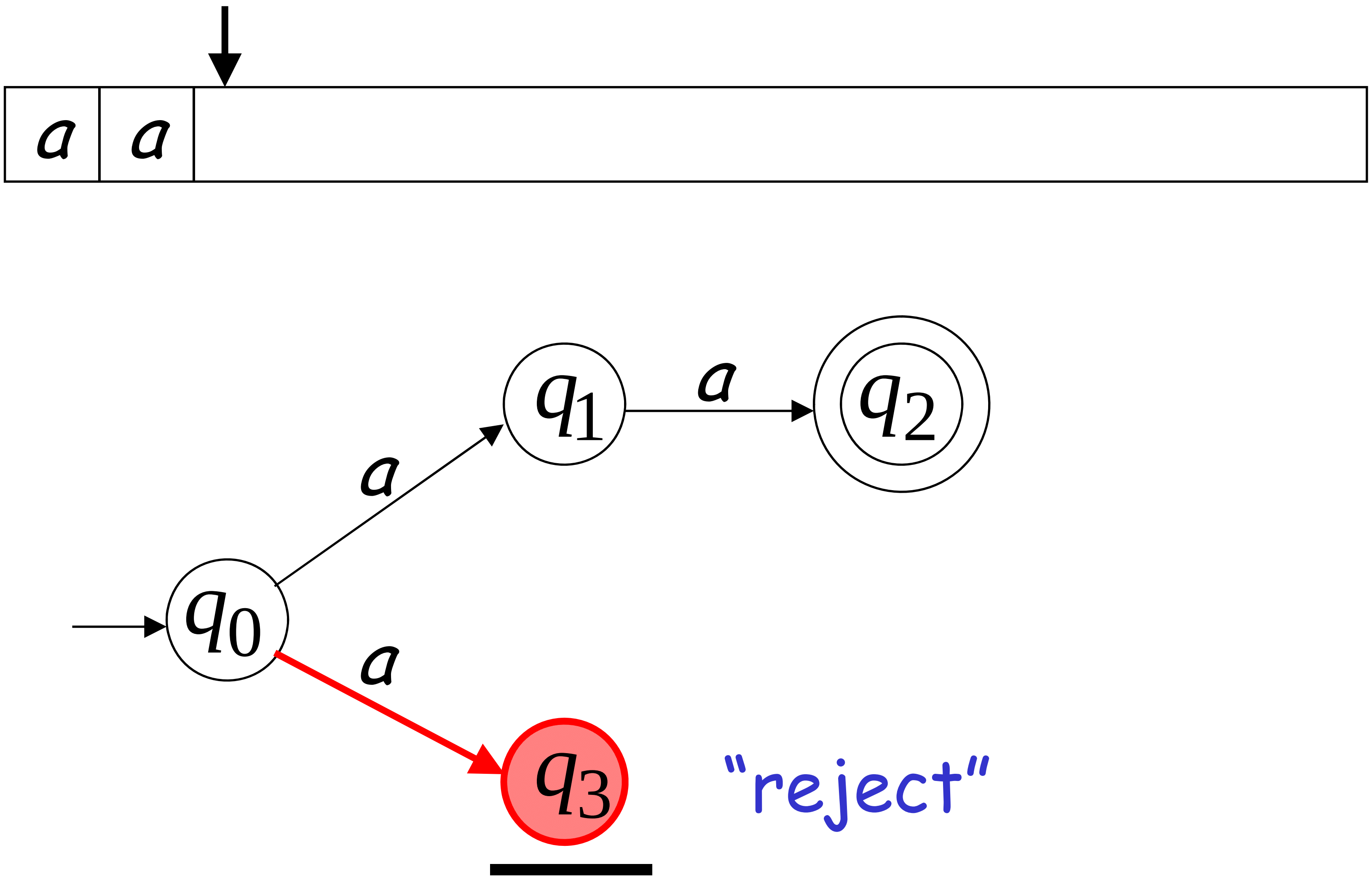


Second Choice



No transition:
the automaton hangs

Second Choice

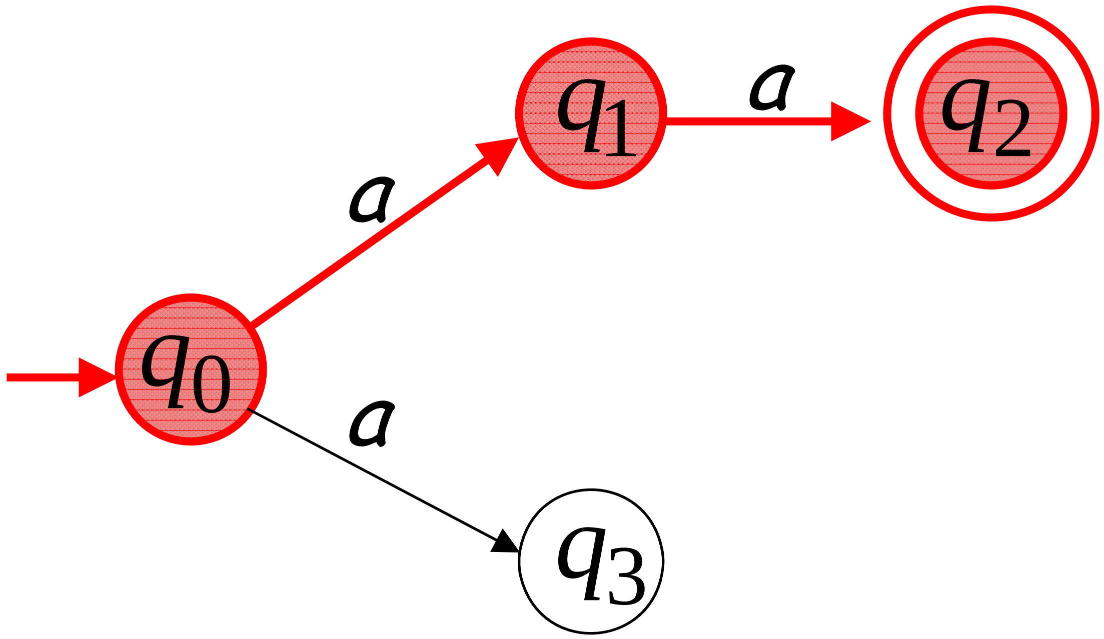


Observation

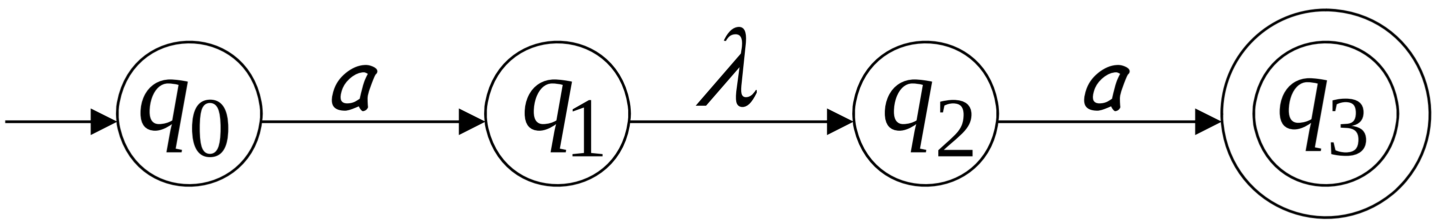
An NFA accepts a string
if
there is a computation of the NFA
that accepts the string

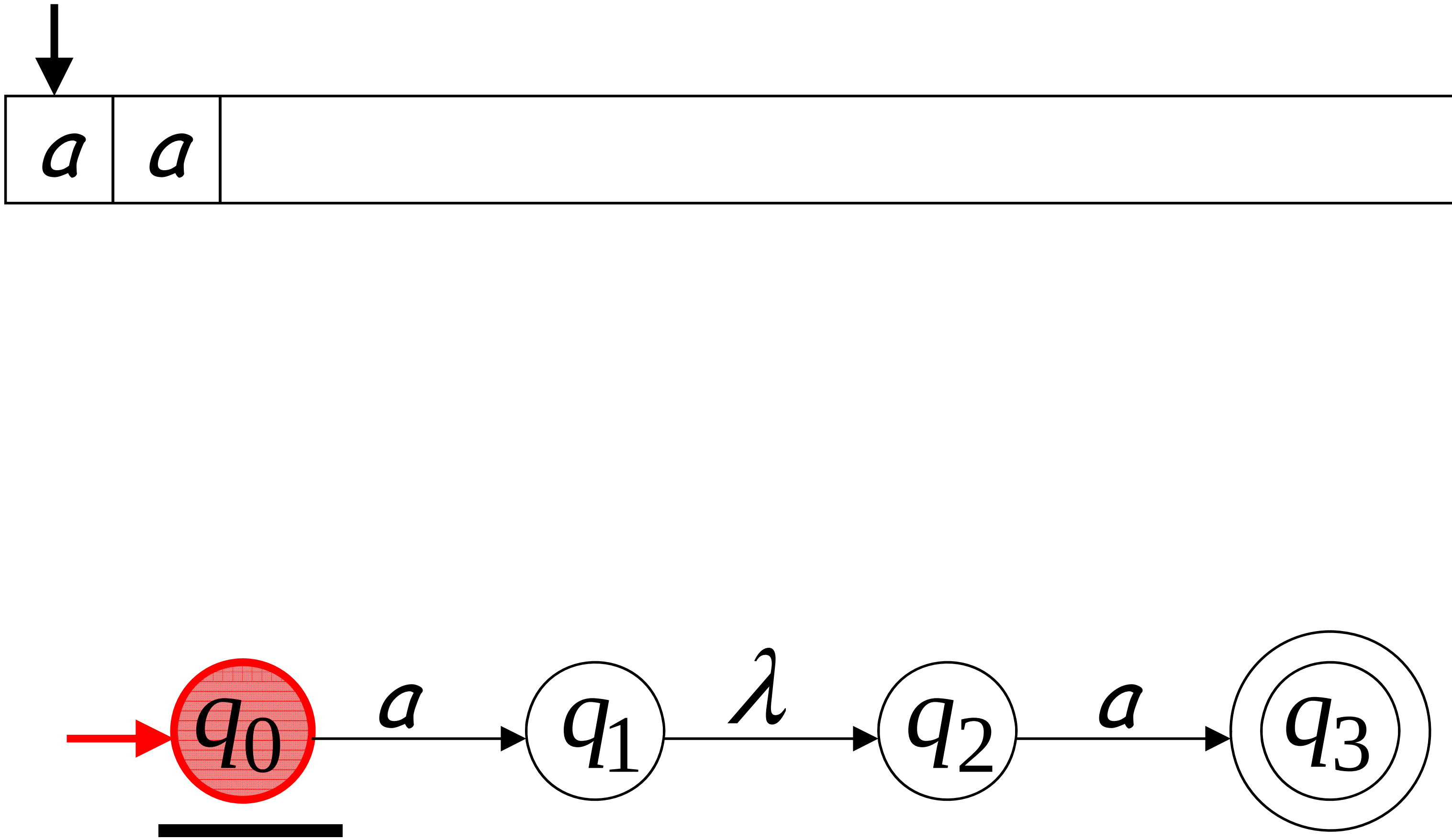
Example

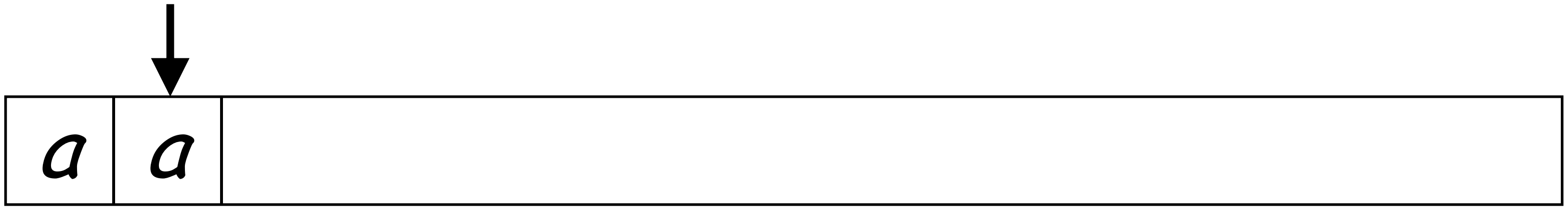
aa is accepted by the NFA:

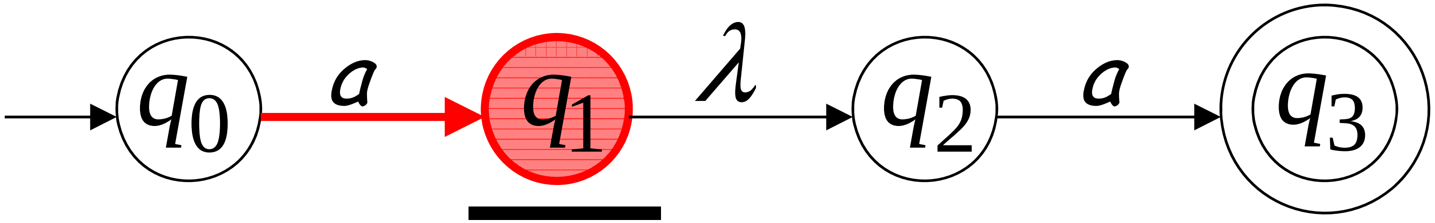


Lambda Transitions

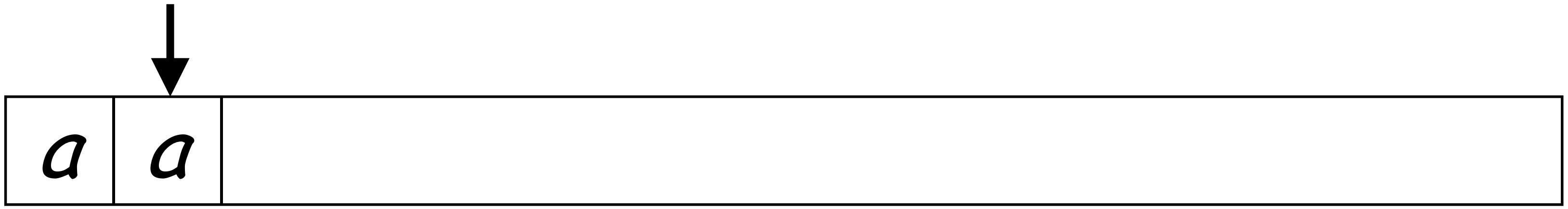


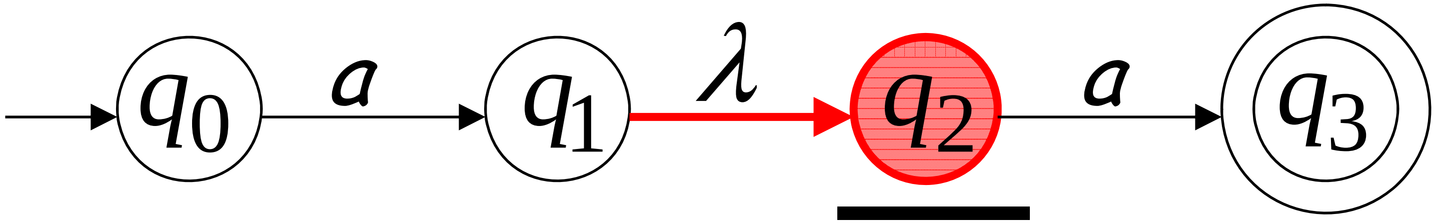

a a
q0 a q1 λ q2 a q3

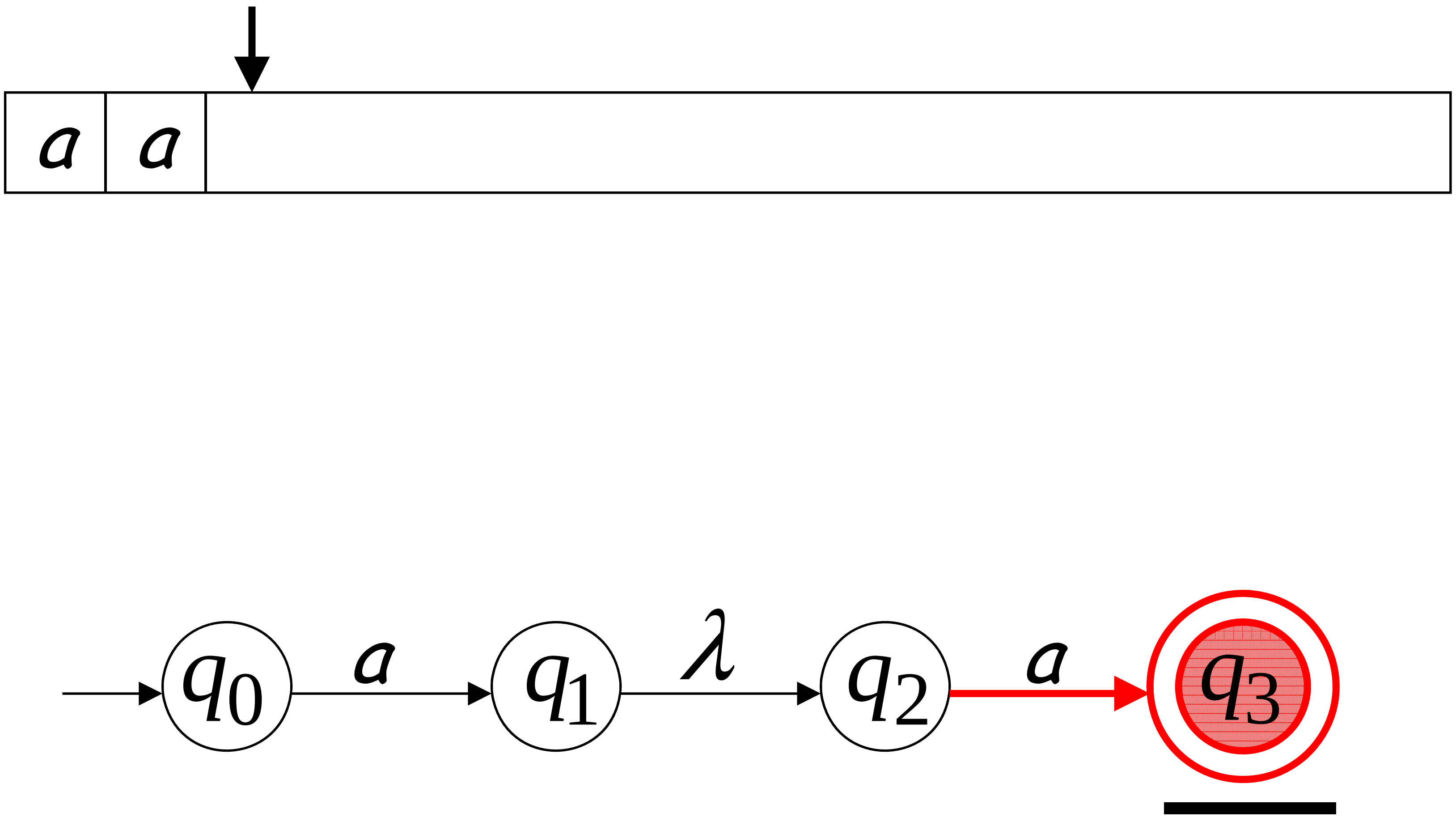

a
a

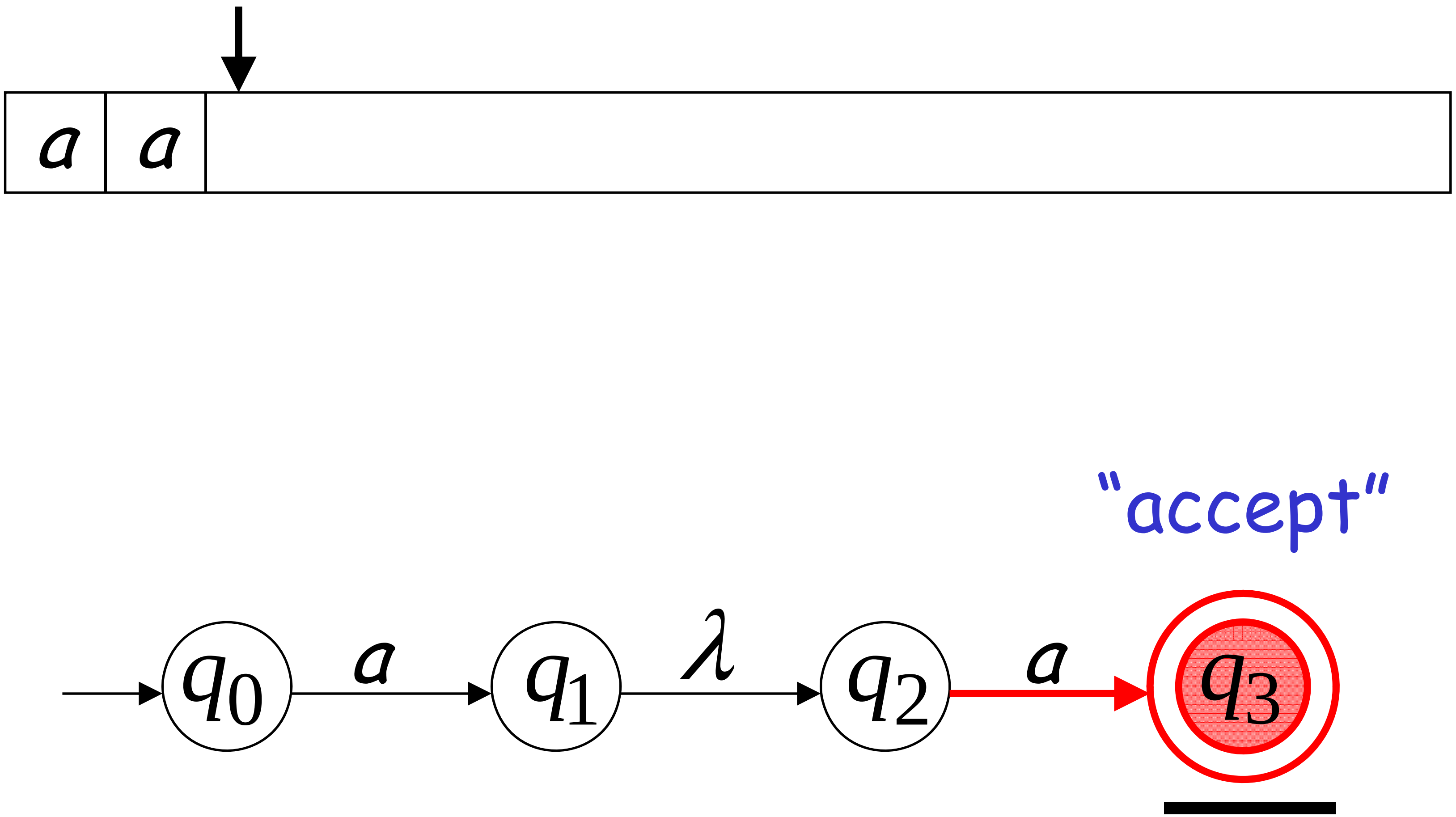

q_0
a
q_1
λ
q_2
a
q_3

(read head doesn't move)



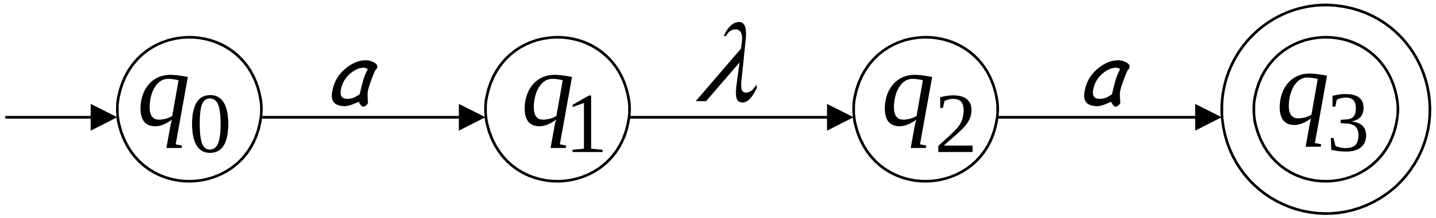



a
a
q0
a
q1
λ
q2
a
q3

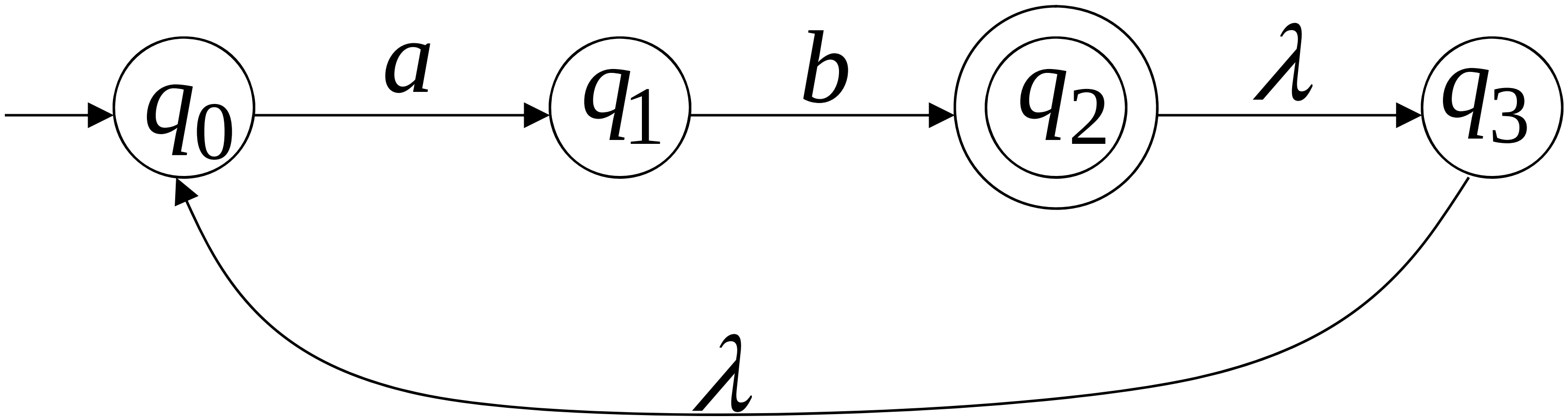


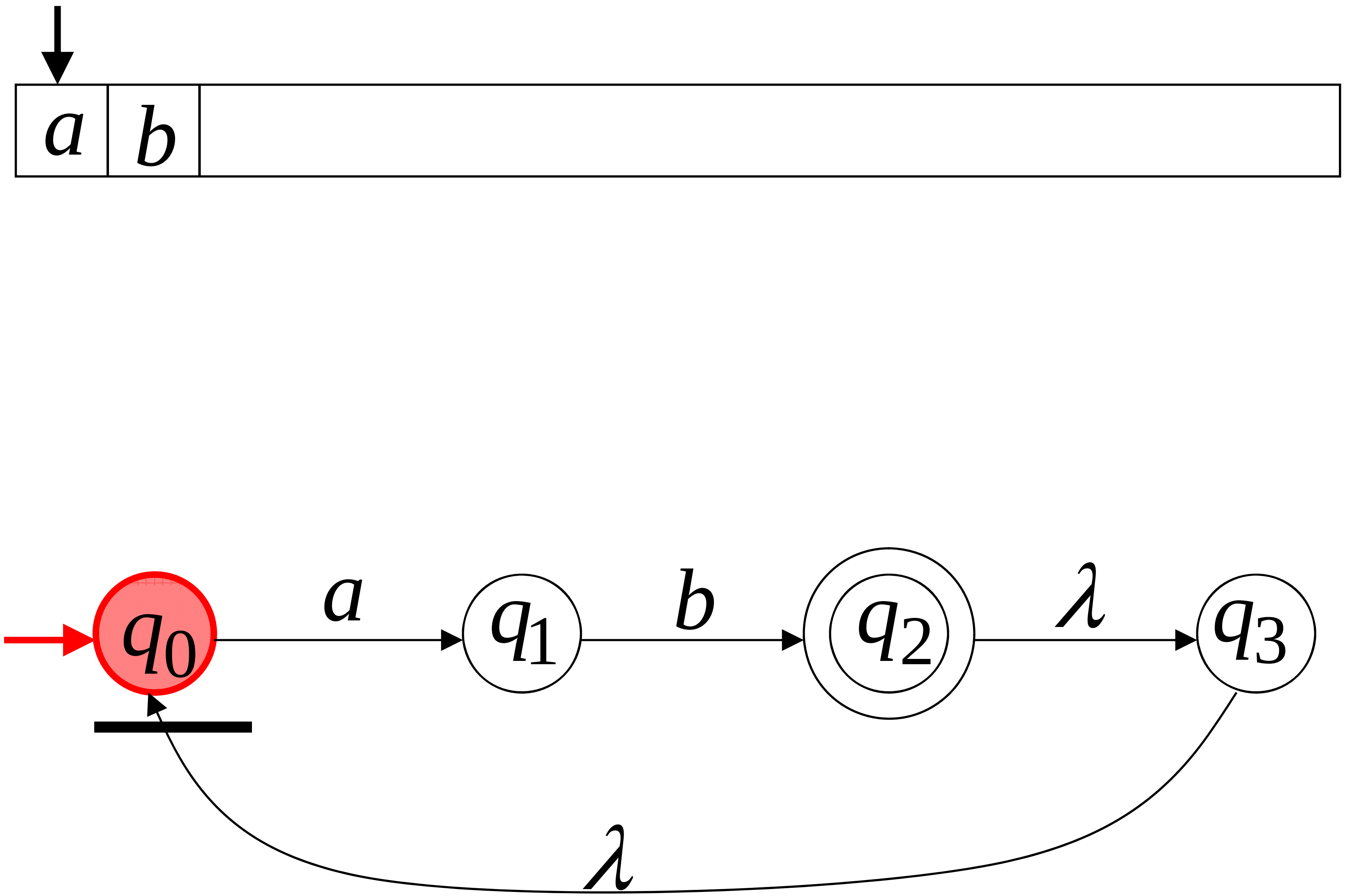
String aa is accepted

Language accepted: $L = \{aa\}$

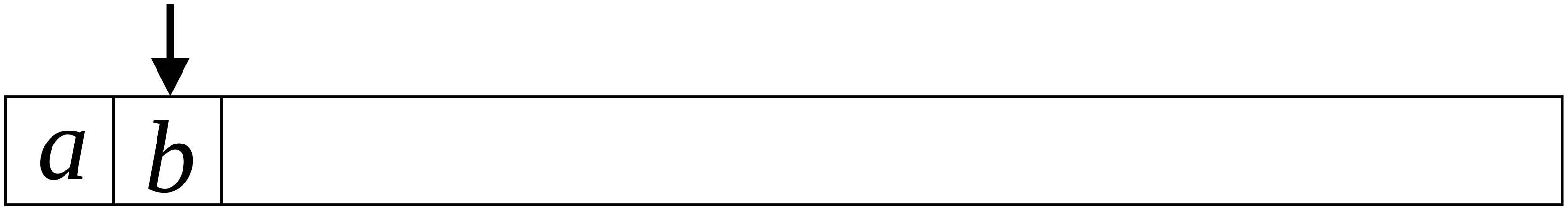


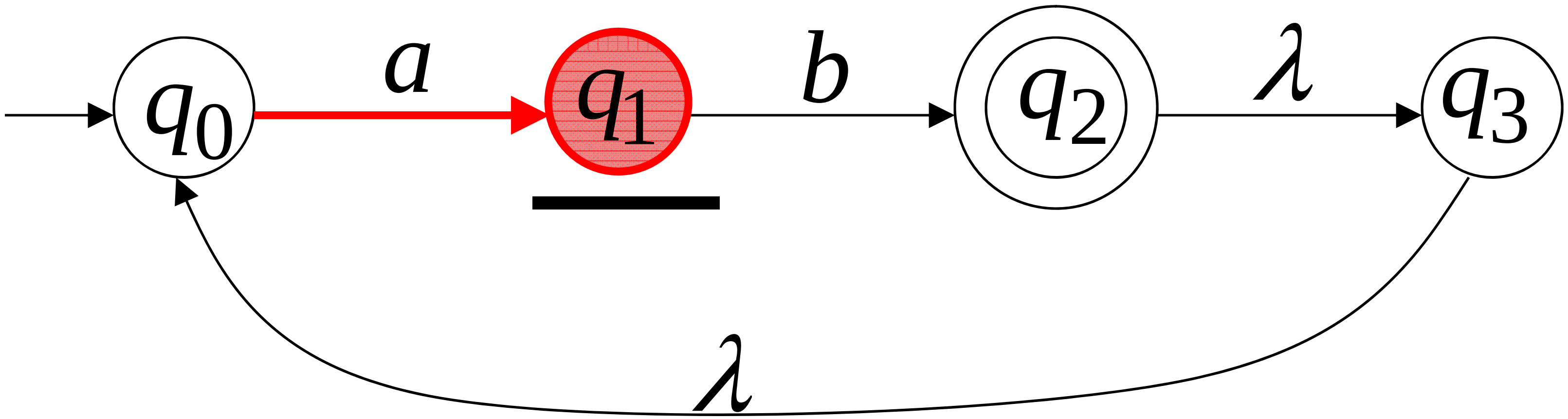
Another NFA Example

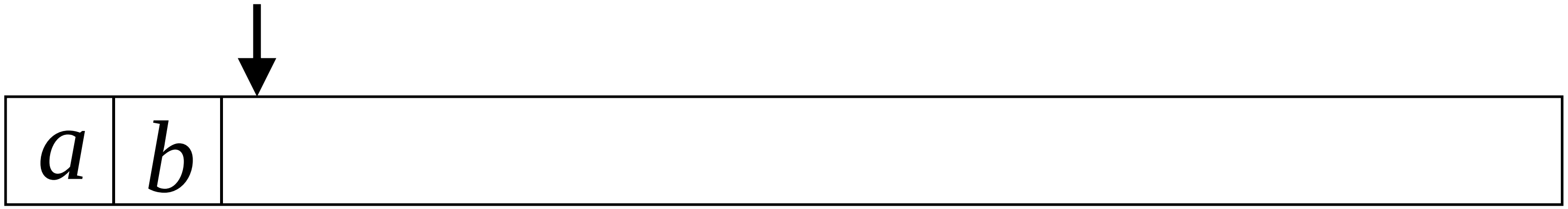


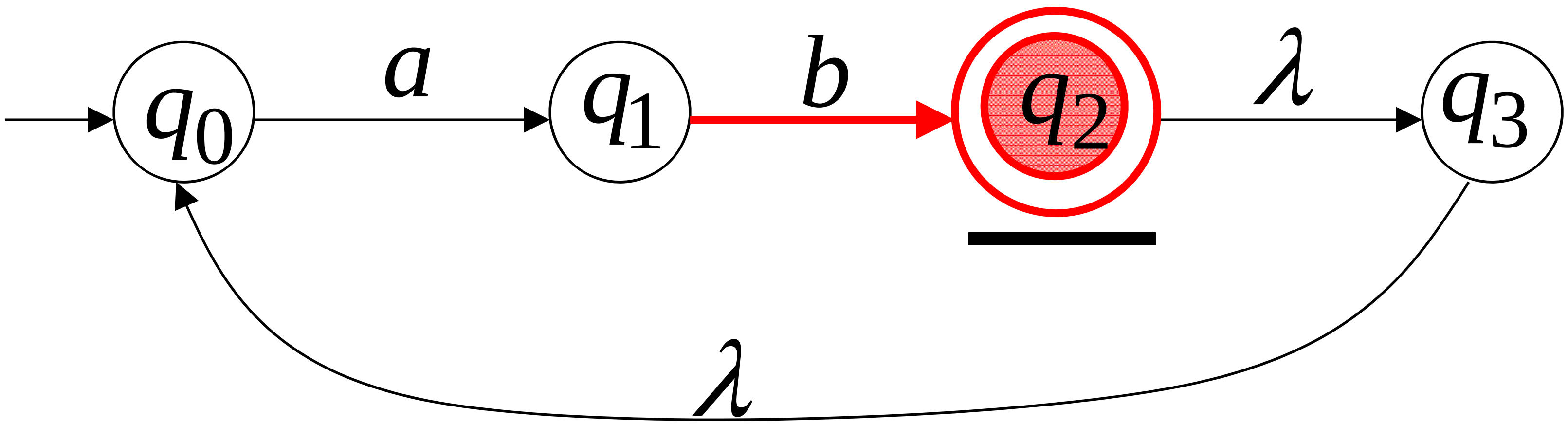


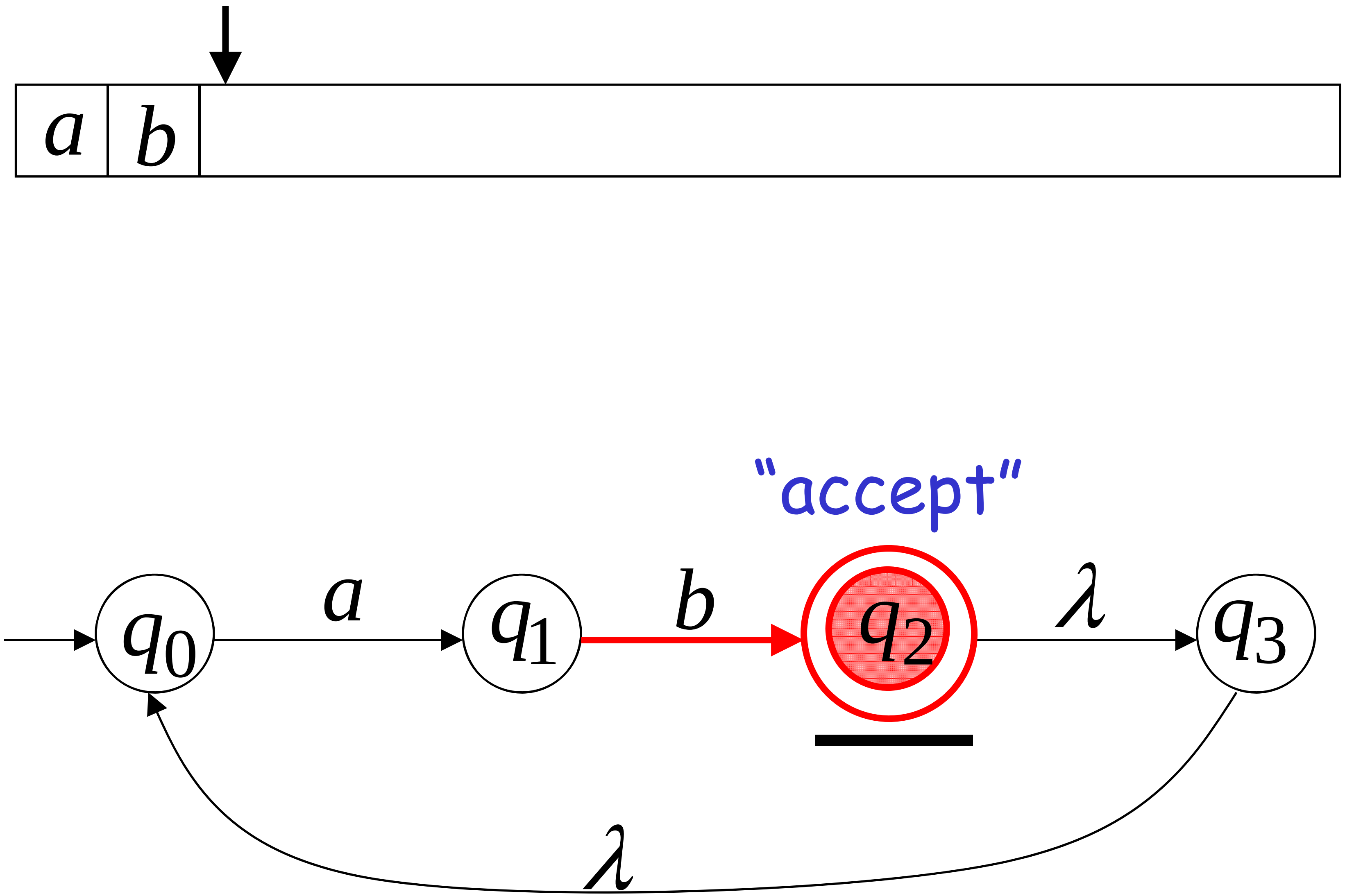
a
b
a
q0
q1
b
q2
λ
q3
λ


a
b


q_0
a
q_1
b
q_2
λ
q_3
λ

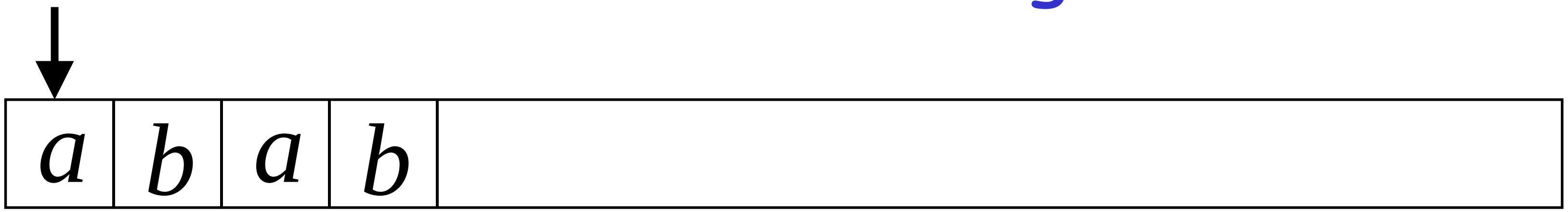

a
b

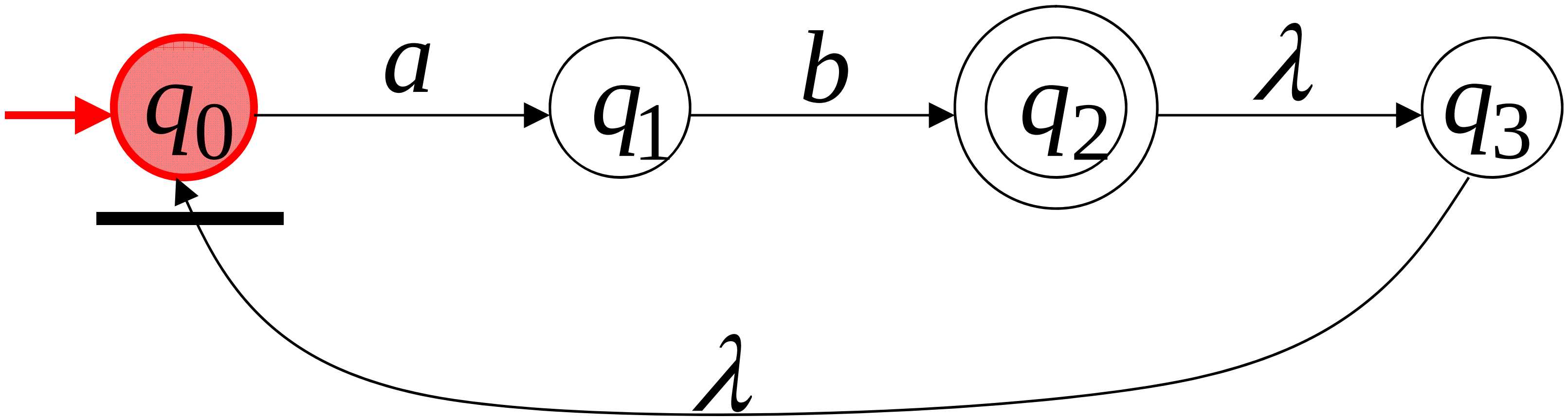

q0
a
q1
b
q2
λ
q3
λ

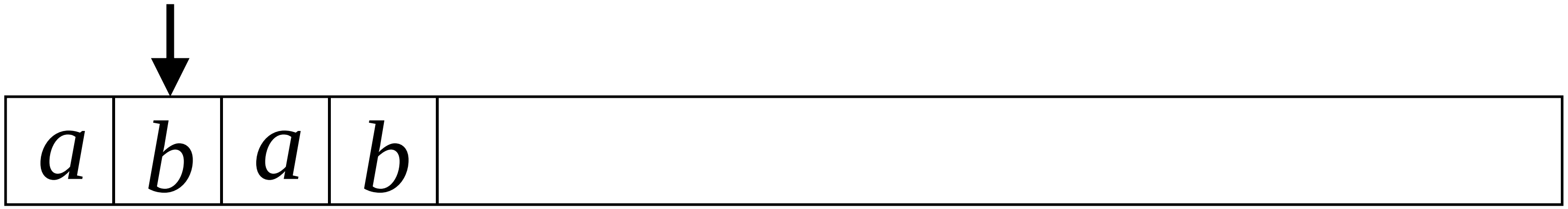


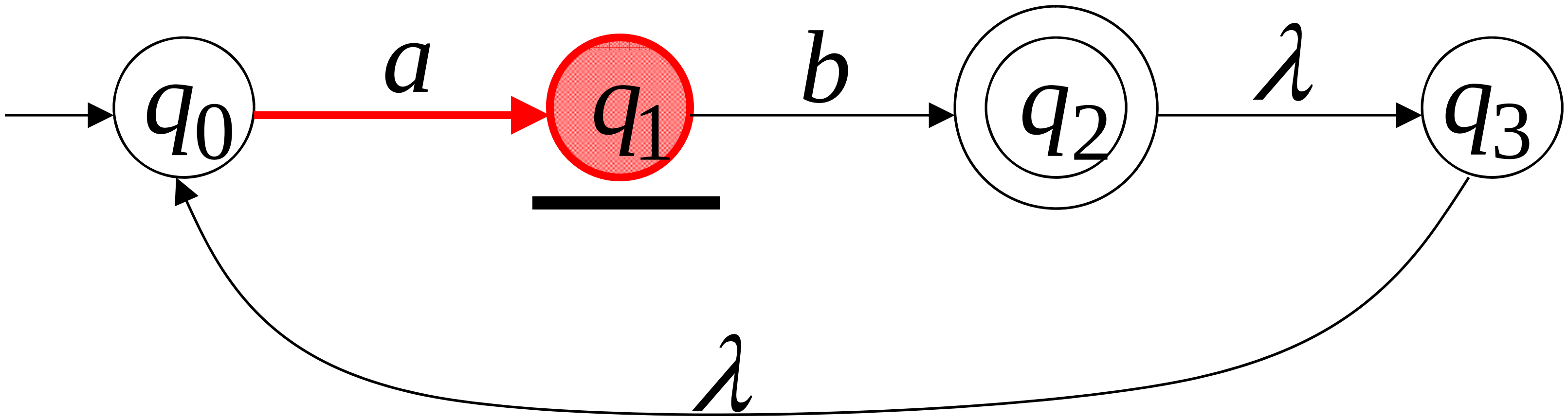
a
b
"accept"
q0
a
q1
b
q2
λ
q3
λ

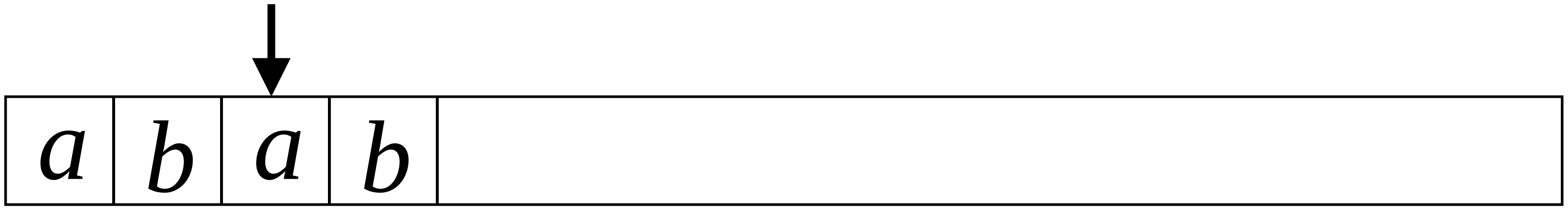
Another String

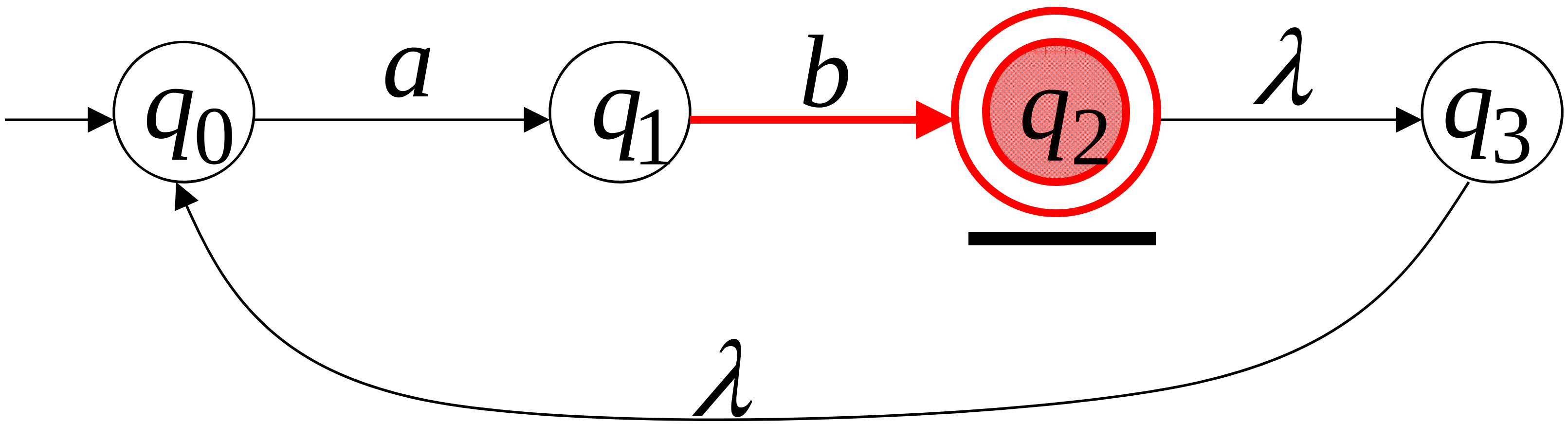


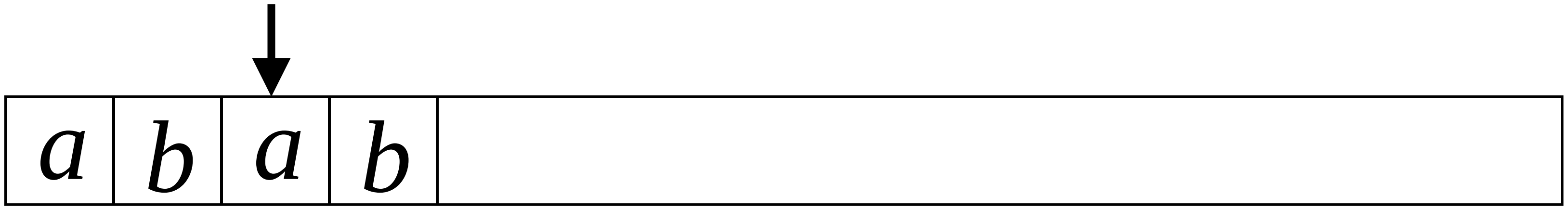


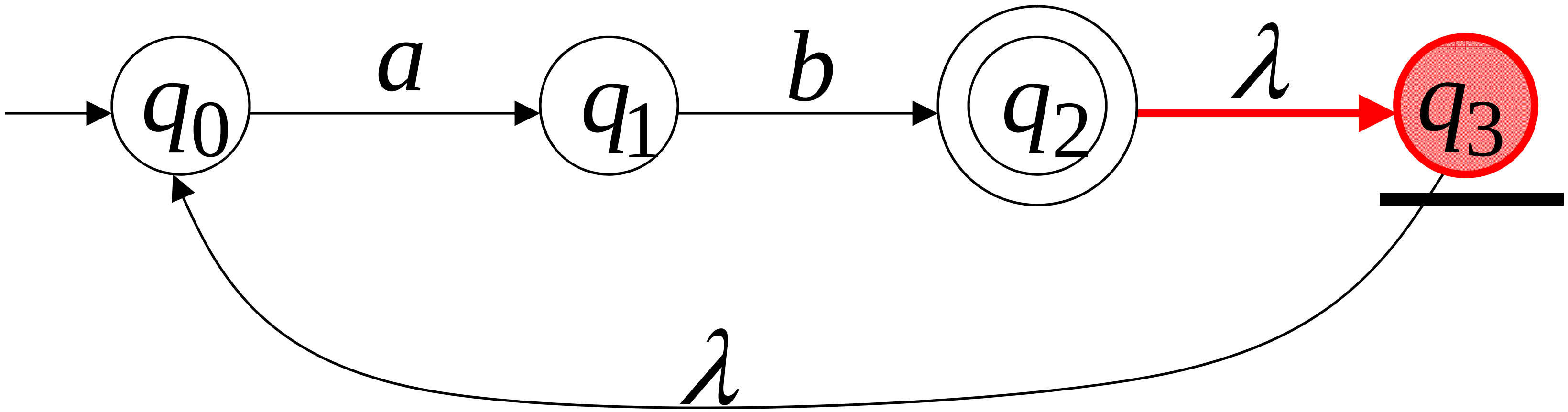

a
b
a
b

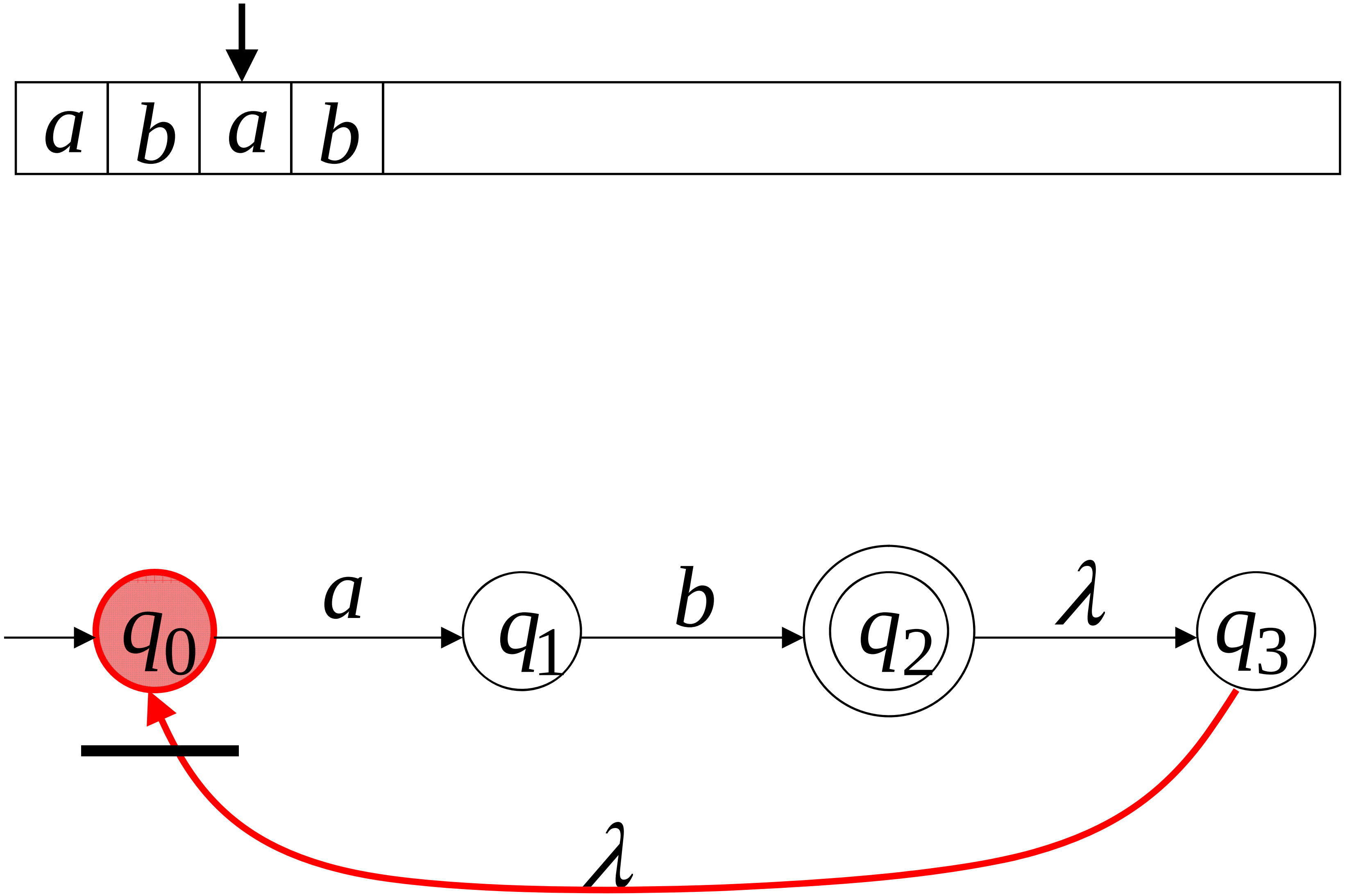

q_0
a
q_1
b
q_2
λ
q_3
λ

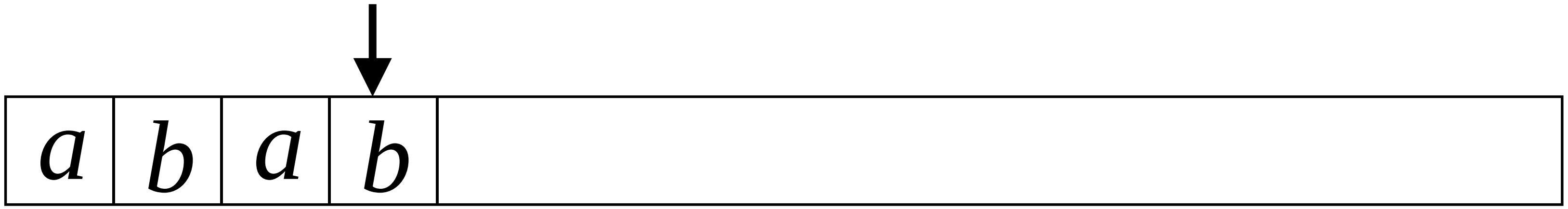

a
b
a
b

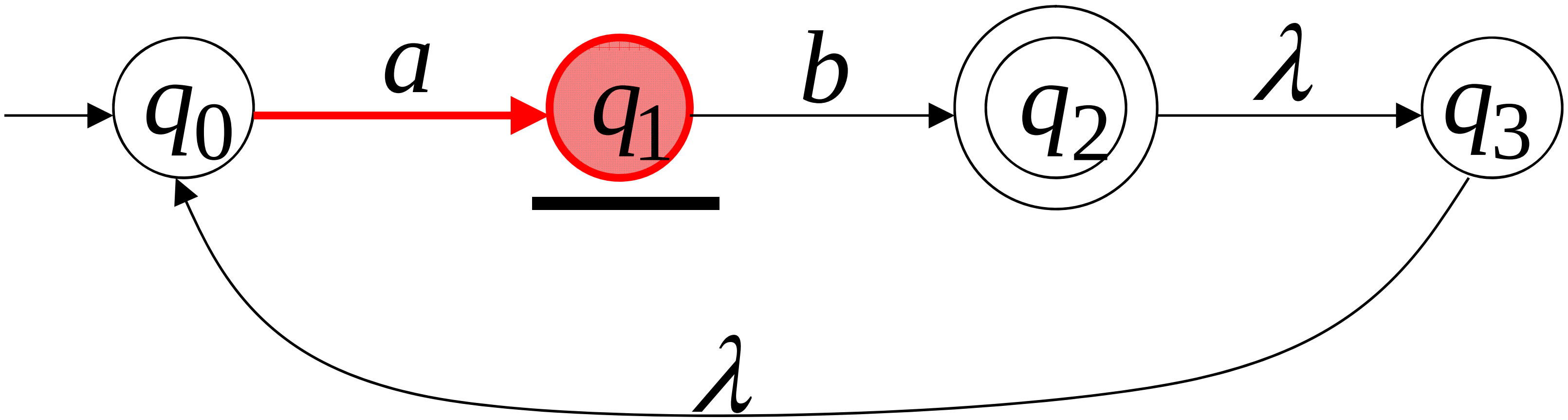

q_0
a
q_1
b
q_2
λ
q_3
λ

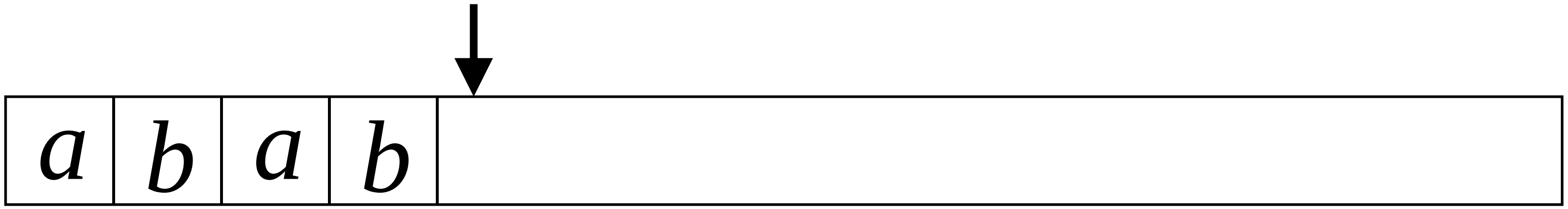

a
b
a
b


q_0
a
q_1
b
q_2
λ
q_3
λ

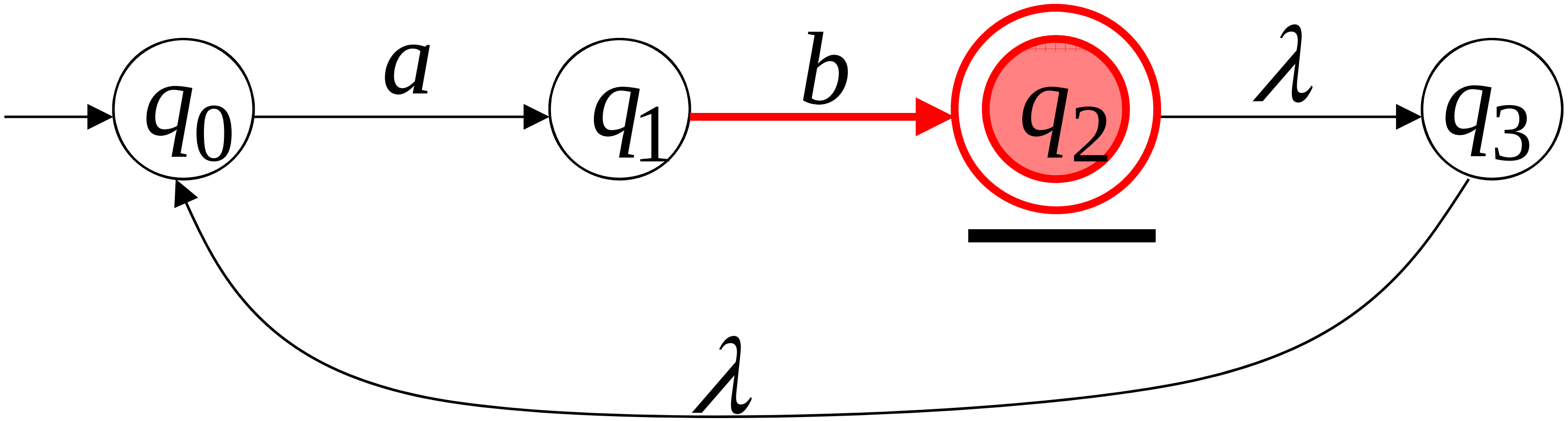

a
b
a
b
a
b
λ
q_0
q_1
q_2
q_3
λ


a
b
a
b

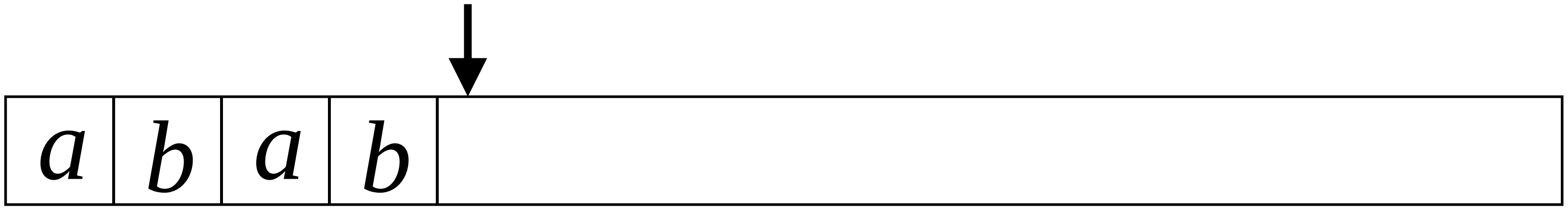

q_0
a
q_1
b
q_2
λ
q_3
λ

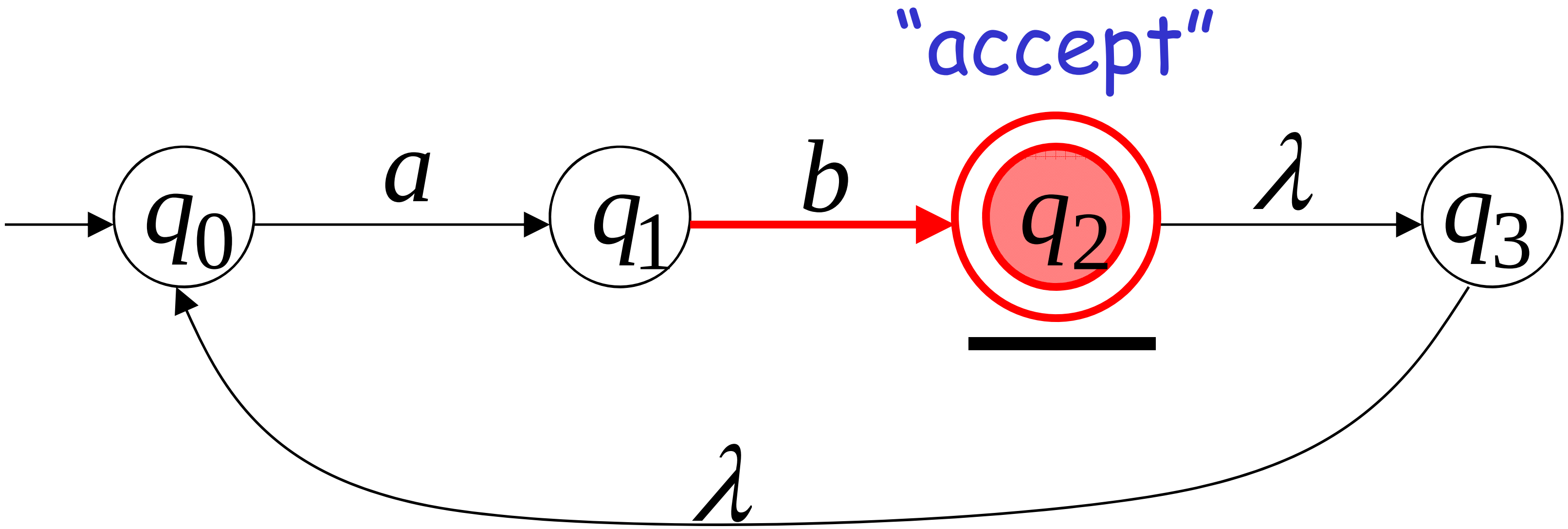


a
b
a
b



q_0
a
q_1
b
q_2
λ
q_3
λ

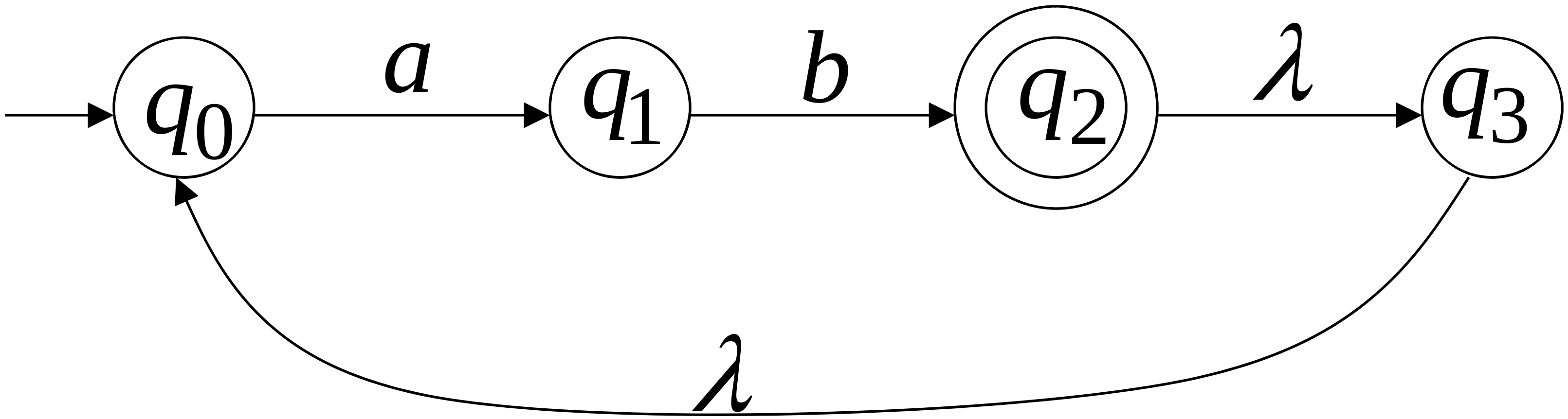

a
b
a
b


"accept"
q_0
a
q_1
b
q_2
λ
q_3
λ

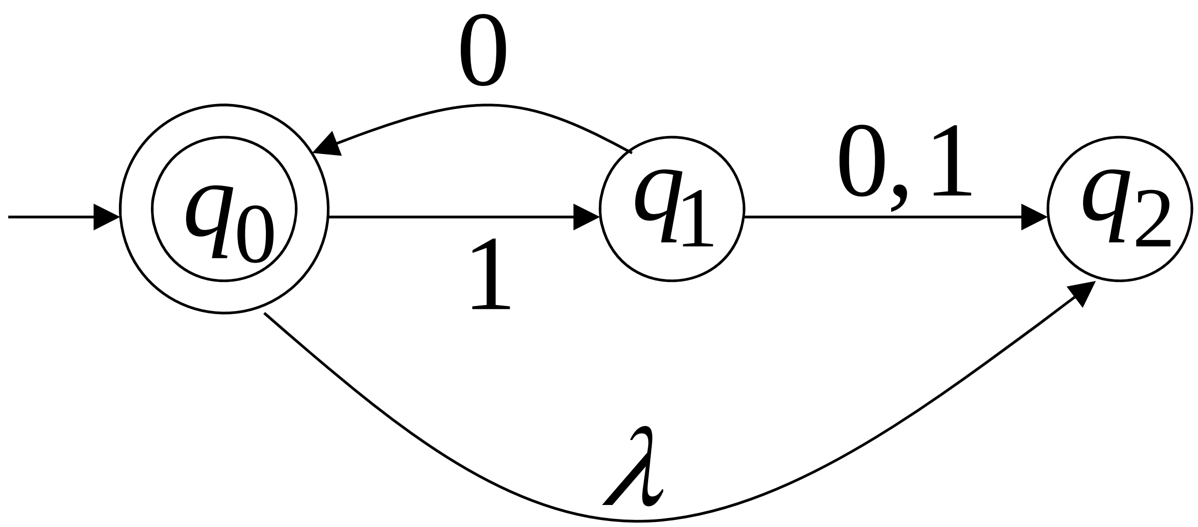
Language accepted

$$L = \{ab,\ abab,\ ababab,\ \ldots\}$$

$$= \{ab\}^+$$



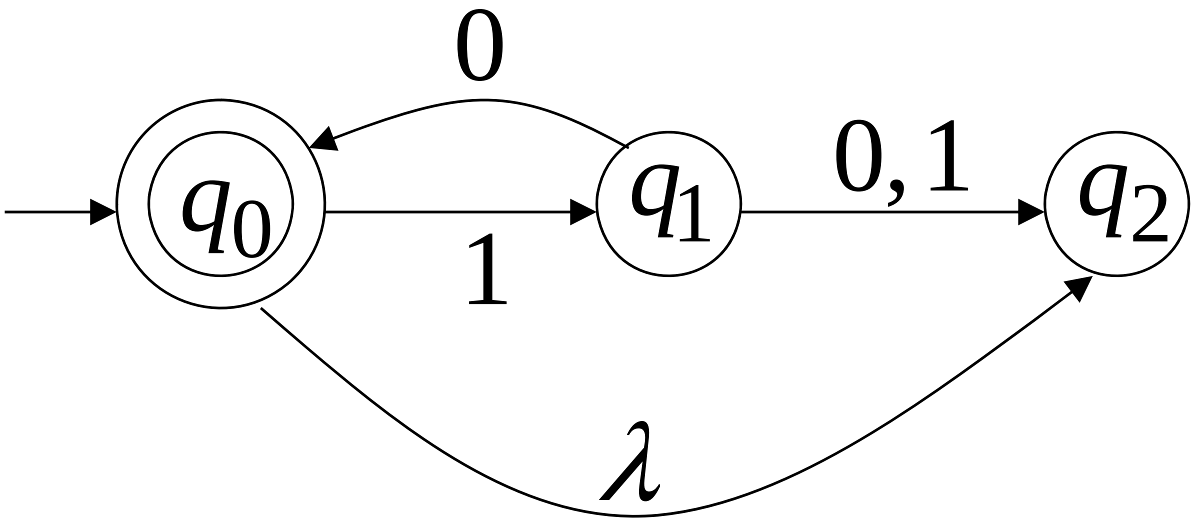
Another NFA Example



Language accepted

$$L = \{\lambda,\ 10,\ 1010,\ 101010,\ \ldots\}$$

$$= \{10\}^*$$



Formal Definition of NFAs

$$M = (Q,\ \Sigma,\ \delta,\ q_0,\ F)$$

$Q:$ Set of states, i.e. $\{q_0, q_1, q_2\}$

$\Sigma:$ Input aplhabet, i.e. $\{a, b\}$

$\delta:$ Transition function

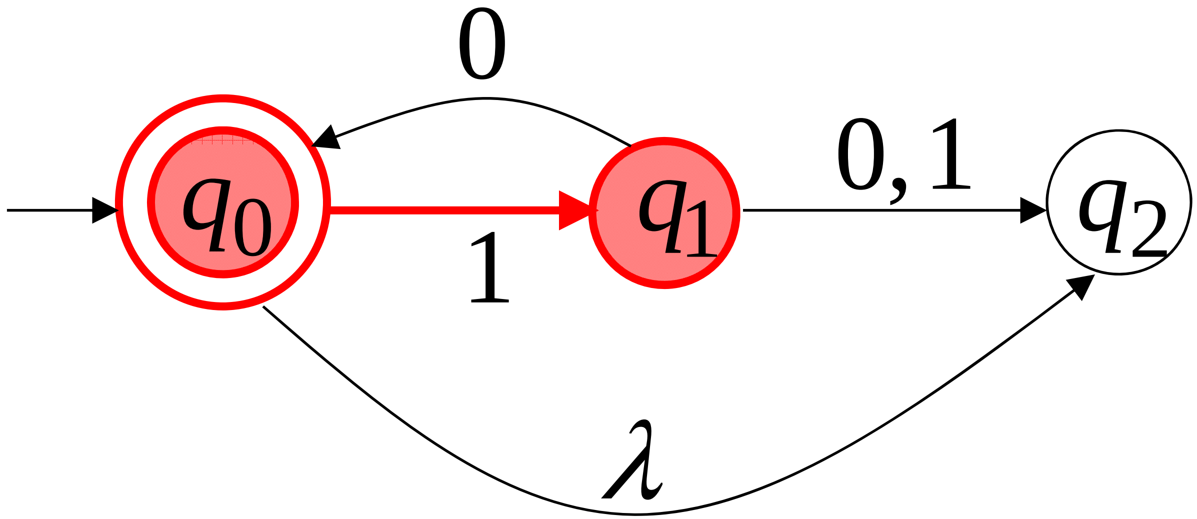
$$\delta : Q \times (\Sigma \cup \{\lambda\}) \rightarrow 2^Q$$

$q_0:$ Initial state

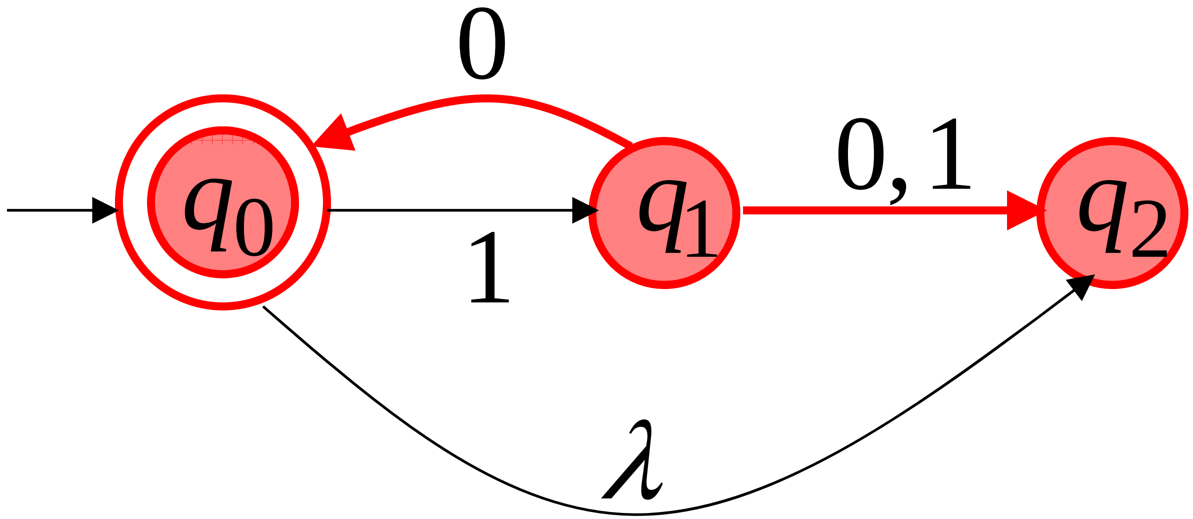
$F:$ Final states

Transition Function δ

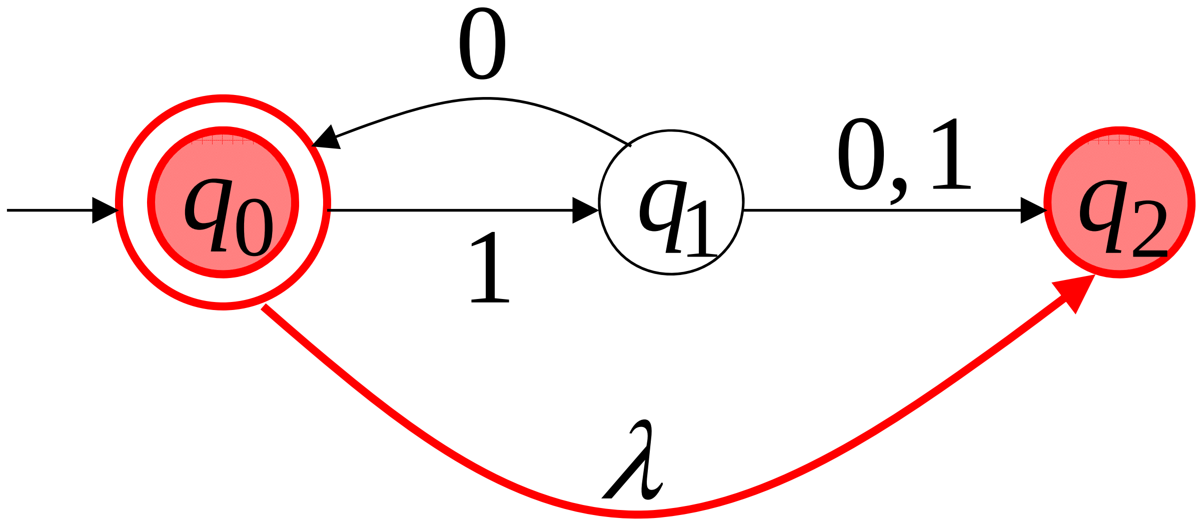
$$\delta(q_0, 1) = \{q_1\}$$



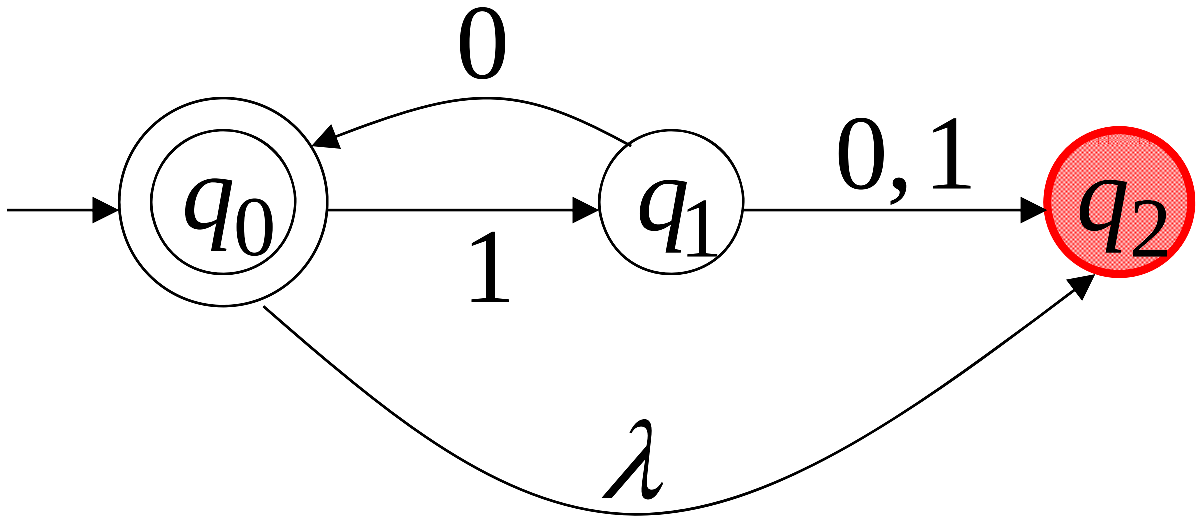
$$\delta(q_1, 0) = \{q_0, q_2\}$$



$$\delta(q_0, \lambda) = \{q_0, q_2\}$$

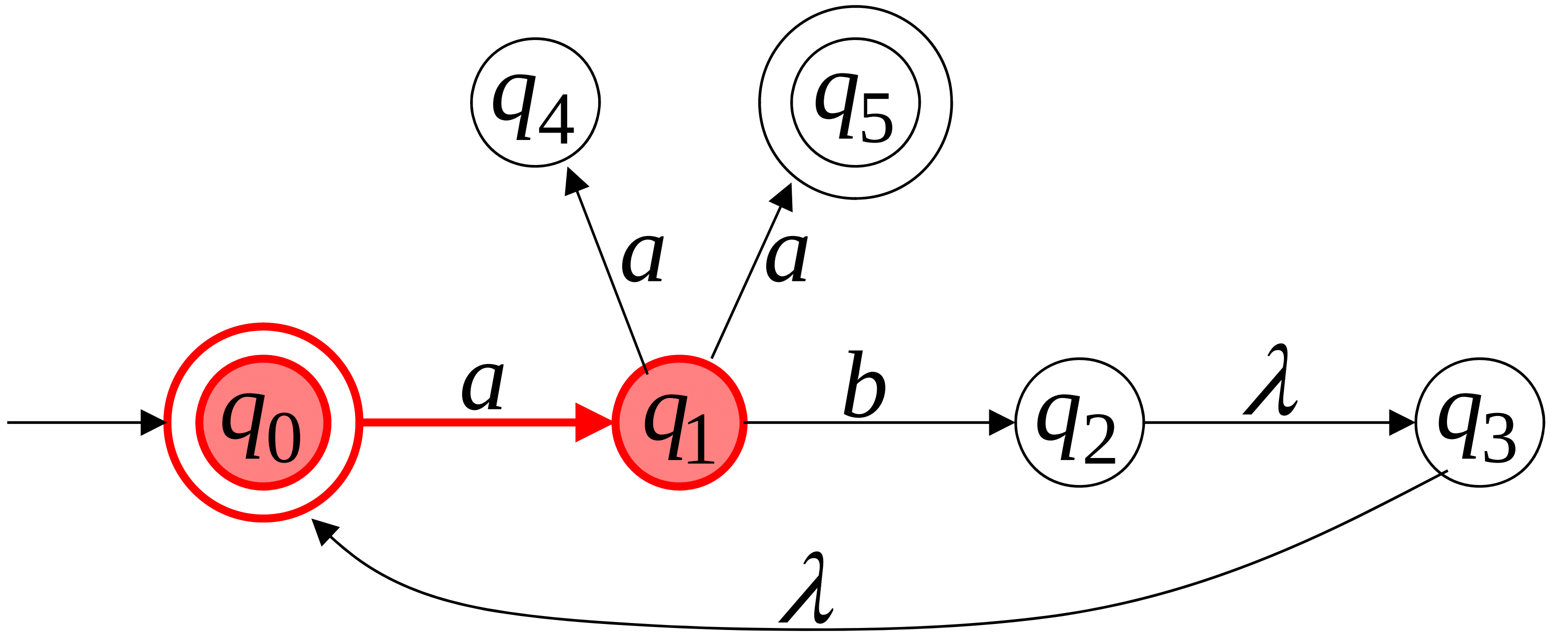


$$\delta(q_2, 1) = \varnothing$$

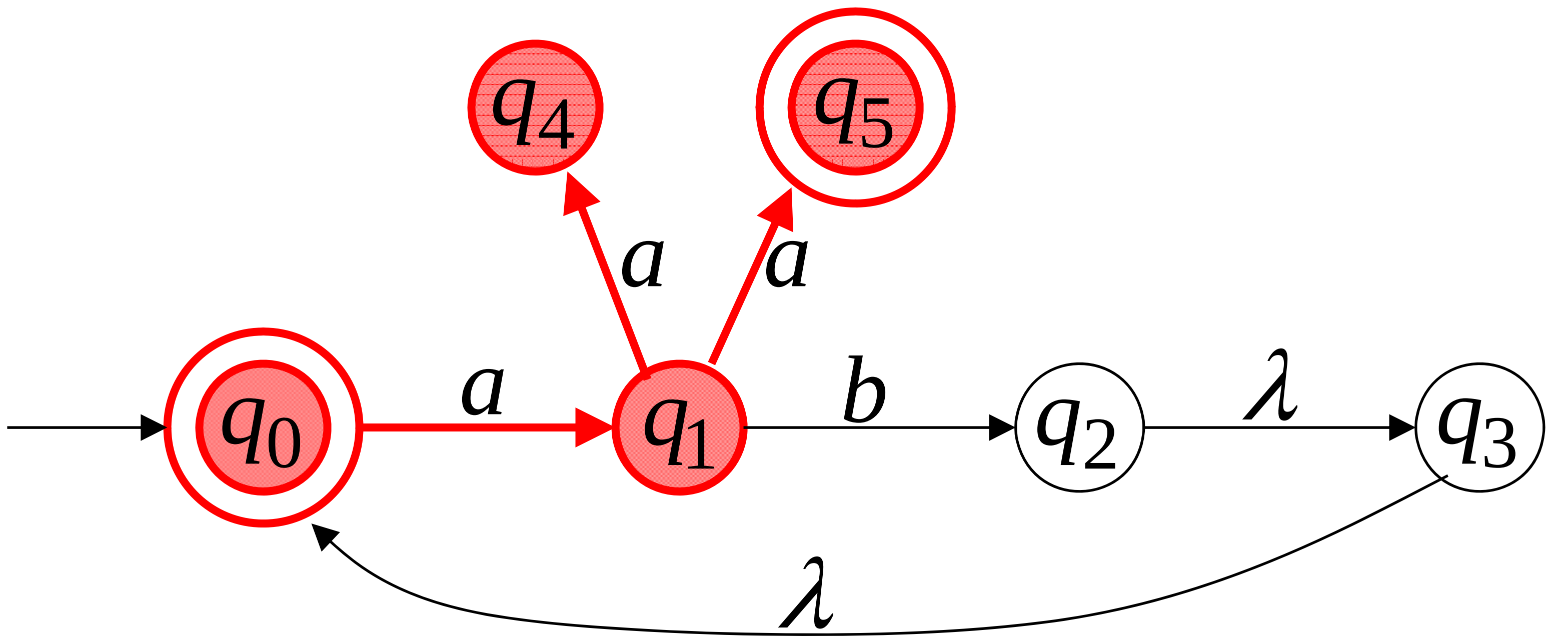


Extended Transition Function δ^*

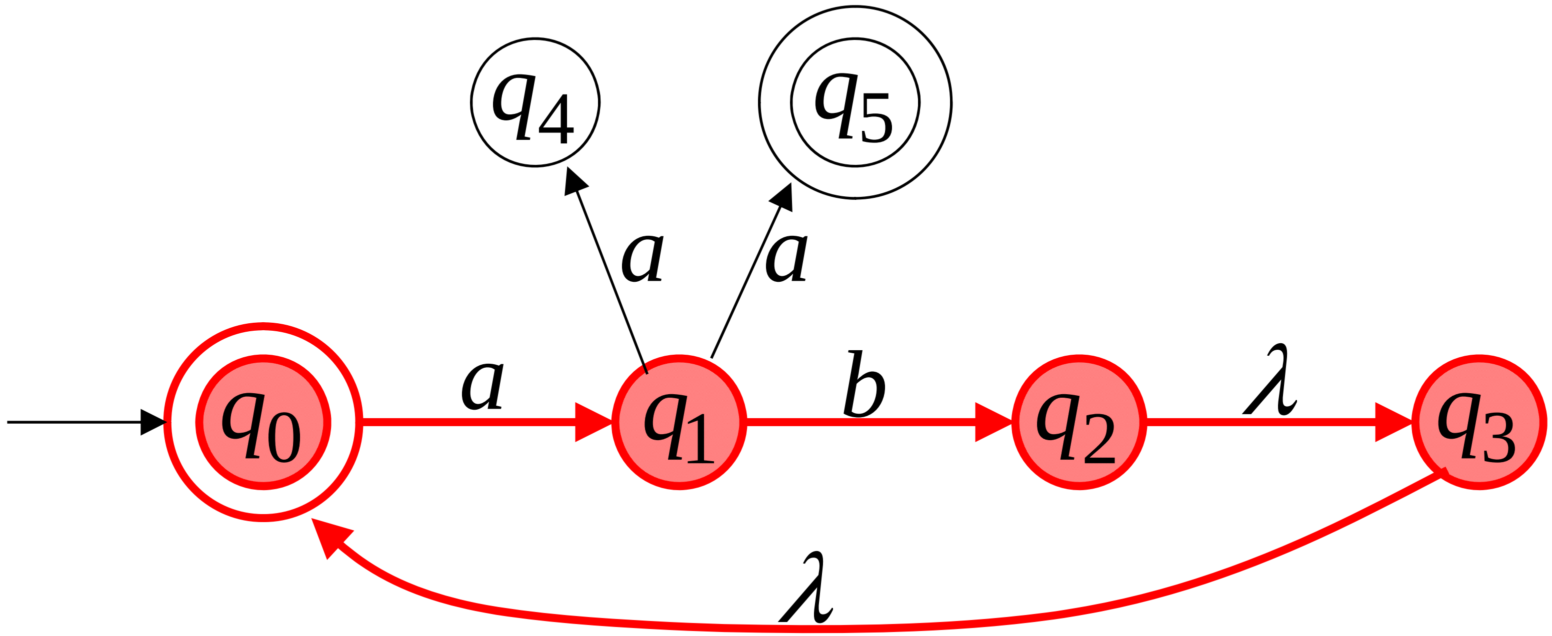
$$\delta^*(q_0, a) = \{q_1\}$$



$$\delta^*(q_0, aa) = \{q_4, q_5\}$$



$$\delta^*(q_0, ab) = \{q_2, q_3, q_0\}$$



Formally

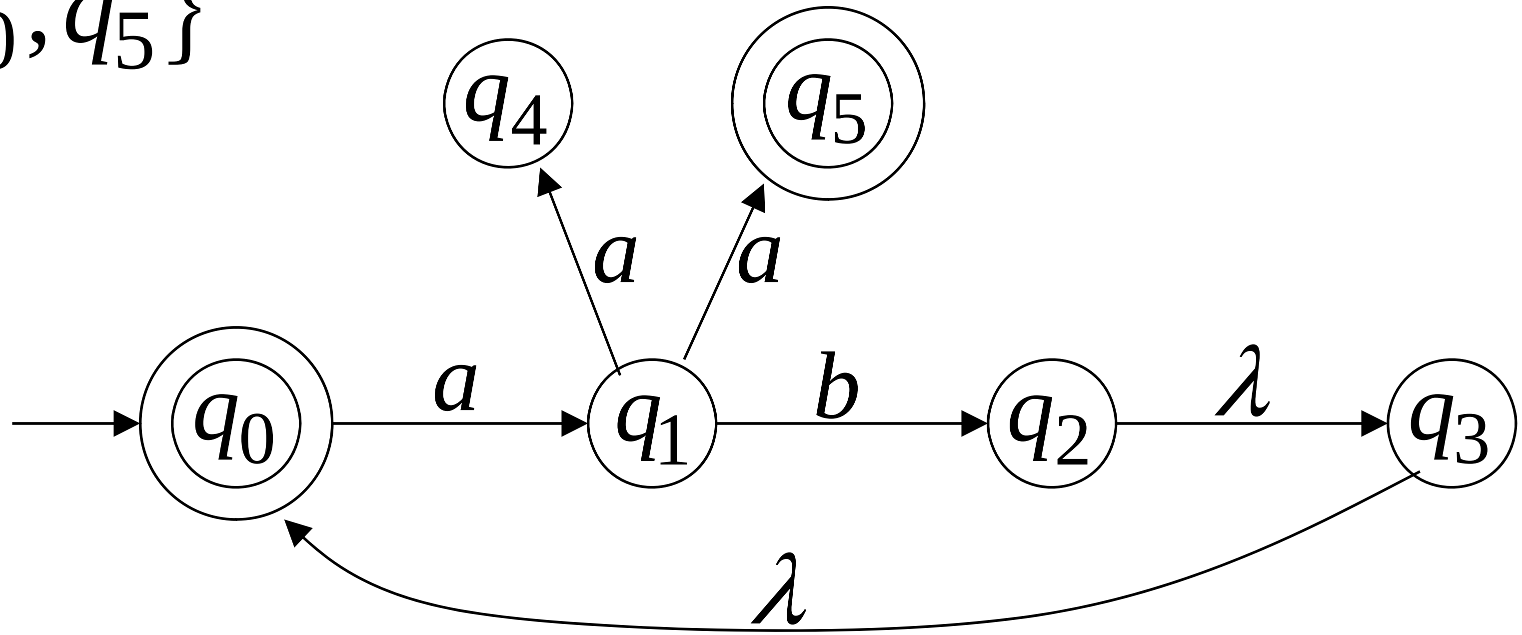
It holds $\quad q_j \in \delta^*(q_i, w)$

if and only if

there is a walk from q_i to q_j
with label w

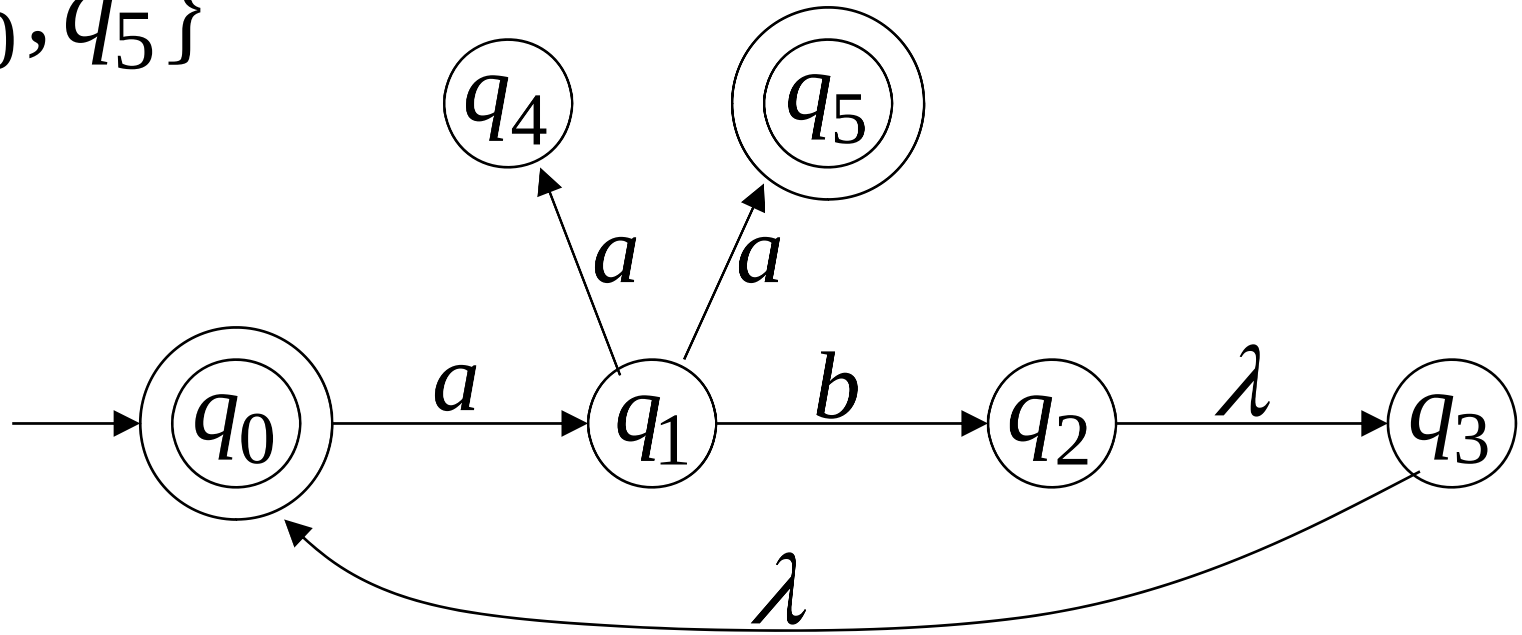
The Language of an NFA M

$$F = \{q_0, q_5\}$$



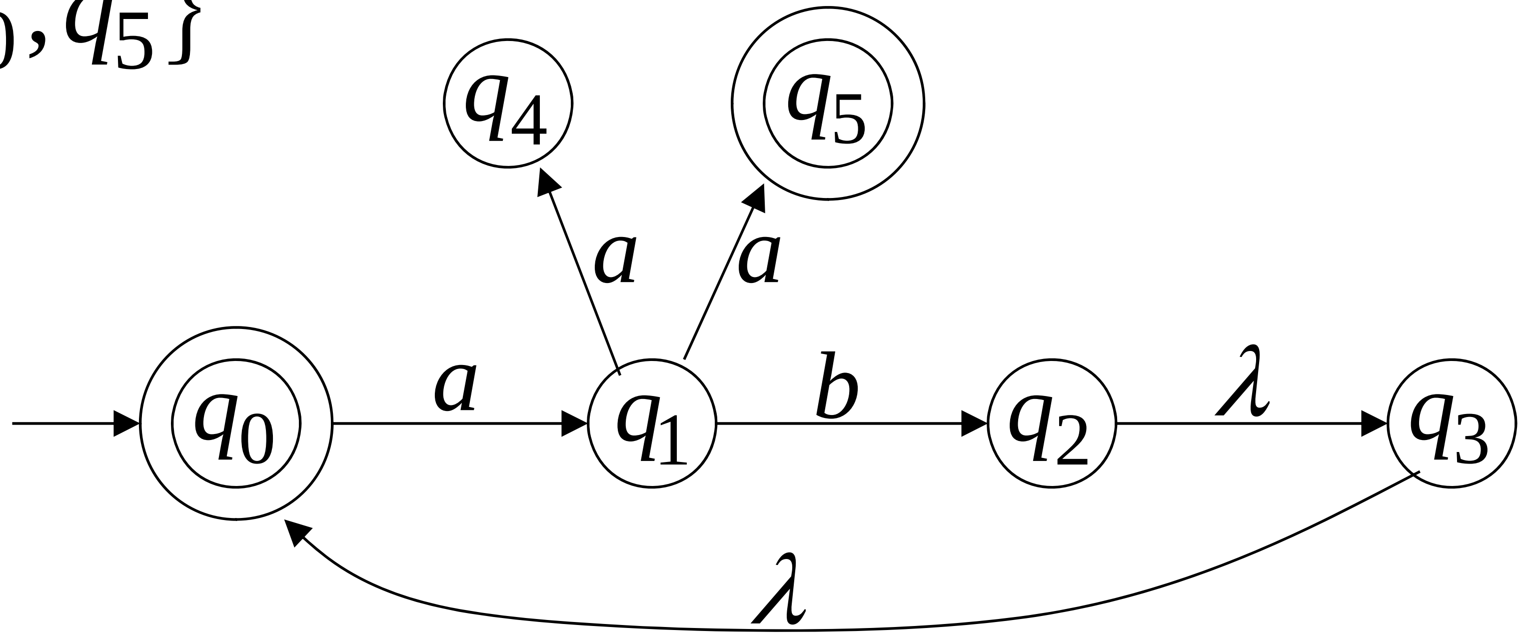
$$\delta^*(q_0, aa) = \{q_4, \underline{q_5}\} \qquad aa \in L(M)$$

$$F = \{q_0, q_5\}$$



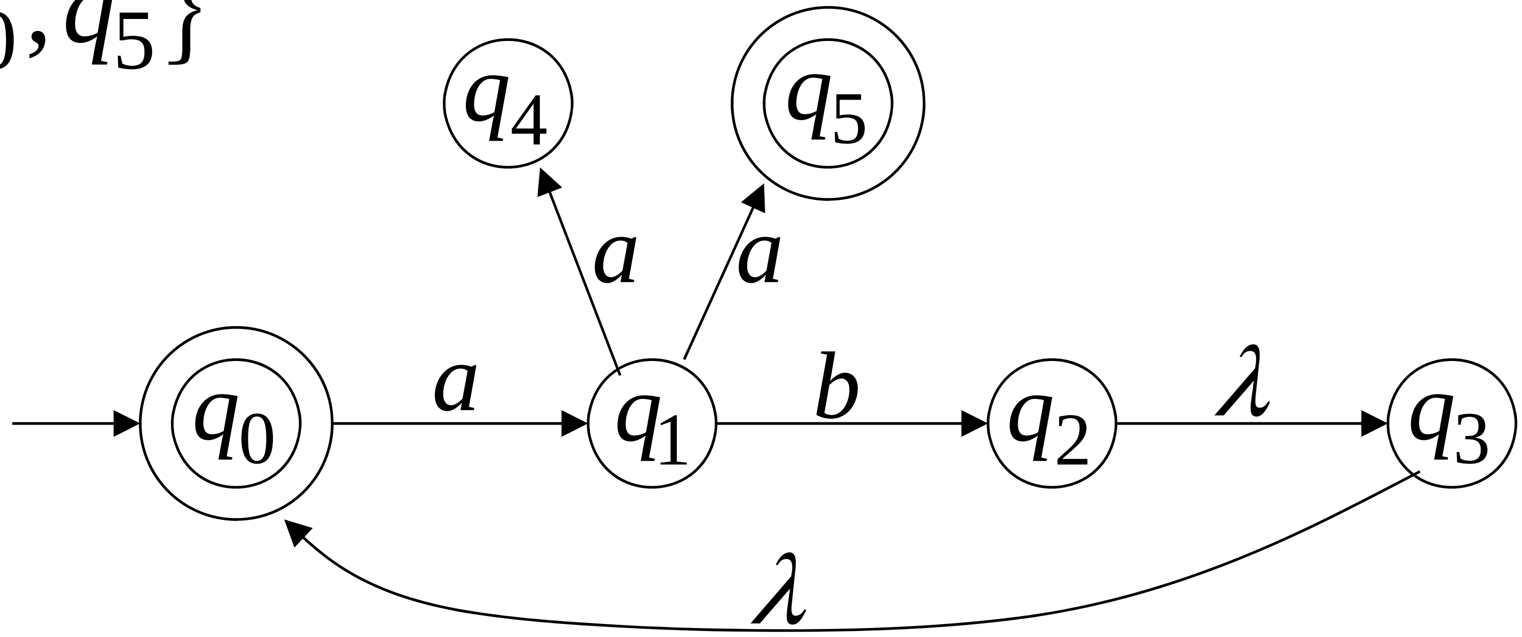
$$\delta^*(q_0, ab) = \{q_2, q_3, \underline{q_0}\} \qquad ab \in L(M)$$

$$F = \{q_0, q_5\}$$

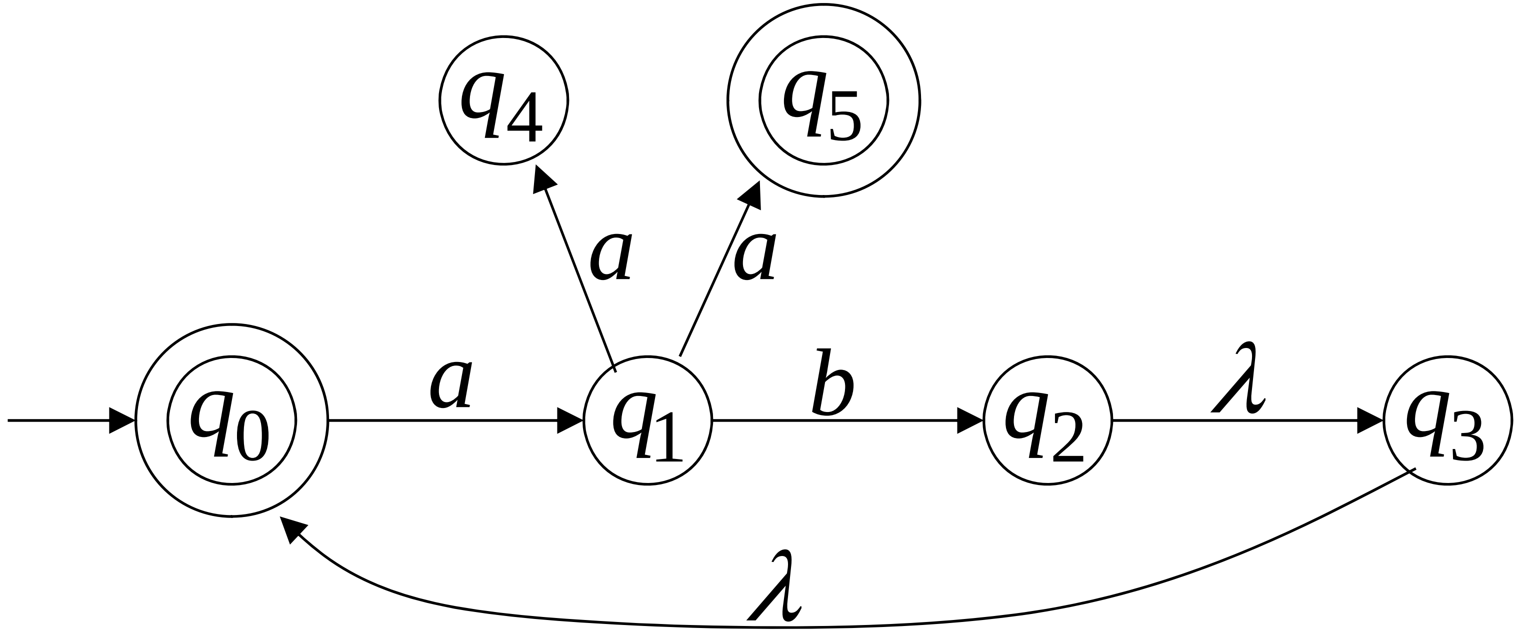


$$\delta^*(q_0, abaa) = \{q_4, \underline{q_5}\} \qquad aaba \in L(M)$$

$$F = \{q_0, q_5\}$$



$$\delta^*(q_0, aba) = \{q_1\} \qquad aba \notin L(M)$$



$$L(M) = \{aa\} \cup \{ab\}^* \cup \{ab\}^+\{aa\}$$

Formally

The language accepted by NFA M is:

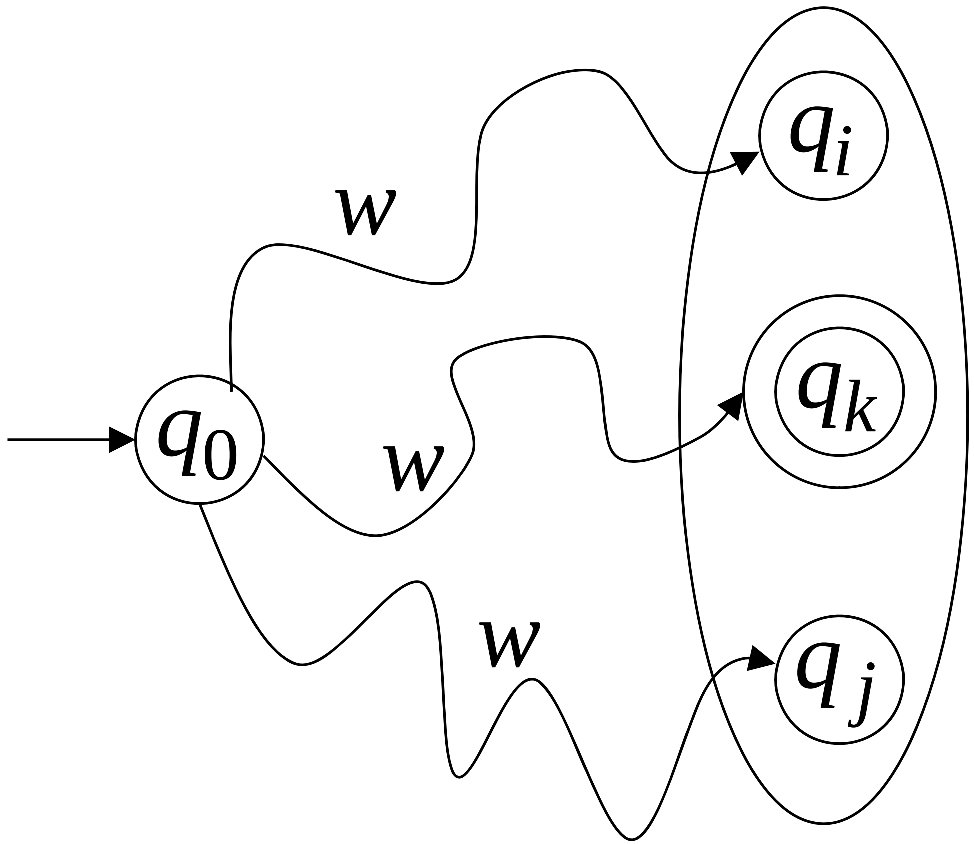
$$L(M) = \{w_1, w_2, w_3, \ldots\}$$

where $\delta^*(q_0, w_m) = \{q_i, q_j, \ldots\}$

and there is some $q_k \in F$ (final state)

$w \in L(M)$

$\delta^*(q_0, w)$



$q_k \in F$

Equivalence of NFAs and DFAs

Equivalence of Machines

For DFAs or NFAs:

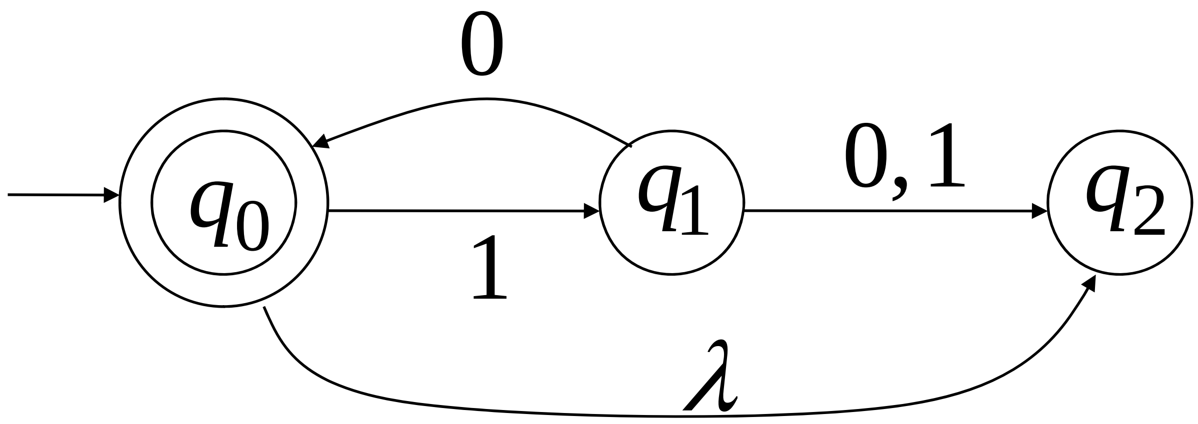
Machine M_1 is equivalent to machine M_2

if $L(M_1) = L(M_2)$

Example

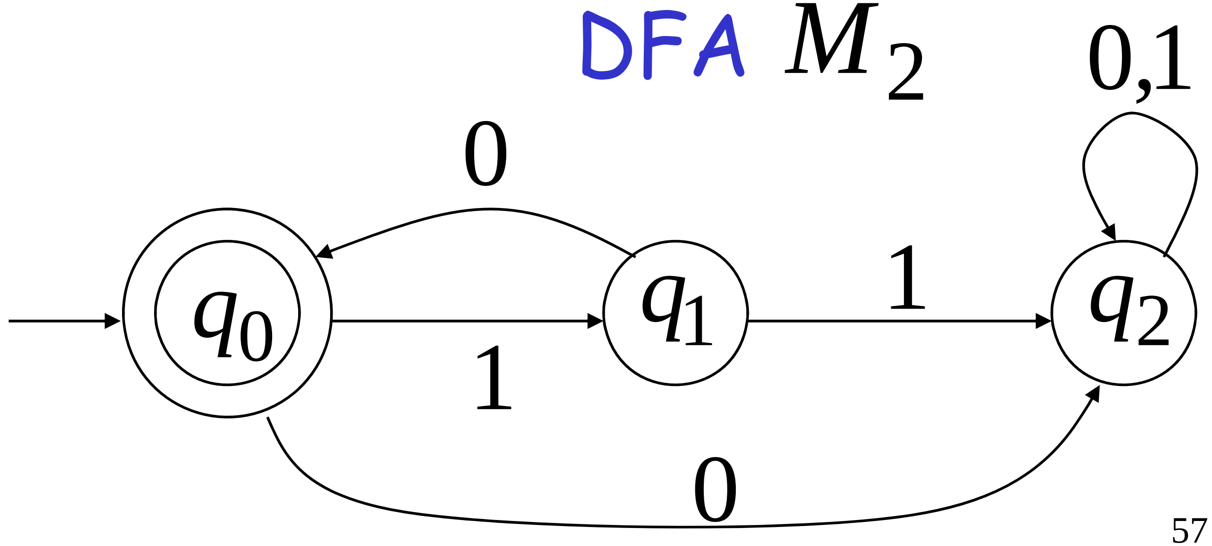
$L(M_1) = \{10\}^*$

NFA M_1



$L(M_2) = \{10\}^*$

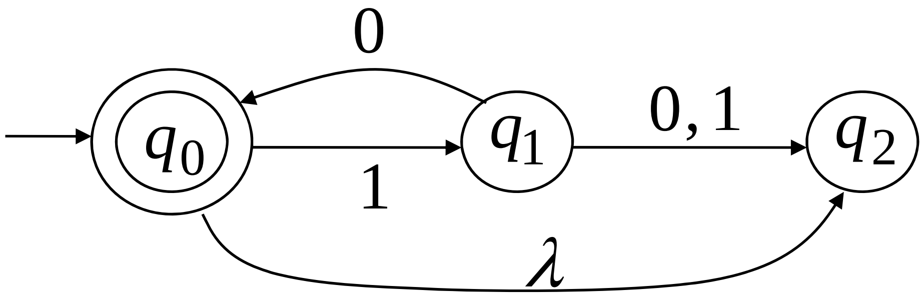
DFA M_2



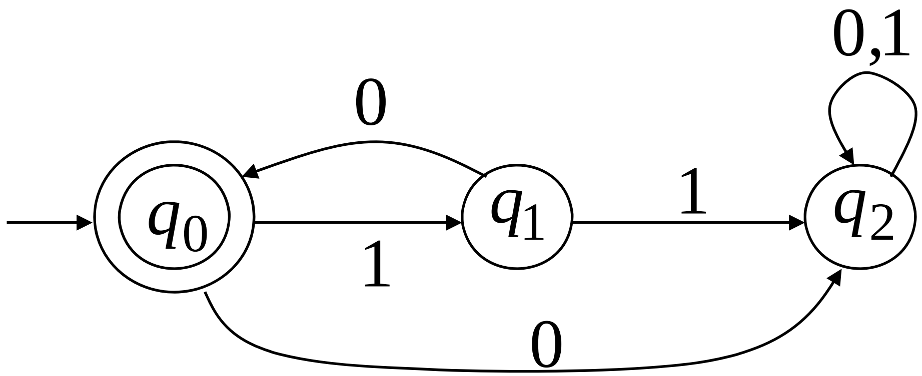
Since $L(M_1) = L(M_2) = \{10\}^*$

machines M_1 and M_2 are equivalent

NFA M_1



DFA M_2



Equivalence of NFAs and DFAs

Question: NFAs = DFAs ?

Same power?

Accept the same languages?

Equivalence of NFAs and DFAs

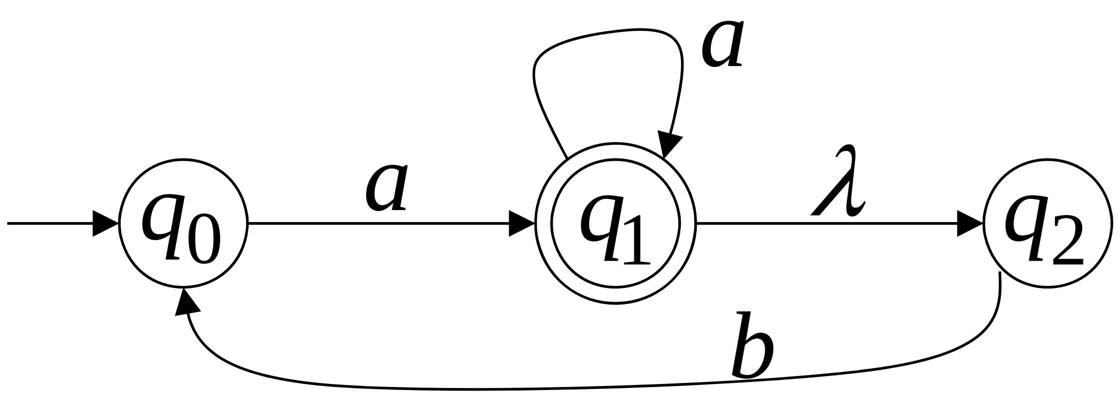
Question: NFAs = DFAs ? **YES!**

Same power?

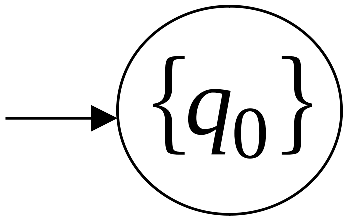
Accept the same languages?

NFA to DFA

NFA

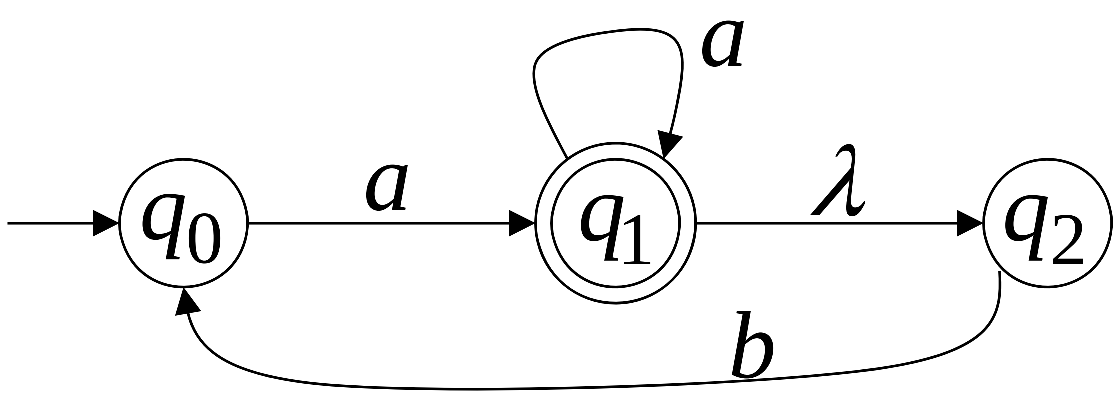


DFA

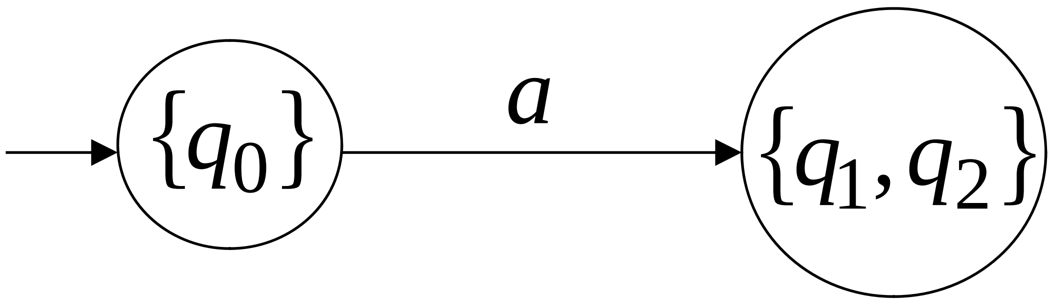


NFA to DFA

NFA

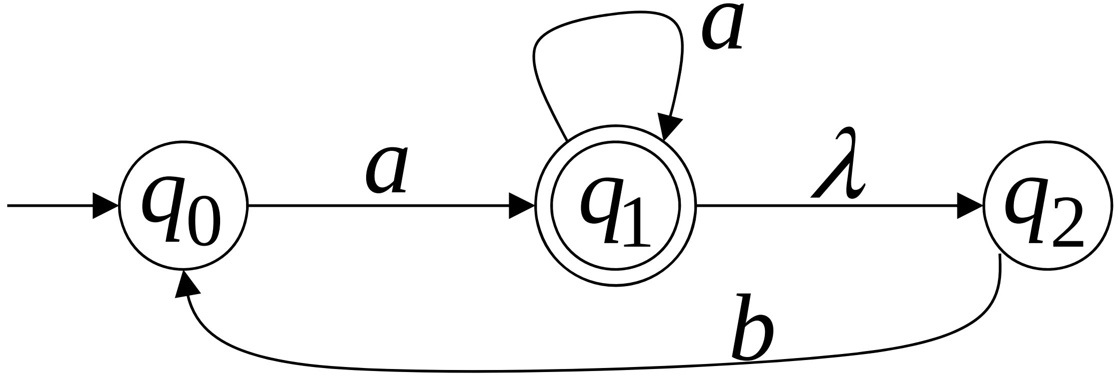


DFA



NFA to DFA

NFA



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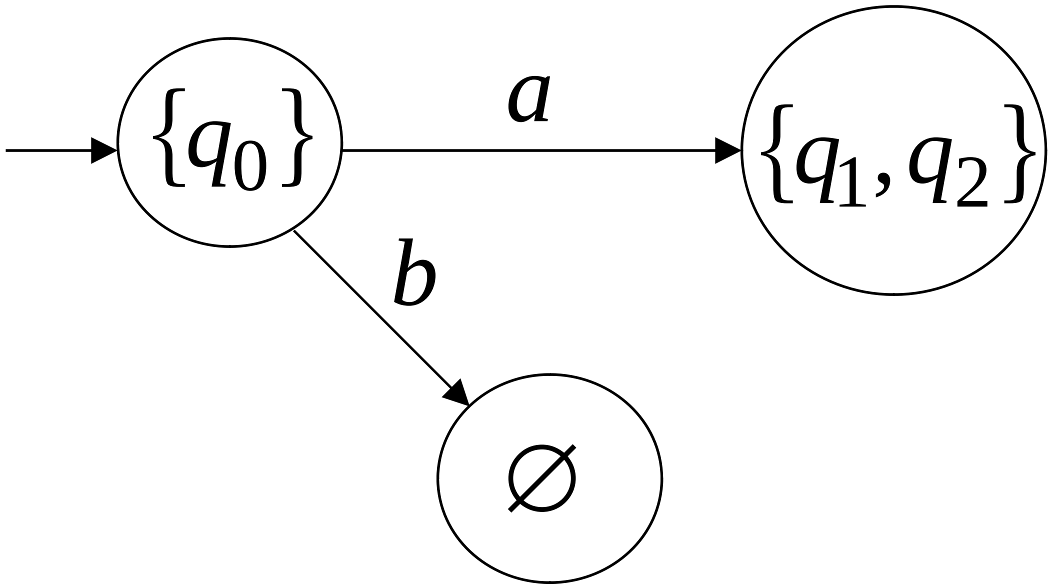
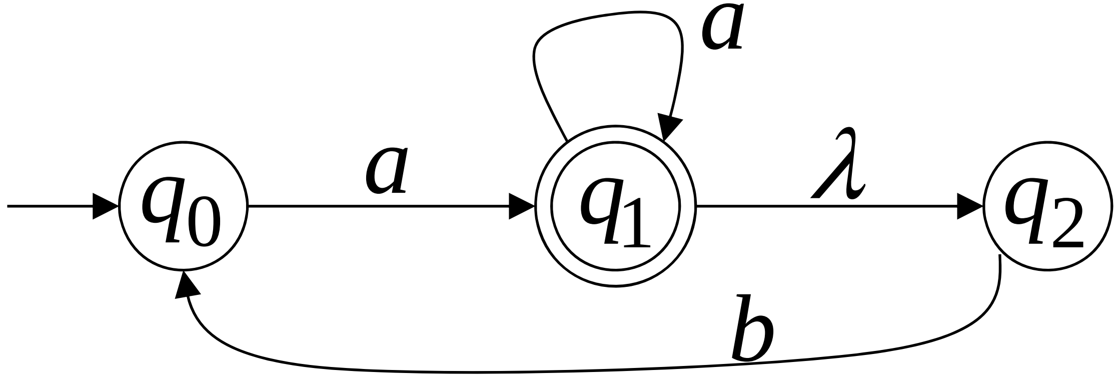


NFA to DFA

NFA



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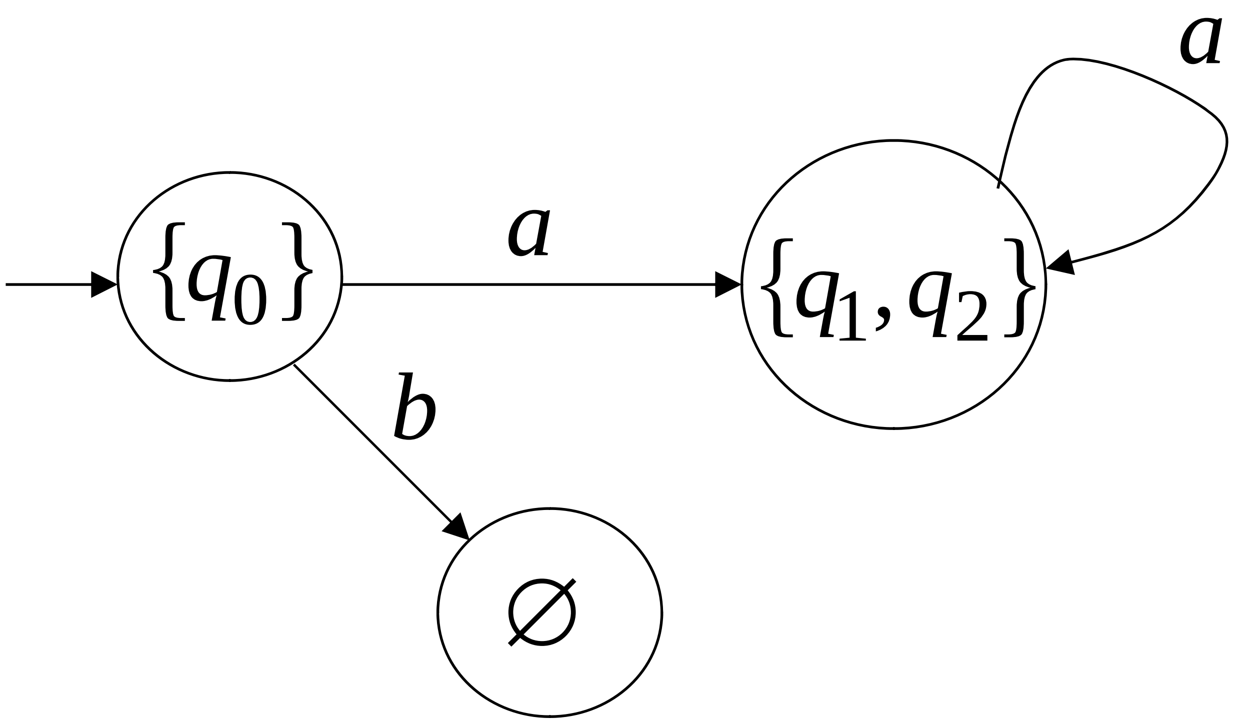
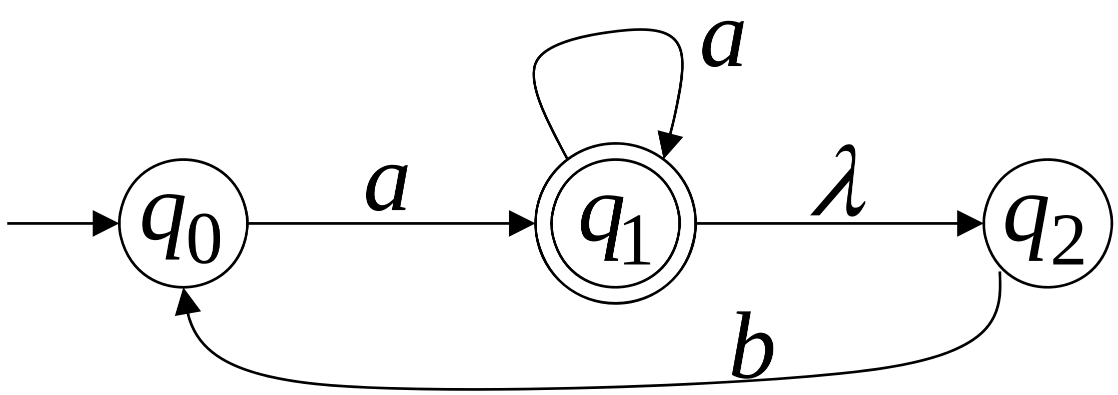


NFA to DFA

NFA



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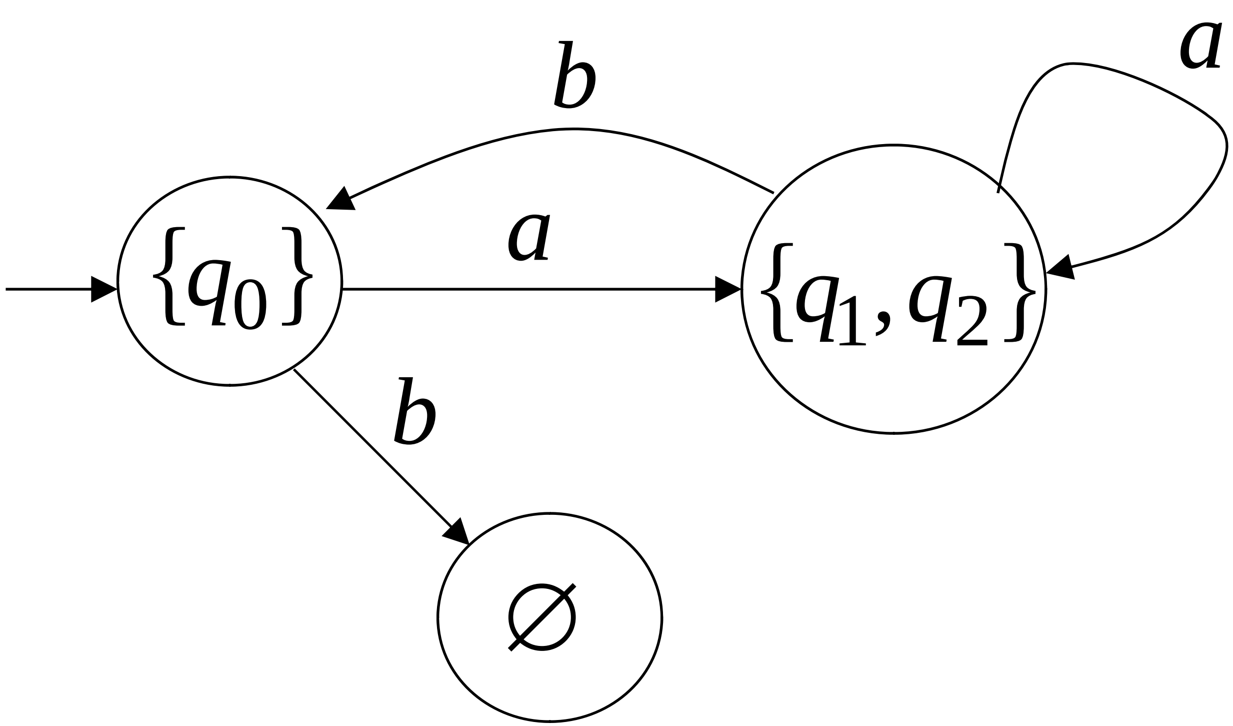
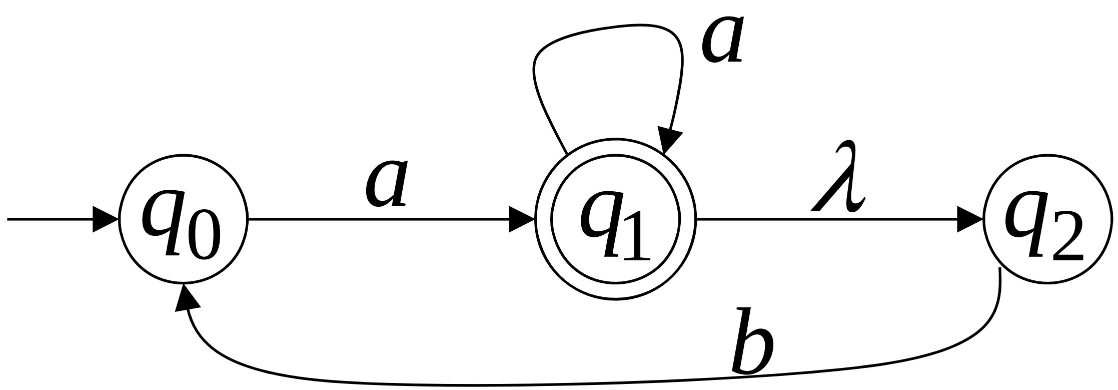


NFA to DFA

NFA



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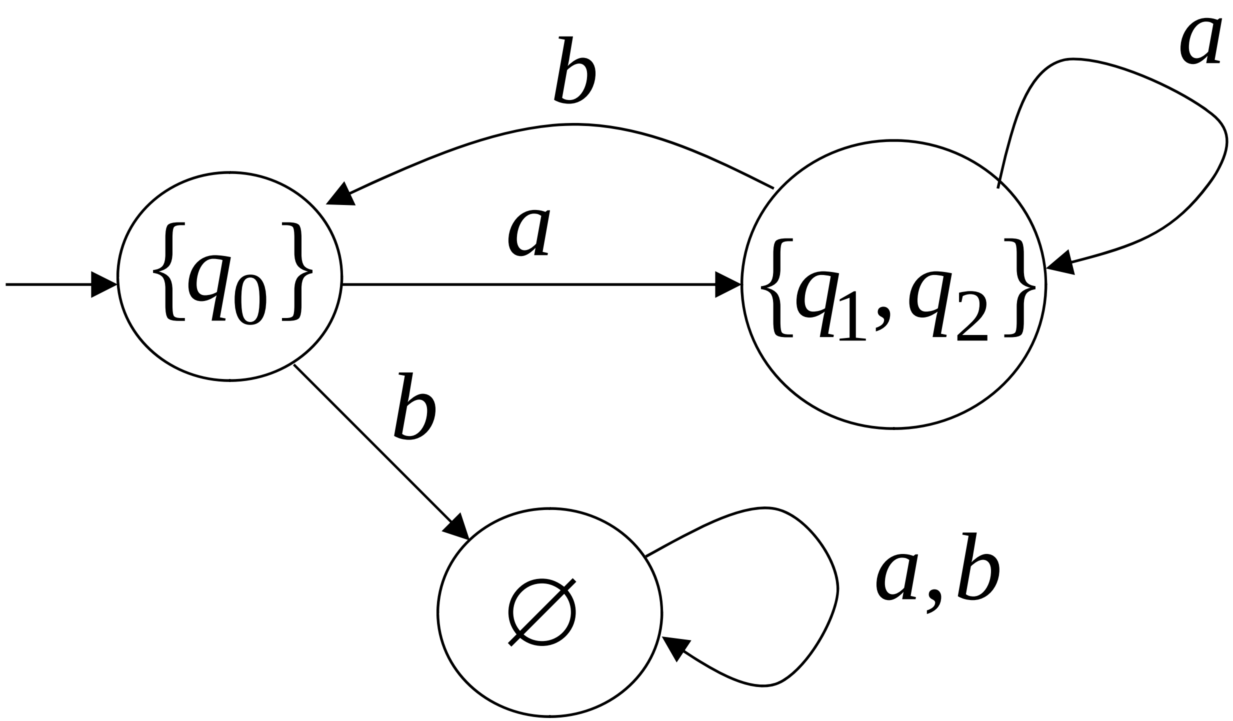
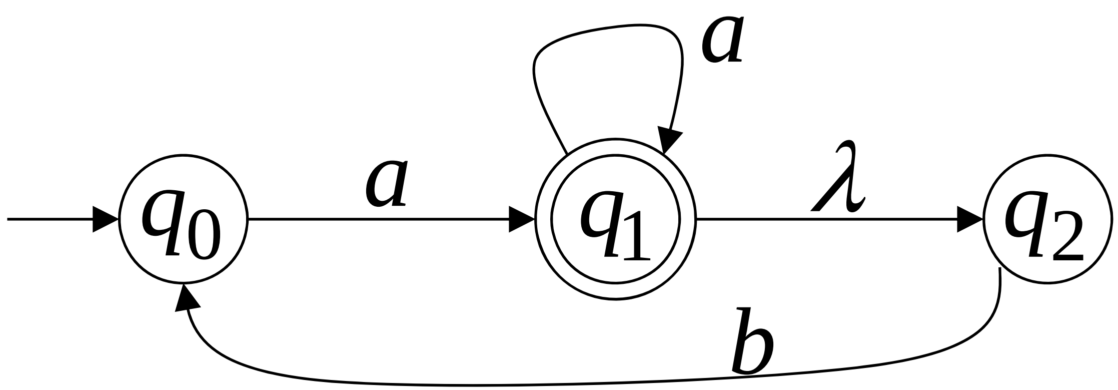
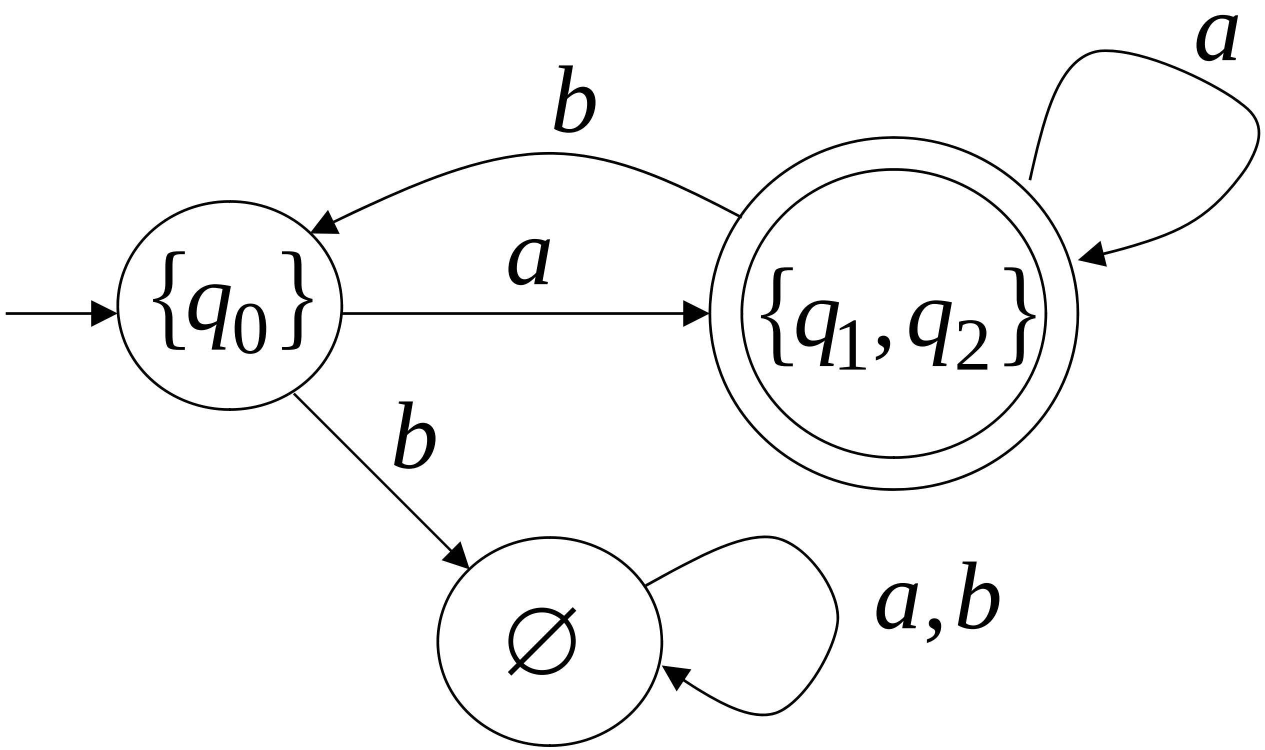


NFA to DFA

NFA



DFA



NFA to DFA: Remarks

We are given an NFA M

We want to convert it
to an equivalent DFA M'

With $L(M) = L(M')$

If the NFA has states

$$q_0, q_1, q_2, \ldots$$

the DFA has states in the powerset

$$\emptyset, \{q_0\}, \{q_1\}, \{q_1, q_2\}, \{q_3, q_4, q_7\}, \ldots.$$

Procedure NFA to DFA

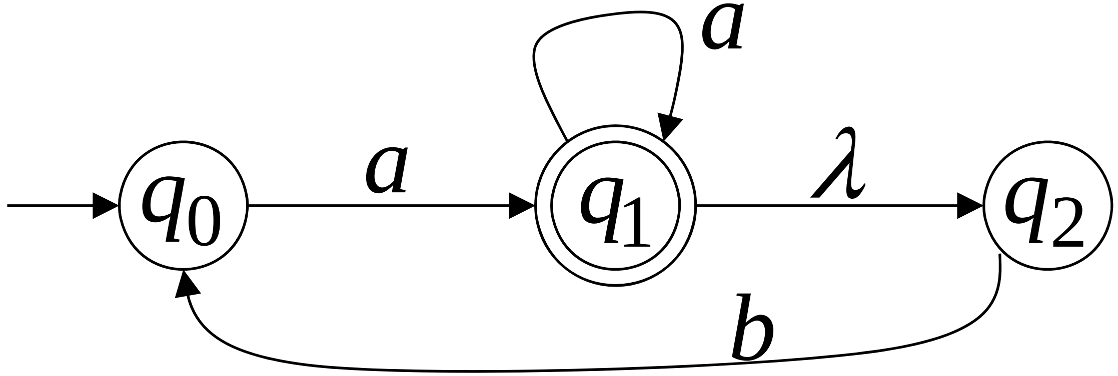
1. Initial state of NFA: q_0

$\Downarrow$

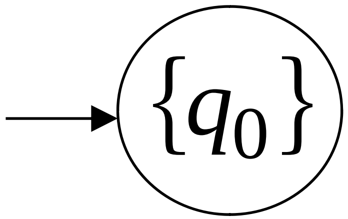
Initial state of DFA: $\{q_0\}$

Example

NFA



DFA



Procedure NFA to DFA

2. For every DFA's state $\{q_i, q_j, \ldots, q_m\}$

Compute in the NFA

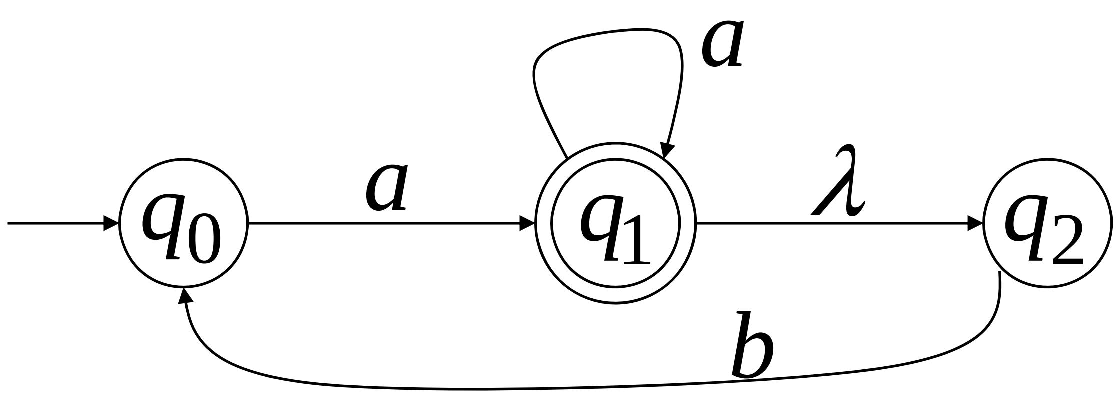
$$\left.\begin{array}{l} \delta^*(q_i, a), \\ \delta^*(q_j, a), \\ \ldots \end{array}\right\} = \{q'_i, q'_j, \ldots, q'_m\}$$

Add transition

$$\delta(\{q_i, q_j, \ldots, q_m\},\ a) = \{q'_i, q'_j, \ldots, q'_m\}$$

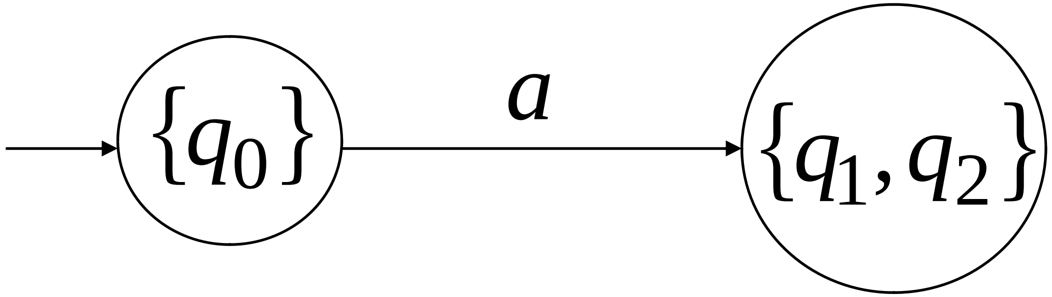
Example

NFA



$$\delta^*(q_0, a) = \{q_1, q_2\}$$

DFA



$$\delta(\{q_0\}, a) = \{q_1, q_2\}$$

Procedure NFA to DFA

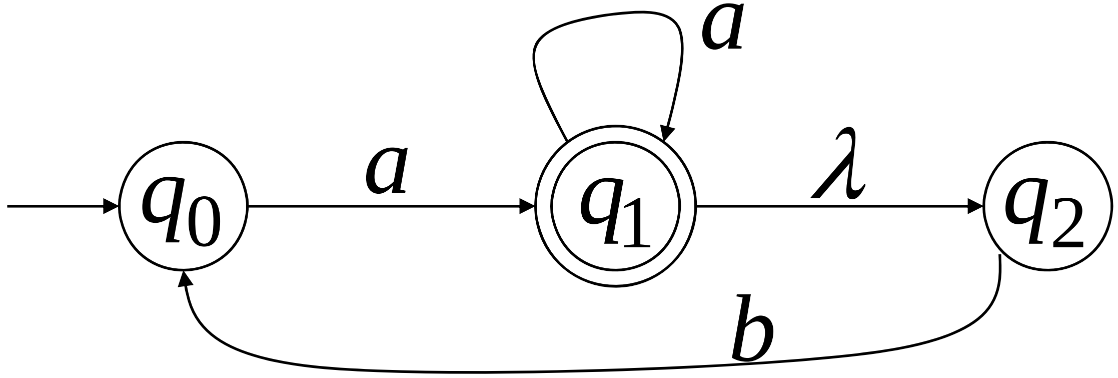
Repeat Step 2 for all letters in alphabet,

until

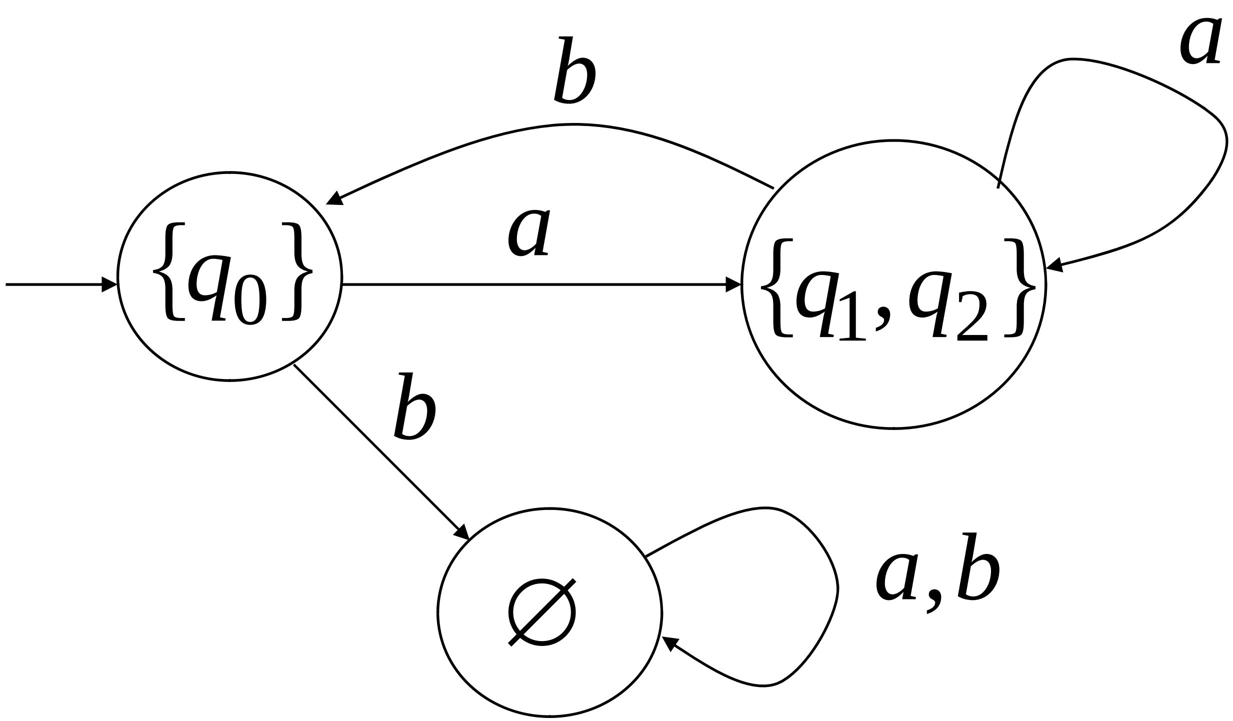
no more transitions can be added.

Example

NFA



DFA



Procedure NFA to DFA

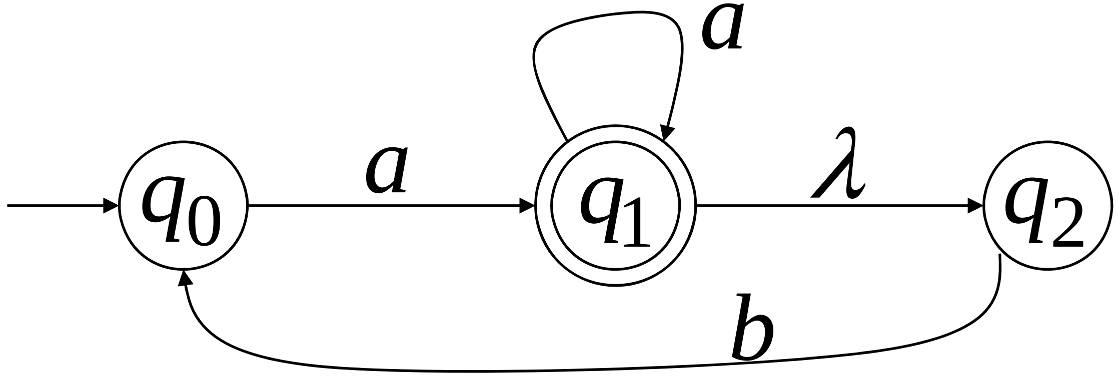
3. For any DFA state $\{q_i, q_j, \ldots, q_m\}$

If some q_j is a final state in the NFA

Then, $\{q_i, q_j, \ldots, q_m\}$
is a final state in the DFA

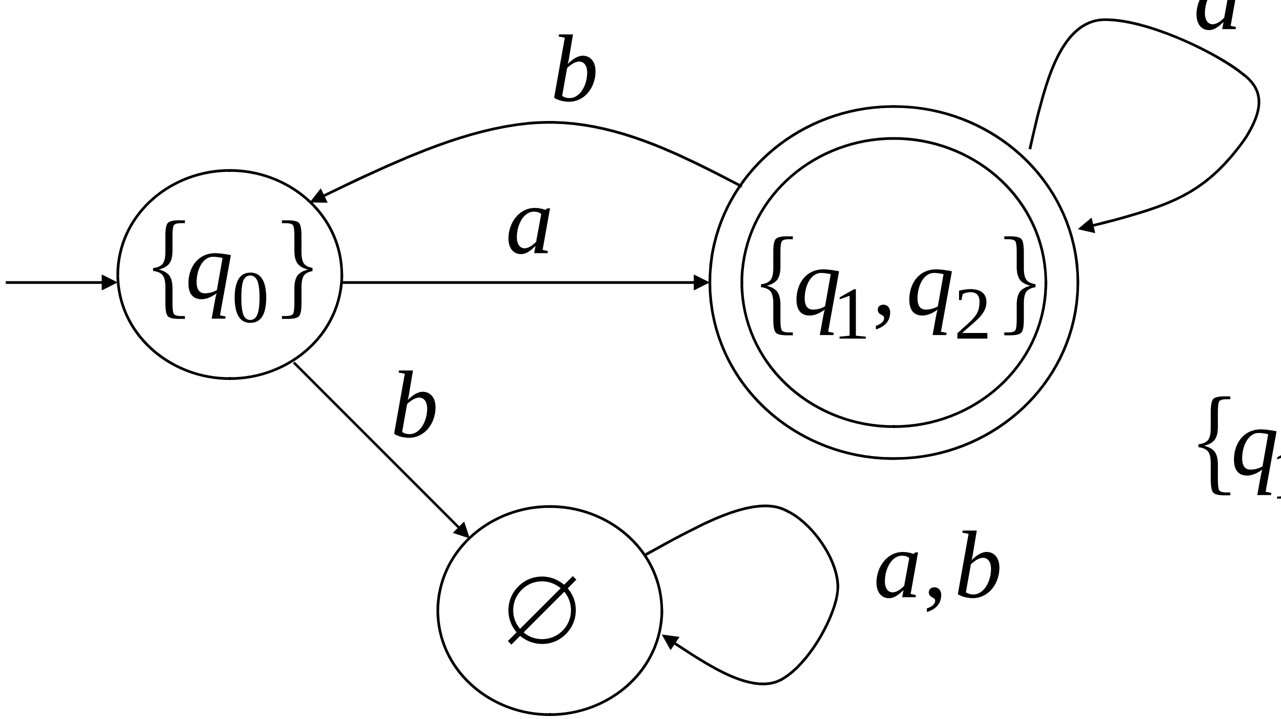
Example

NFA



$q_1 \in F$

DFA



$\{q_1, q_2\} \in F'$

Theorem

Take NFA M

Apply procedure to obtain DFA M'

Then M and M' are equivalent :

$$L(M) = L(M')$$

Finally

We have proven

$$\left\{\begin{array}{l}\text{Languages}\\\text{accepted}\\\text{by NFAs}\end{array}\right\} = \left\{\begin{array}{l}\text{Languages}\\\text{accepted}\\\text{by DFAs}\end{array}\right\}$$

We have proven

$$\left\{ \begin{array}{l} \text{Languages} \\ \text{accepted} \\ \text{by NFAs} \end{array} \right\} = \left\{ \begin{array}{l} \text{Languages} \\ \text{accepted} \\ \text{by DFAs} \end{array} \right\}$$

Regular Languages

We have proven

$$\left\{ \begin{array}{l} \text{Languages} \\ \text{accepted} \\ \text{by NFAs} \end{array} \right\} = \left\{ \begin{array}{l} \text{Languages} \\ \text{accepted} \\ \text{by DFAs} \end{array} \right\}$$

Regular Languages

Regular Languages