NFAs

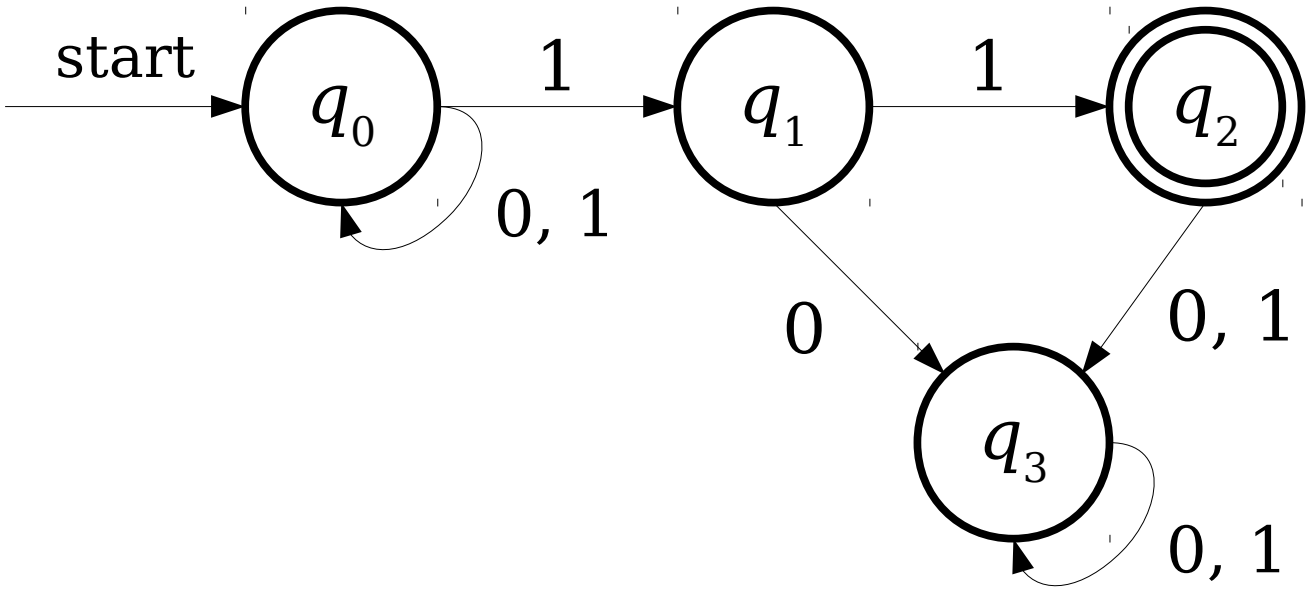
NFAs

- An ***NFA*** is a
  - ***N***ondeterministic
  - ***F***inite
  - ***A***utomaton
- Structurally similar to a DFA, but represents a fundamental shift in how we'll think about computation.

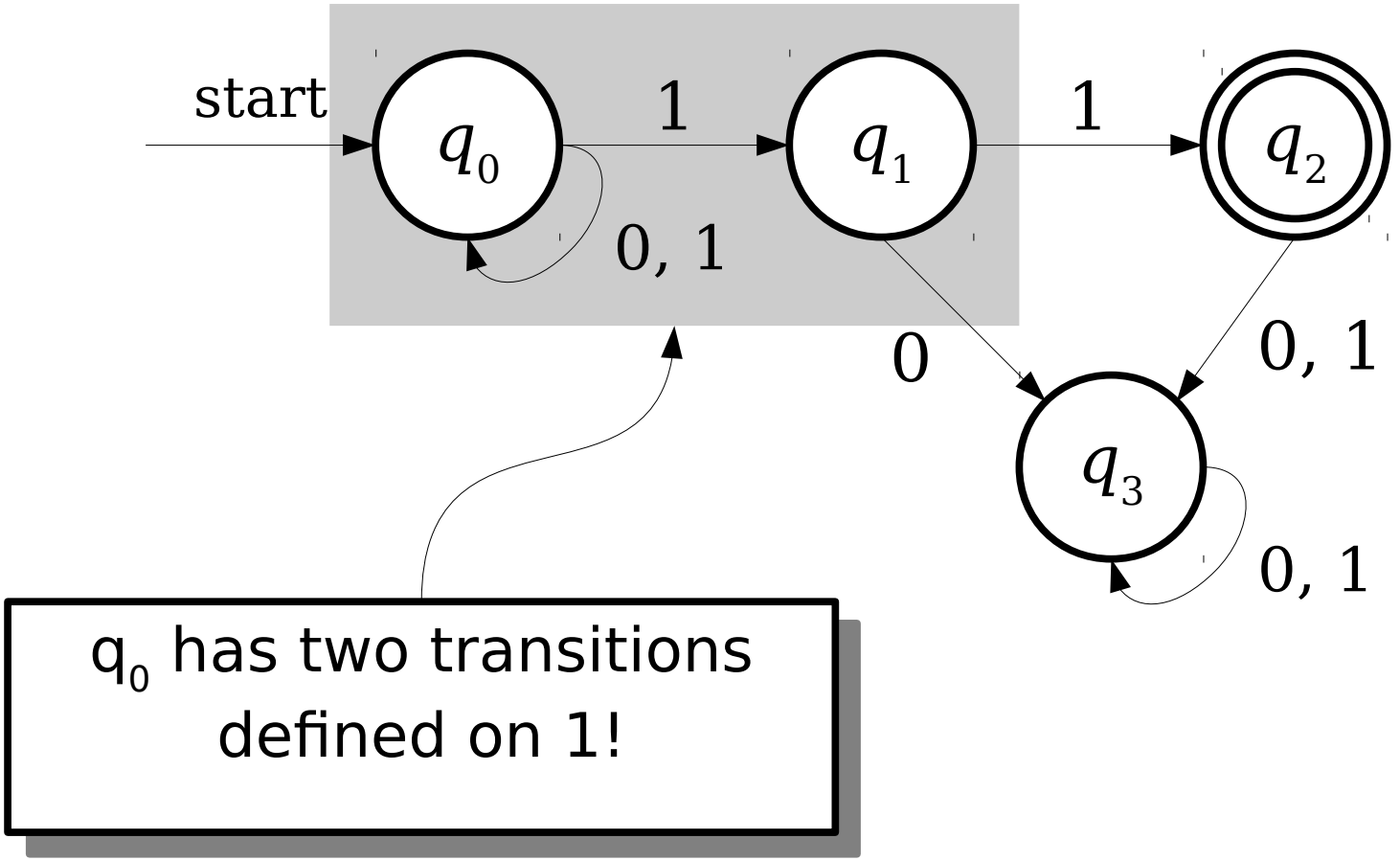
(Non)determinism

- A model of computation is ***deterministic*** if at every point in the computation, there is exactly one choice that can make.
- The machine accepts if that series of choices leads to an accepting state.
- A model of computation is ***nondeterministic*** if the computing machine may have multiple decisions that it can make at one point.
- The machine accepts if ***any*** series of choices leads to an accepting state.
  - (This sort of nondeterminism is technically called ***existential nondeterminism***, the most philosophical-sounding term we'll introduce all quarter.)

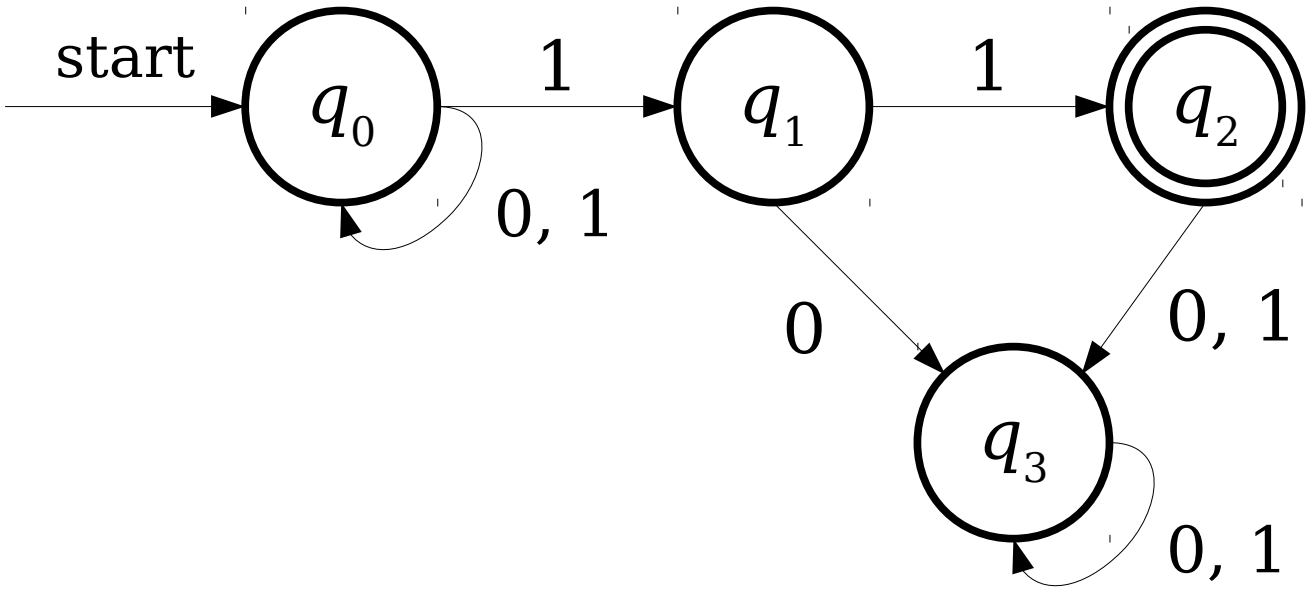
A Simple NFA



A Simple NFA

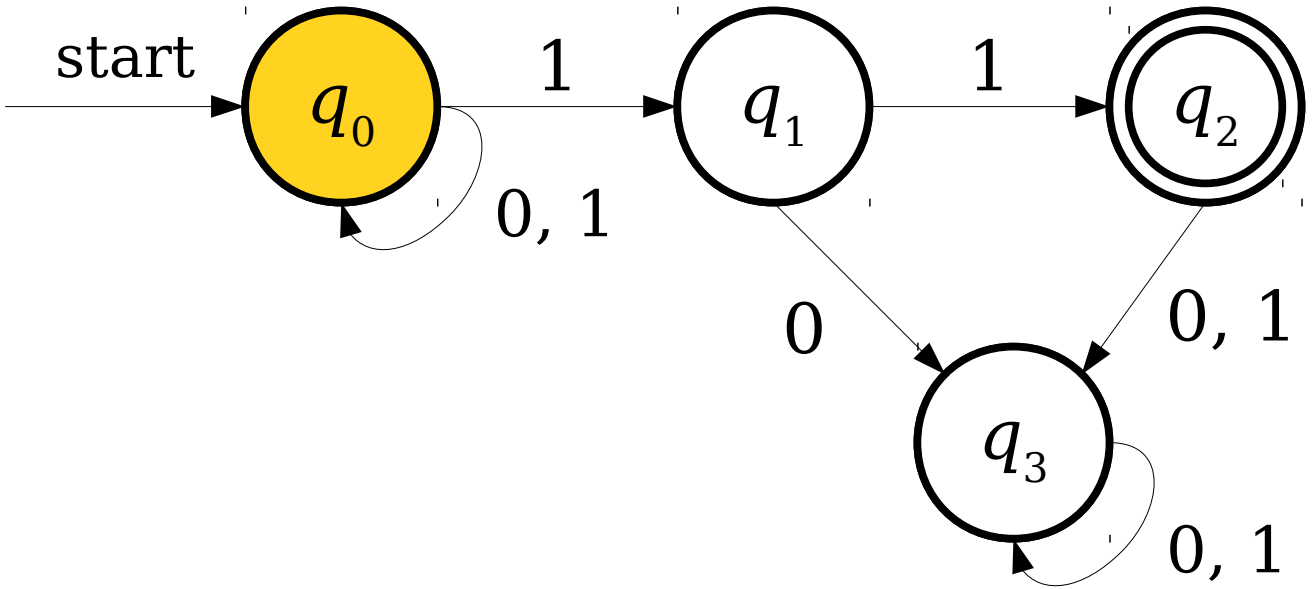

start
q_0
q_1
q_2
q_3
1
1
0, 1
0
0, 1
0, 1
q_0 has two transitions defined on 1!

A Simple NFA



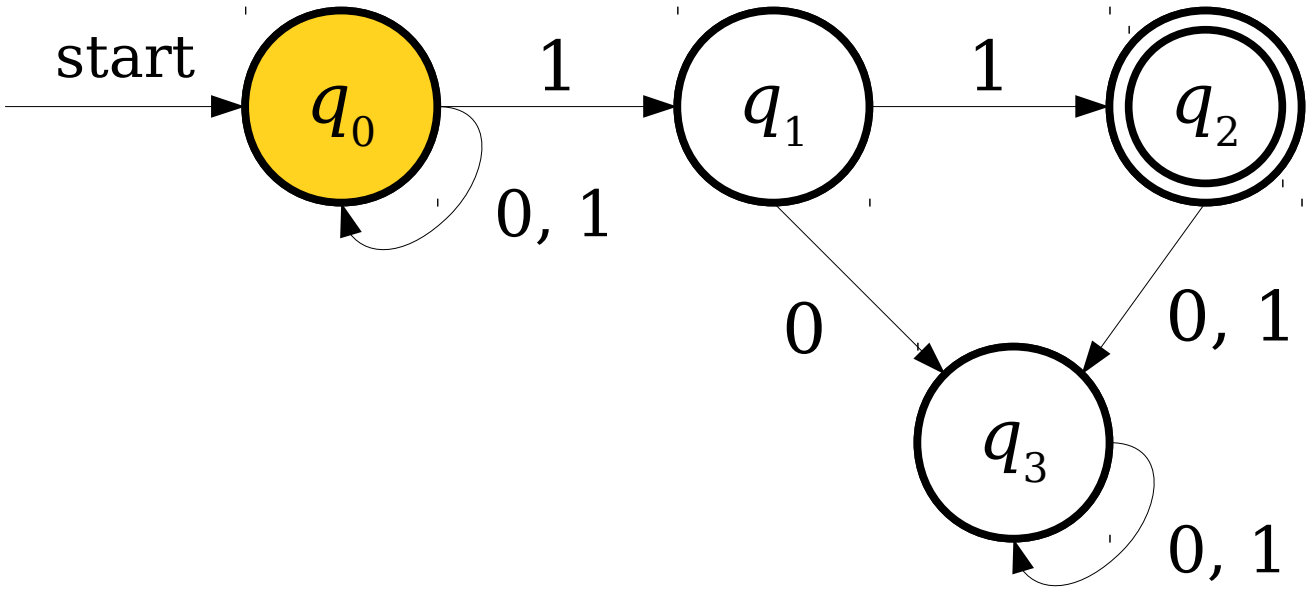
0 1 0 1 1

A Simple NFA

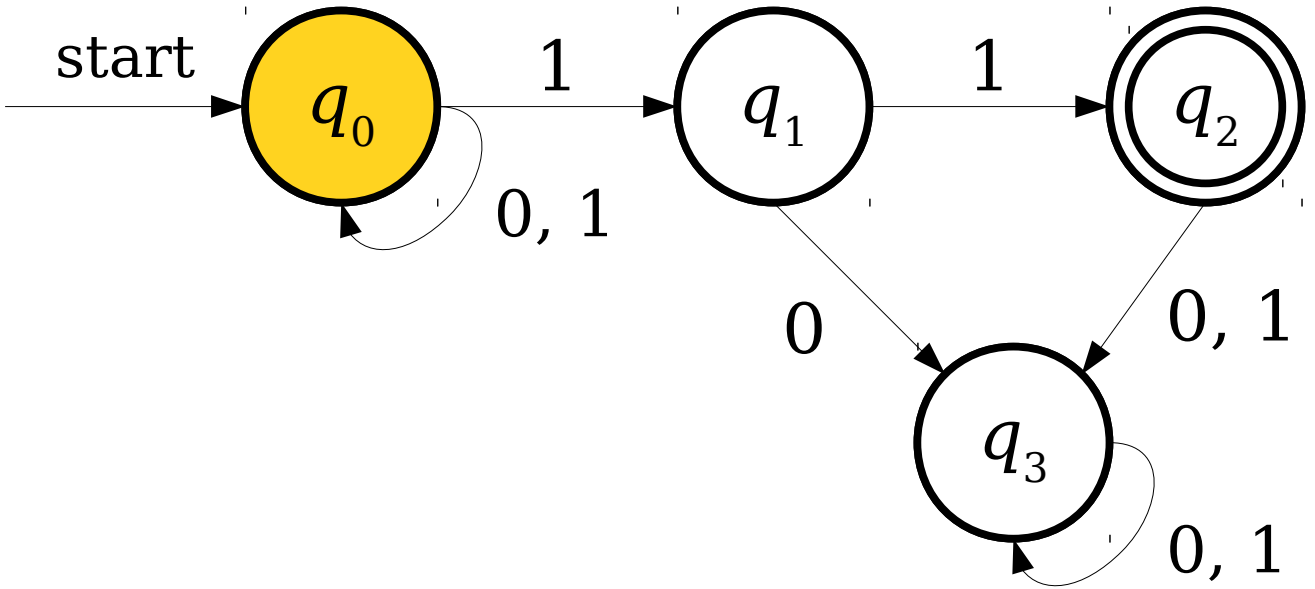


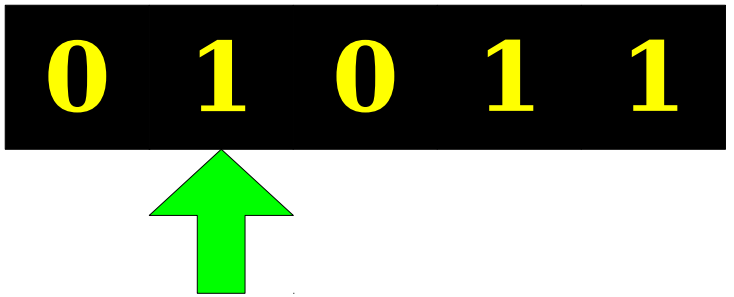
0 1 0 1 1

A Simple NFA

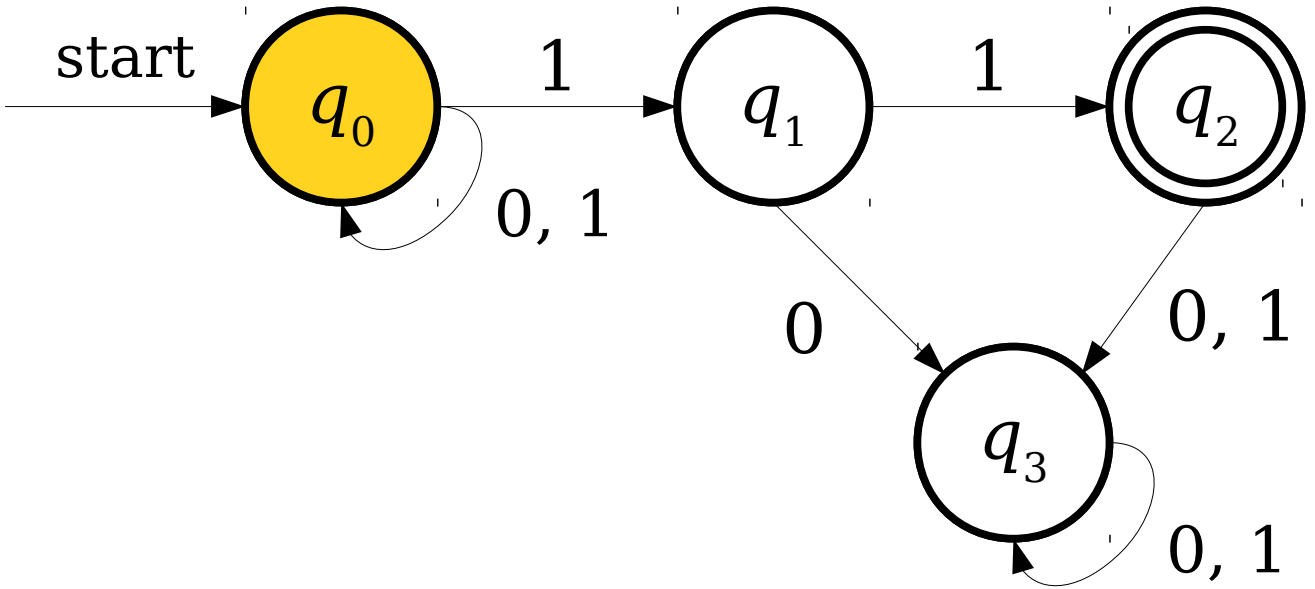


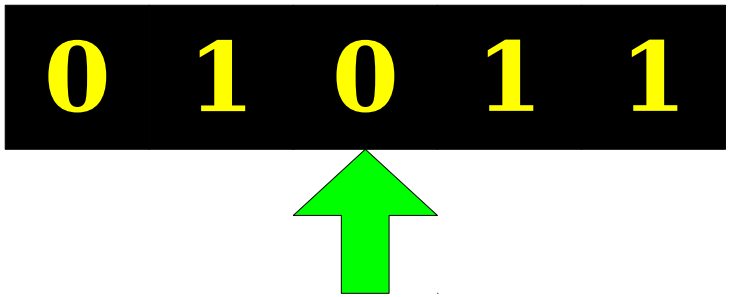
A Simple NFA



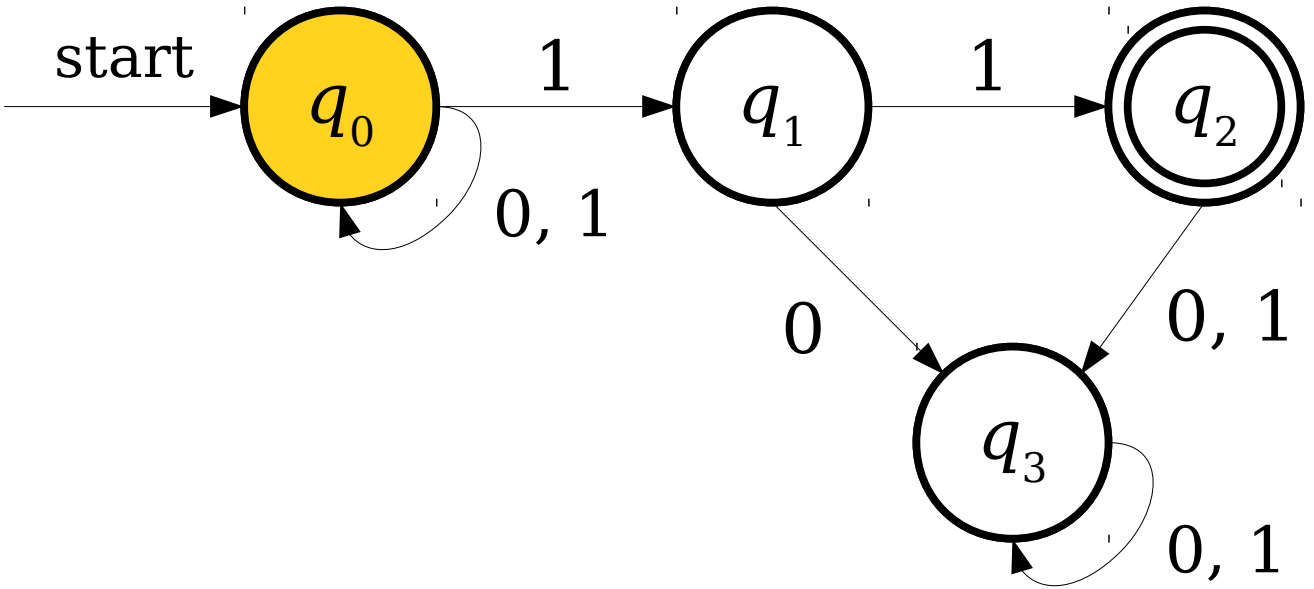


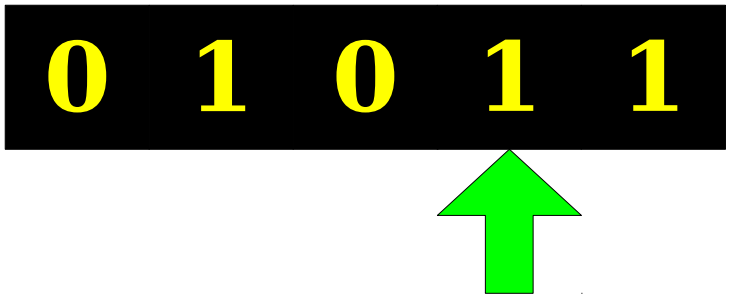
A Simple NFA



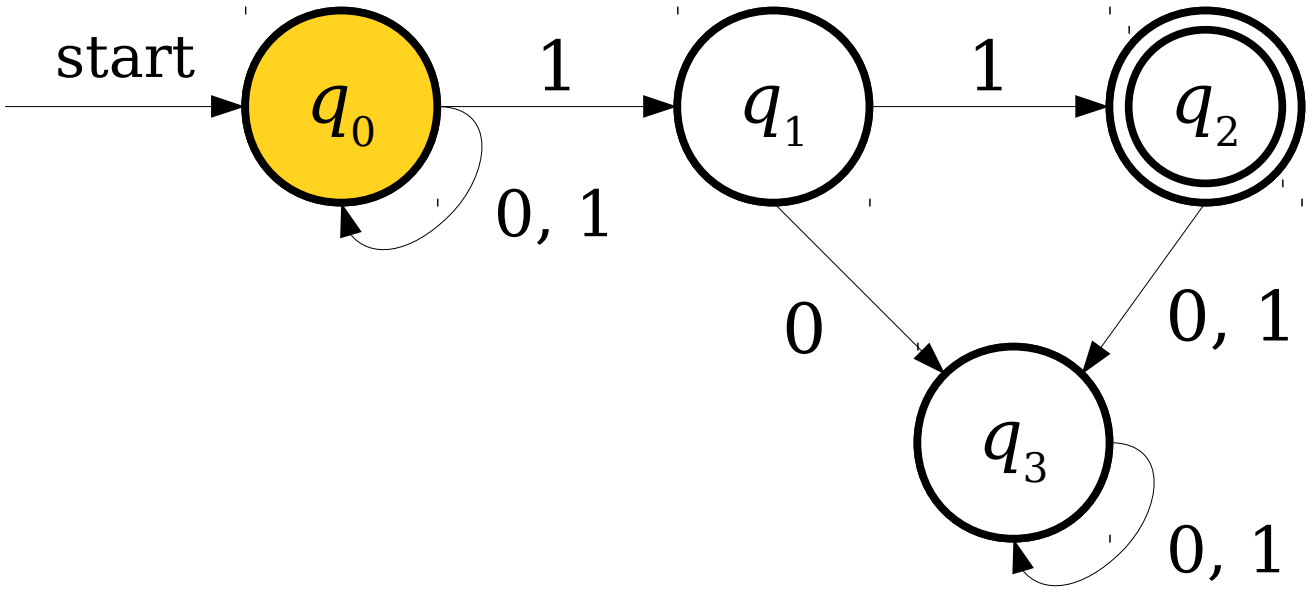


A Simple NFA

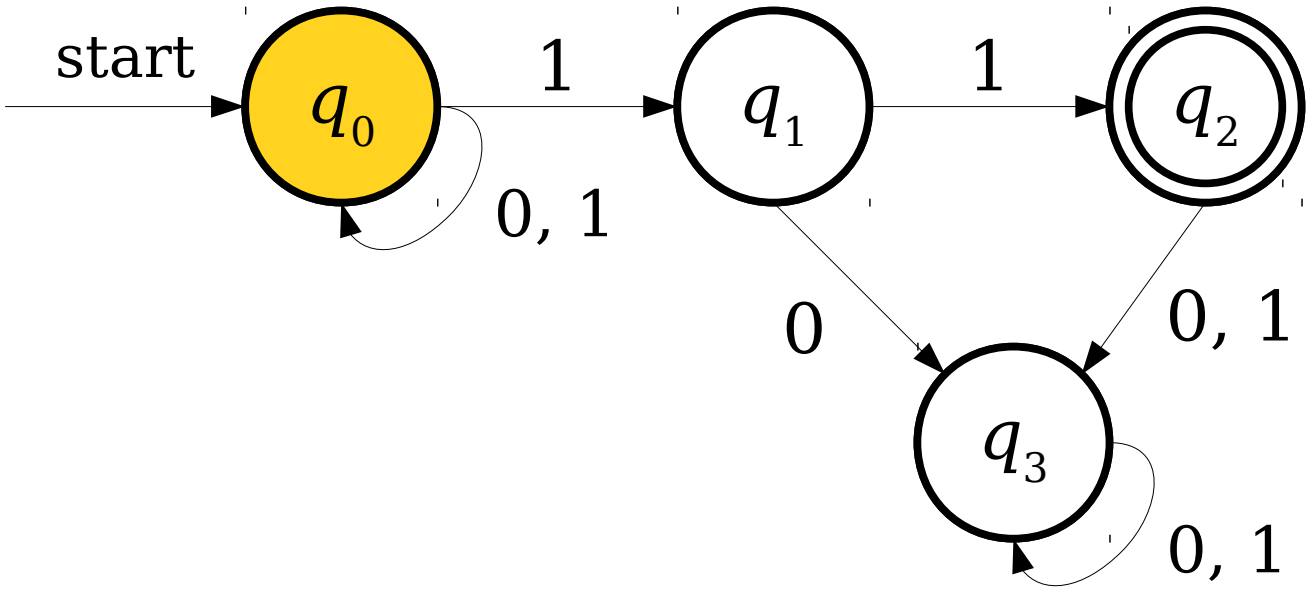




A Simple NFA

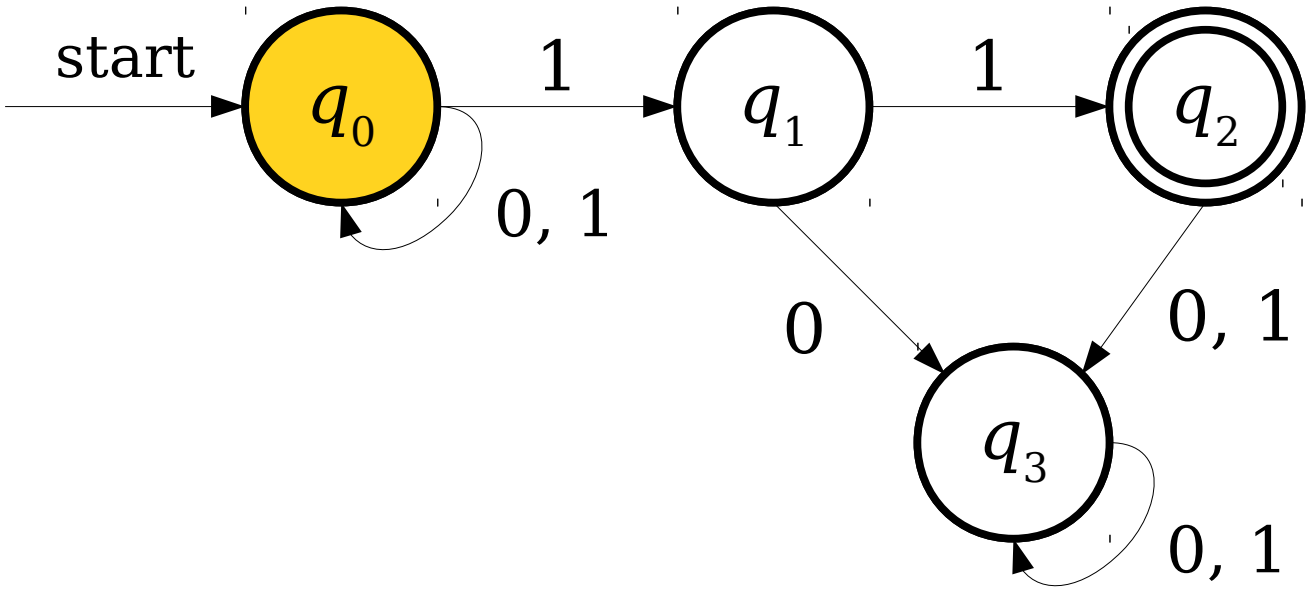


A Simple NFA

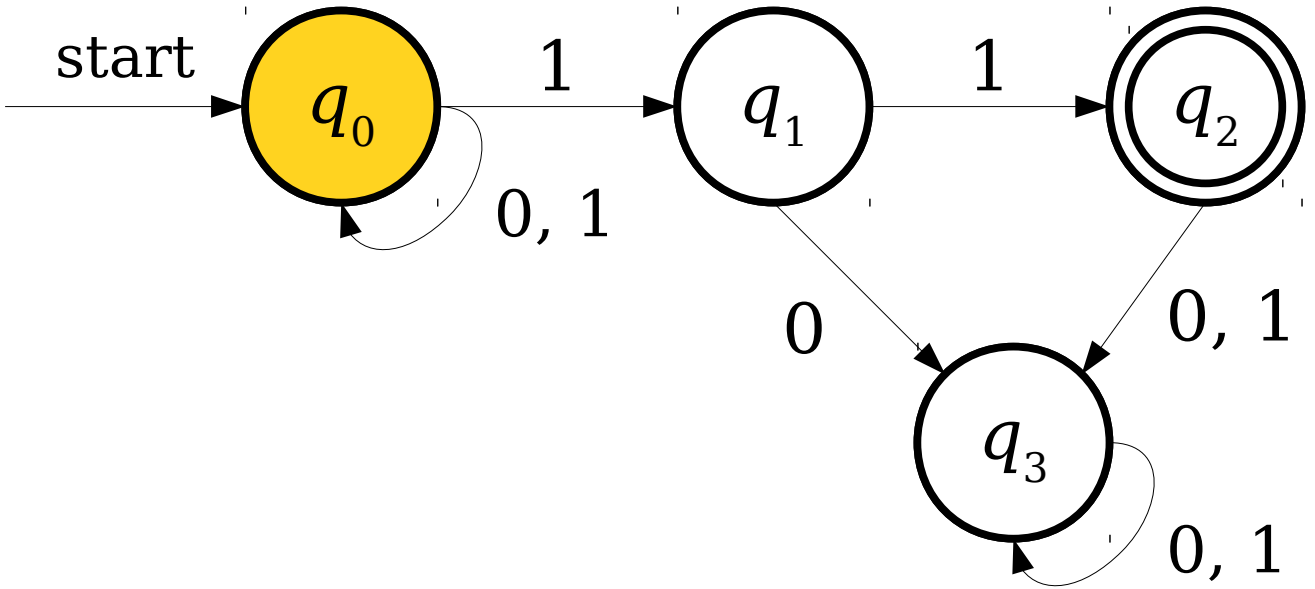


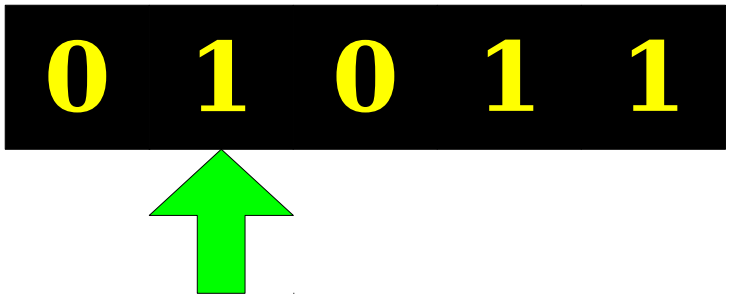
0 1 0 1 1

A Simple NFA

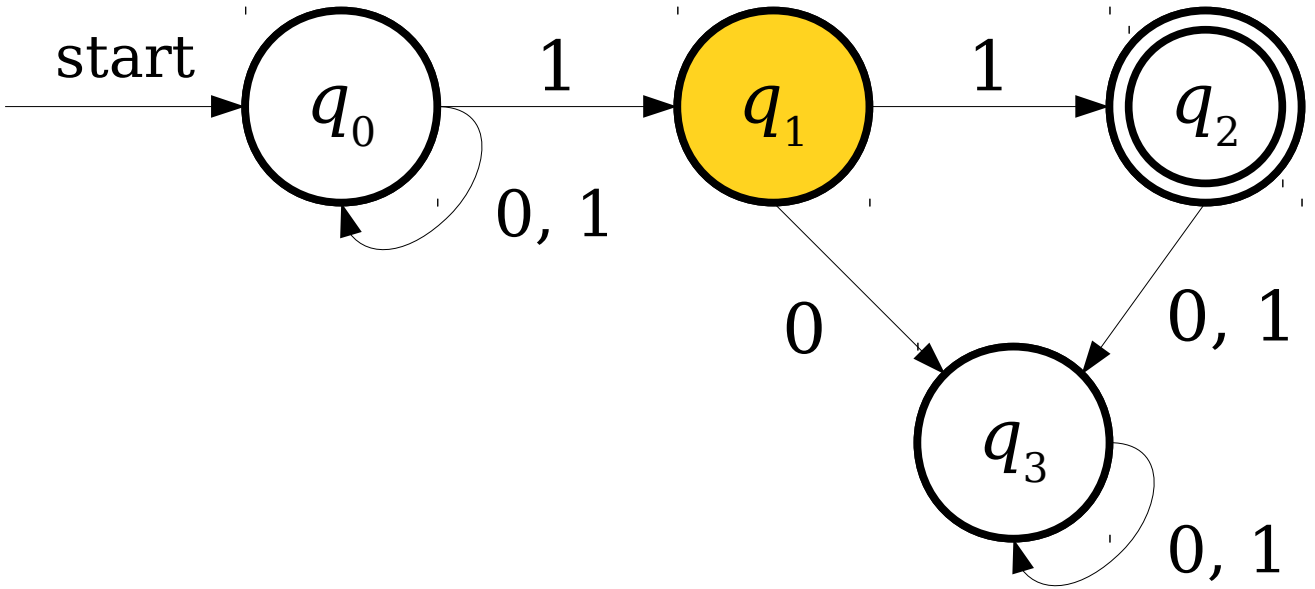


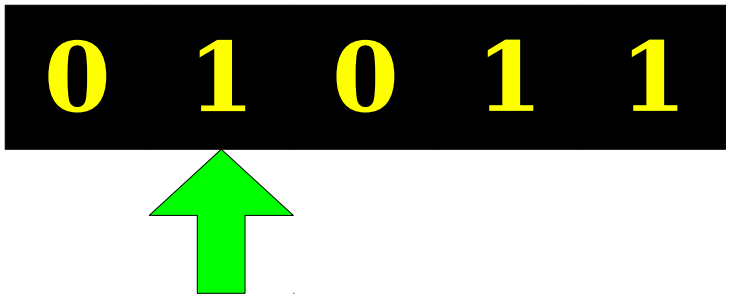
A Simple NFA



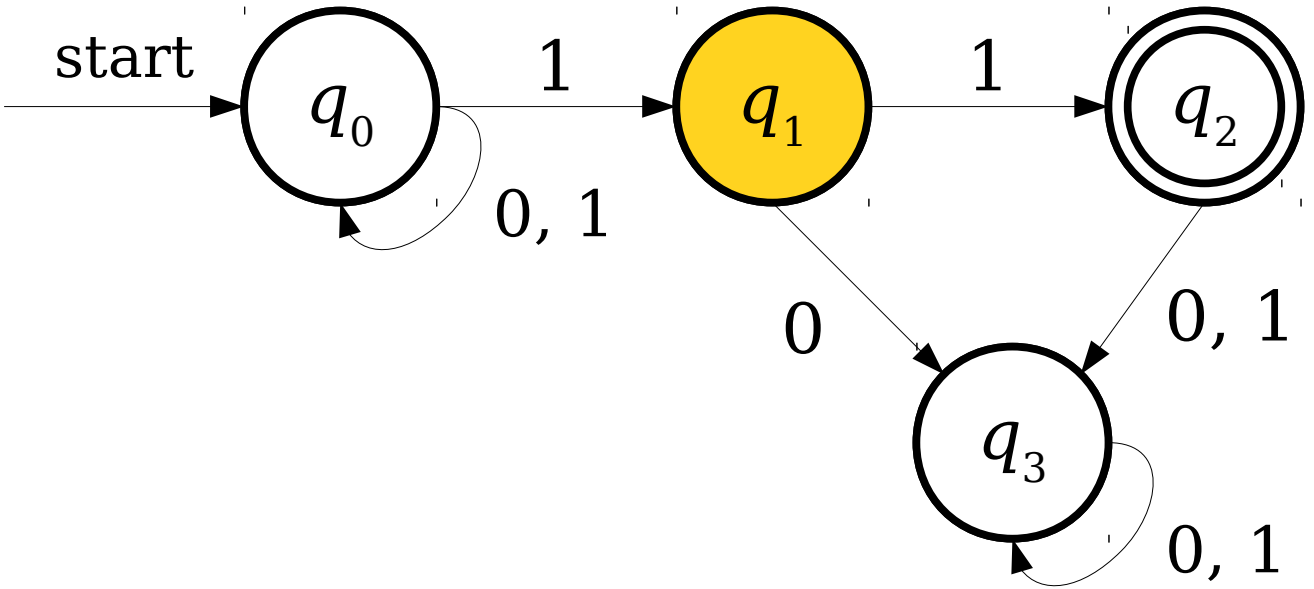


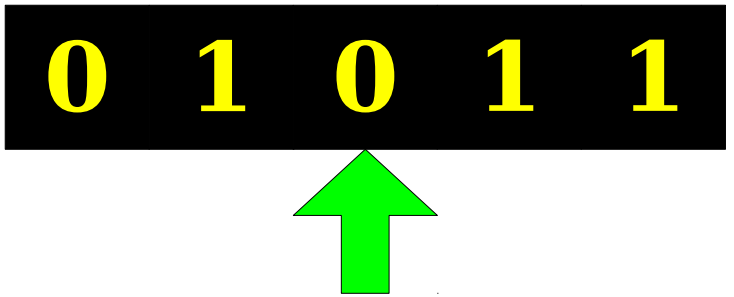
A Simple NFA



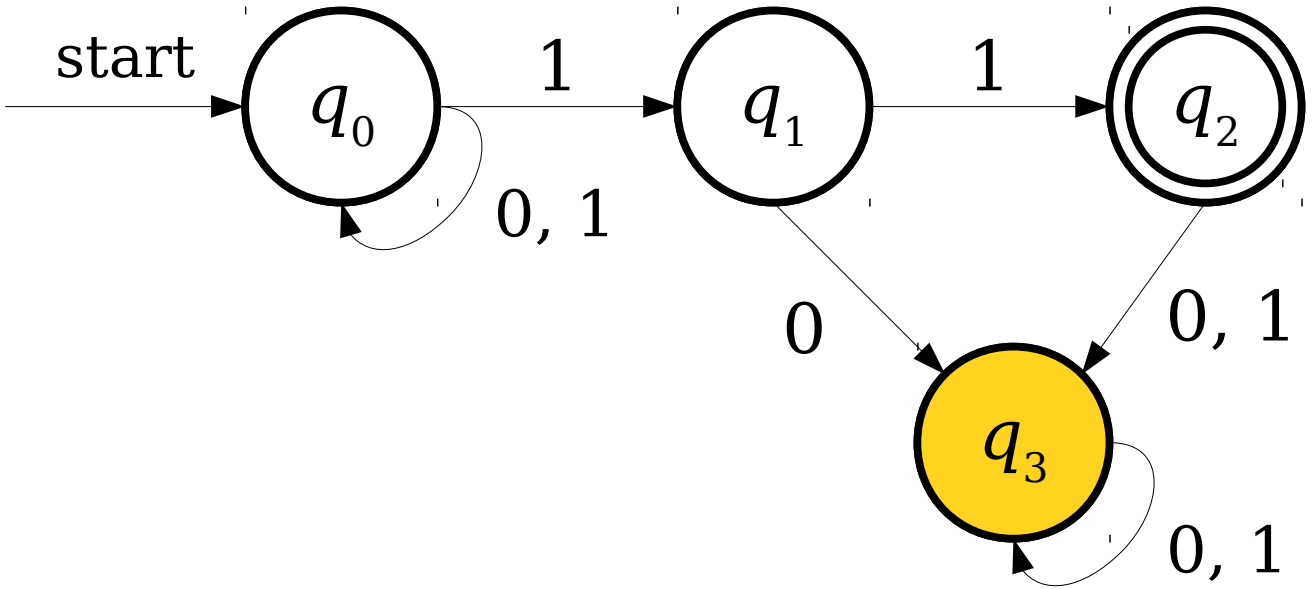


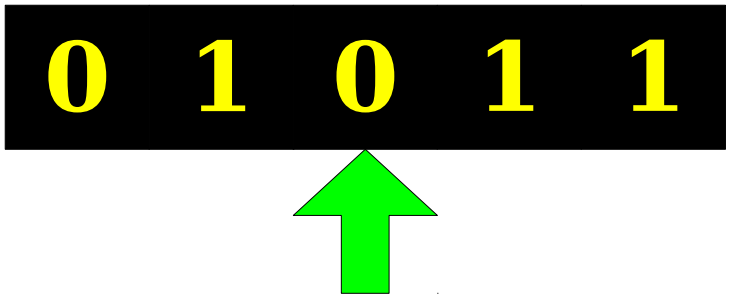
A Simple NFA



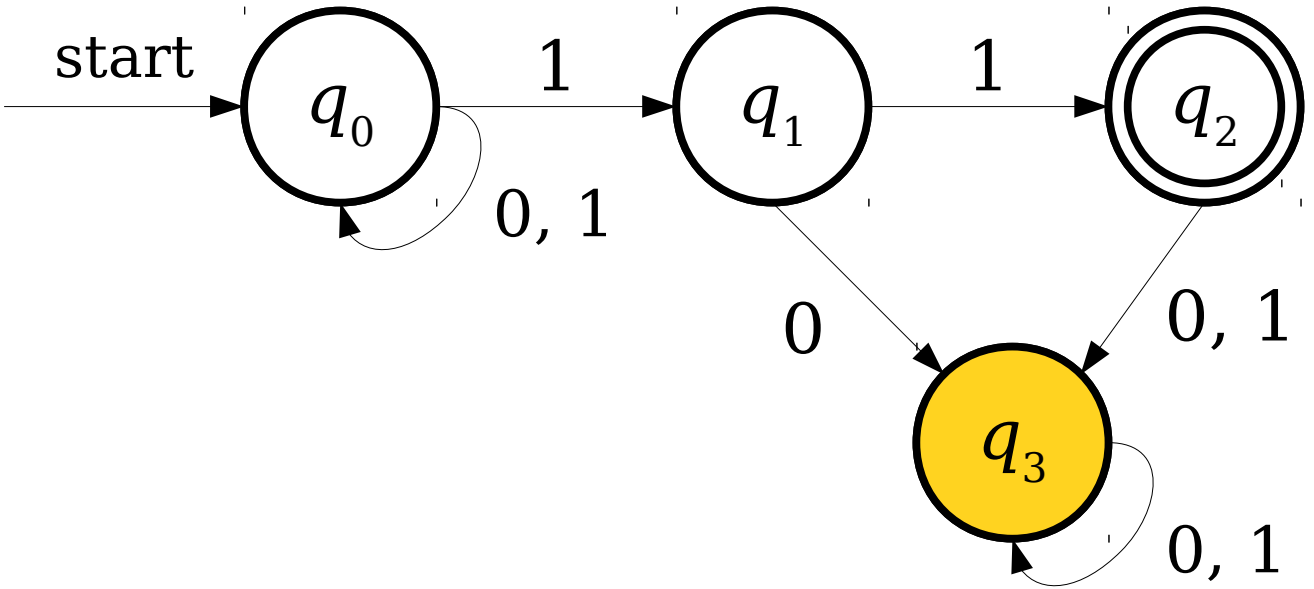


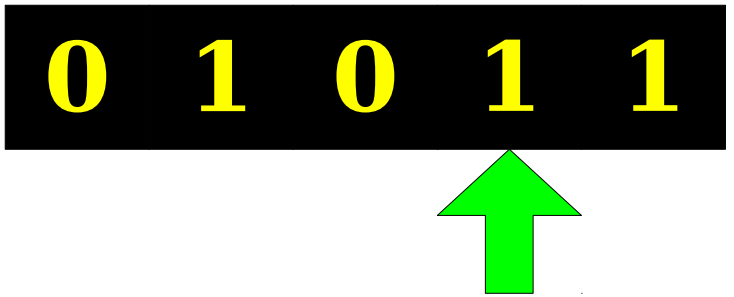
A Simple NFA



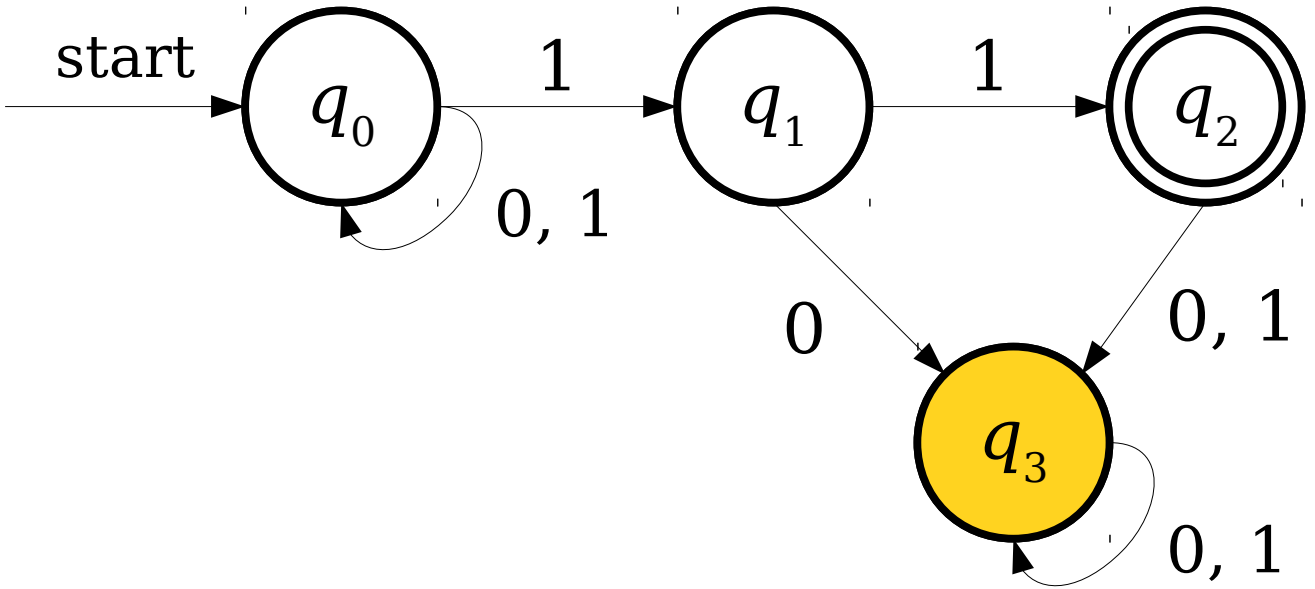


A Simple NFA

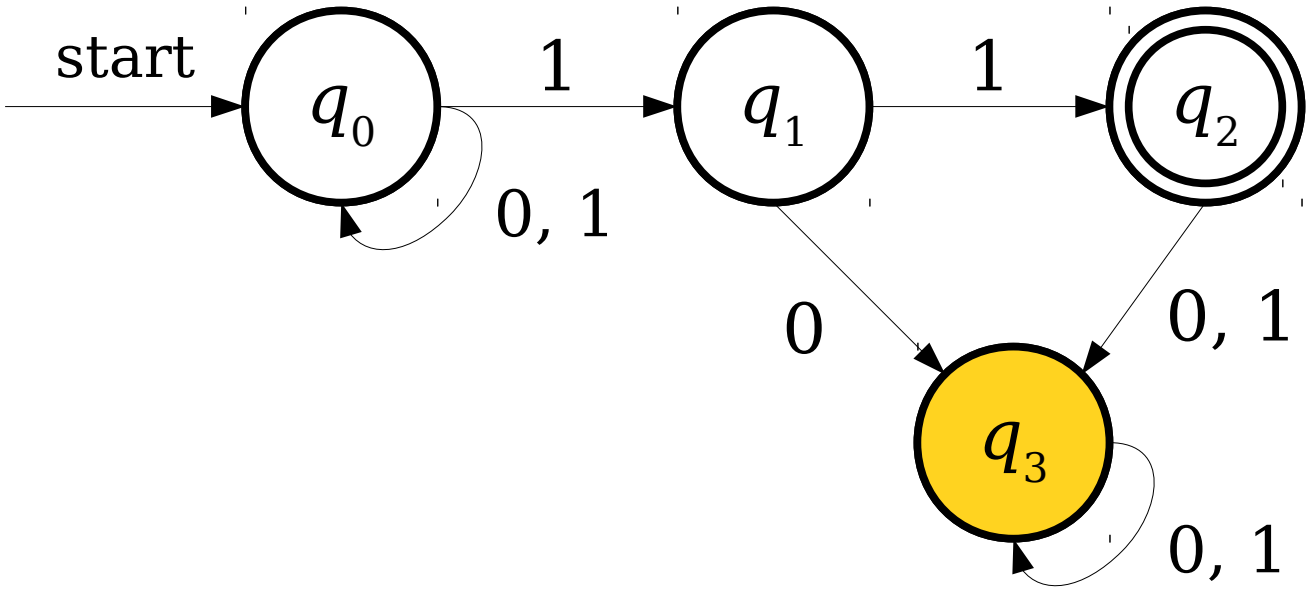




A Simple NFA

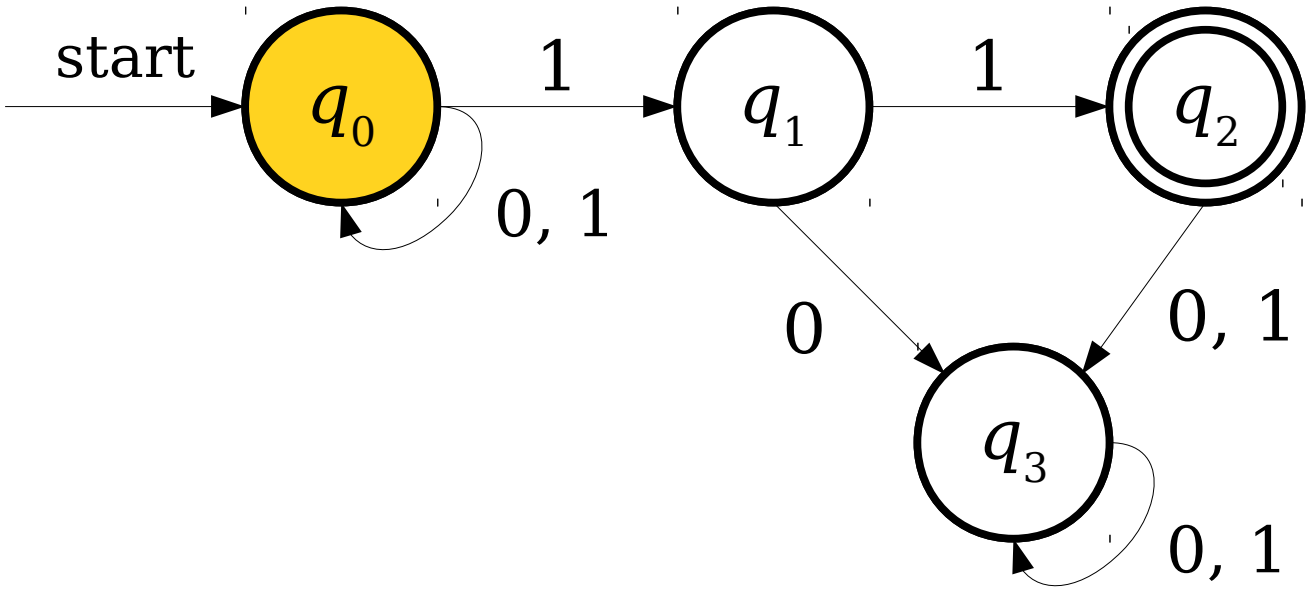


A Simple NFA

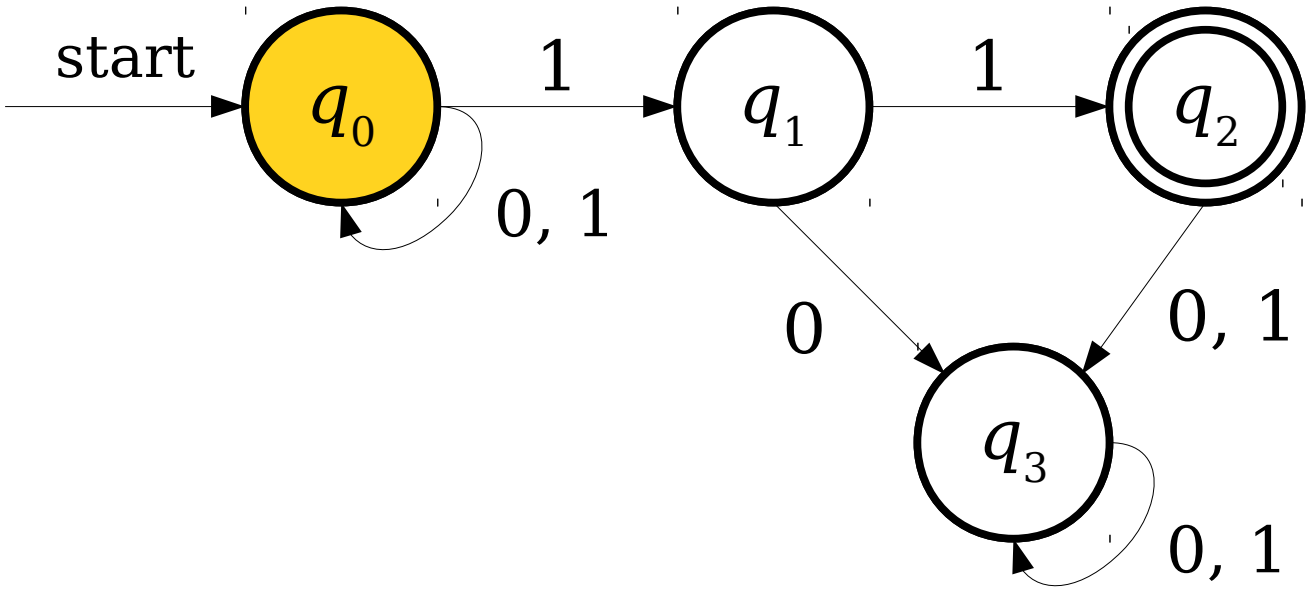


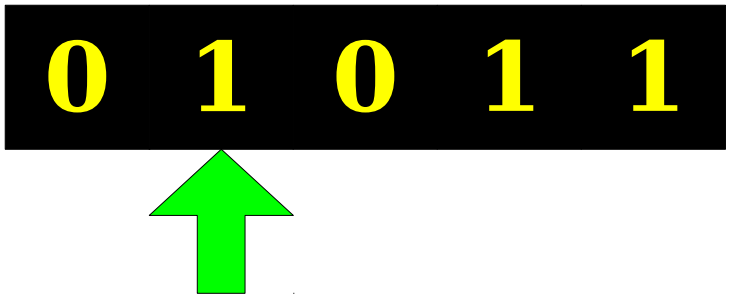
0 1 0 1 1

A Simple NFA

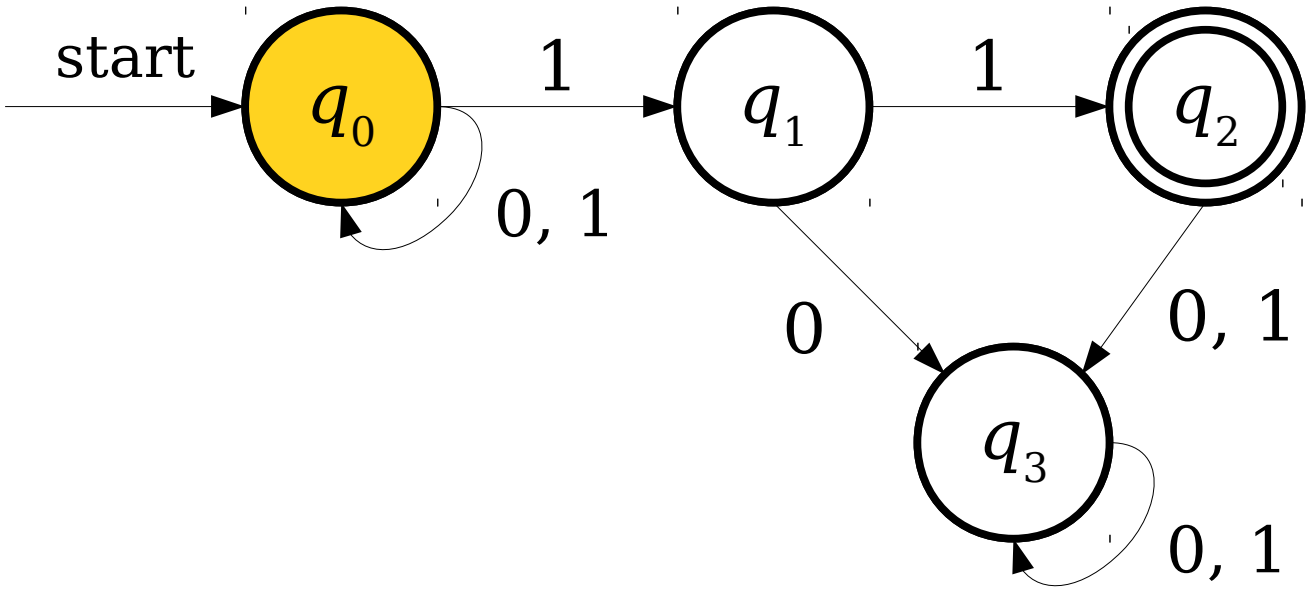


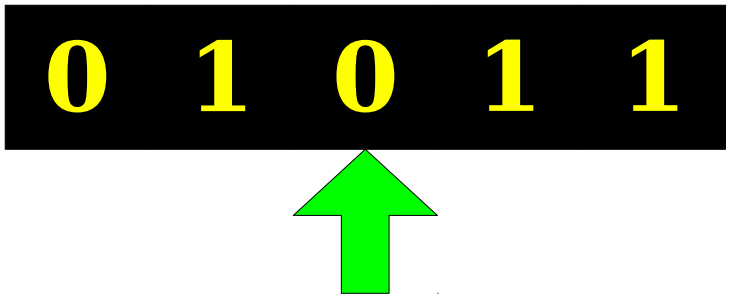
A Simple NFA



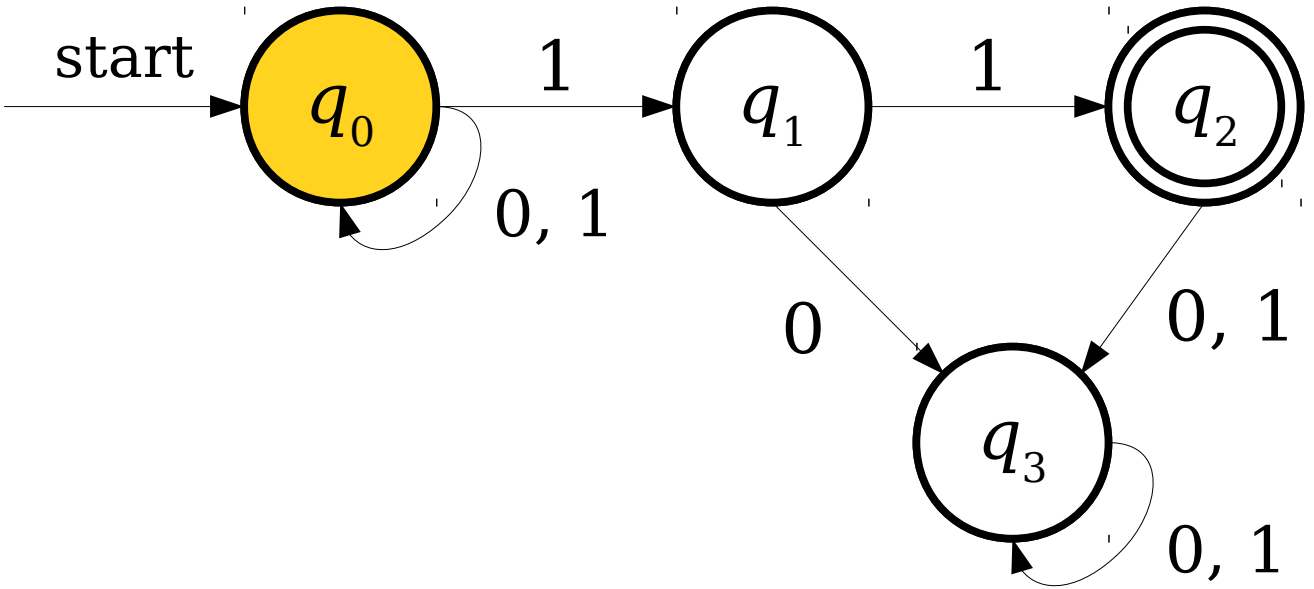


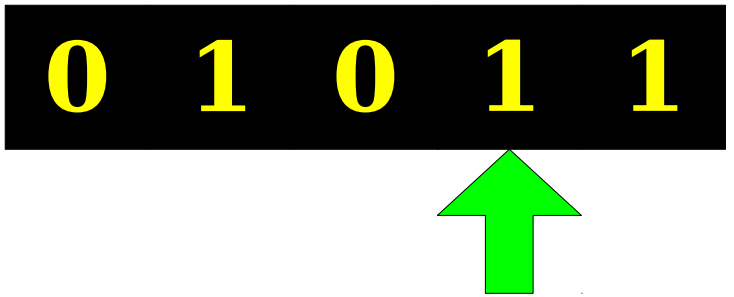
A Simple NFA



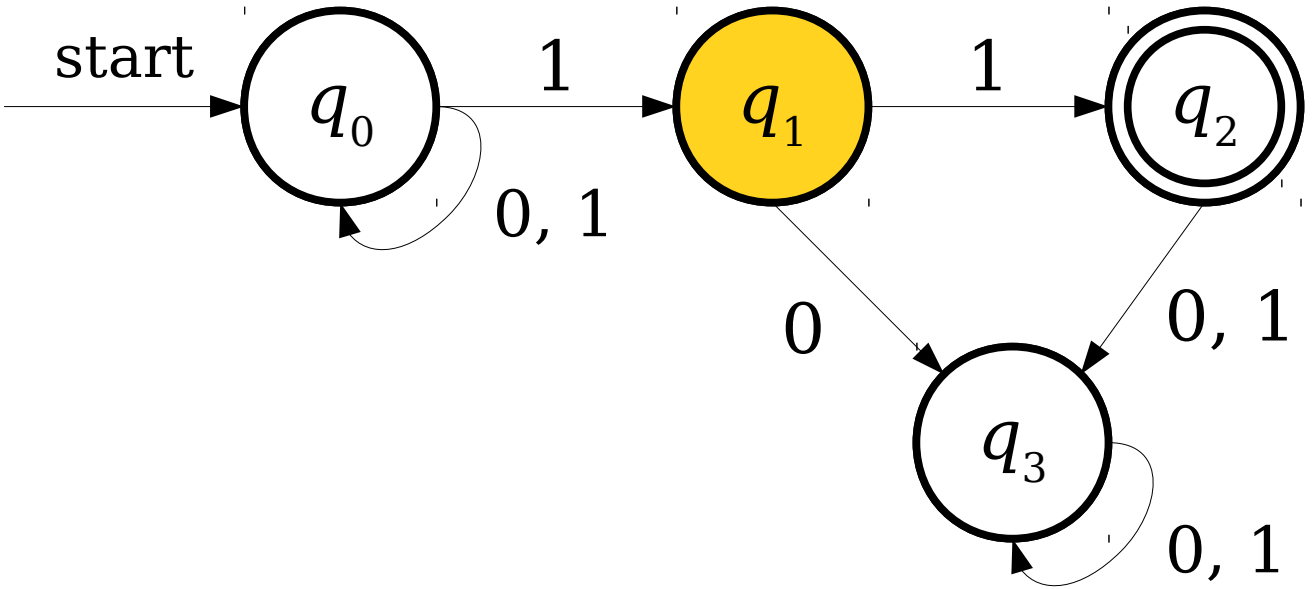


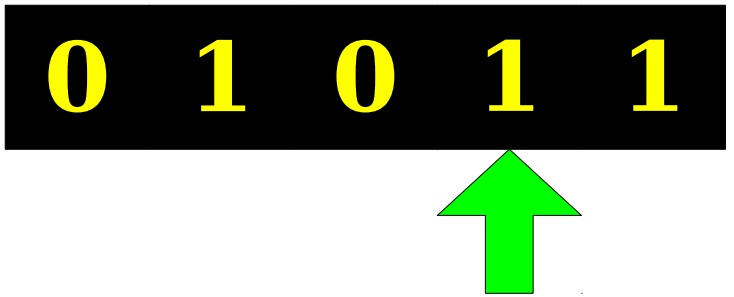
A Simple NFA



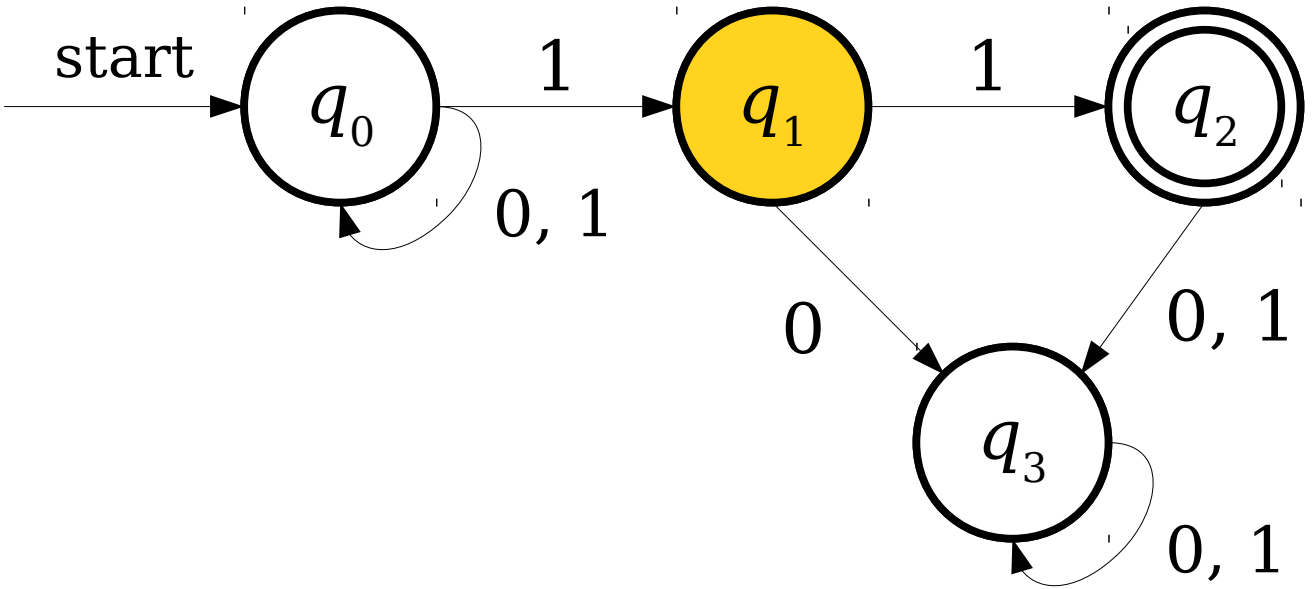


A Simple NFA

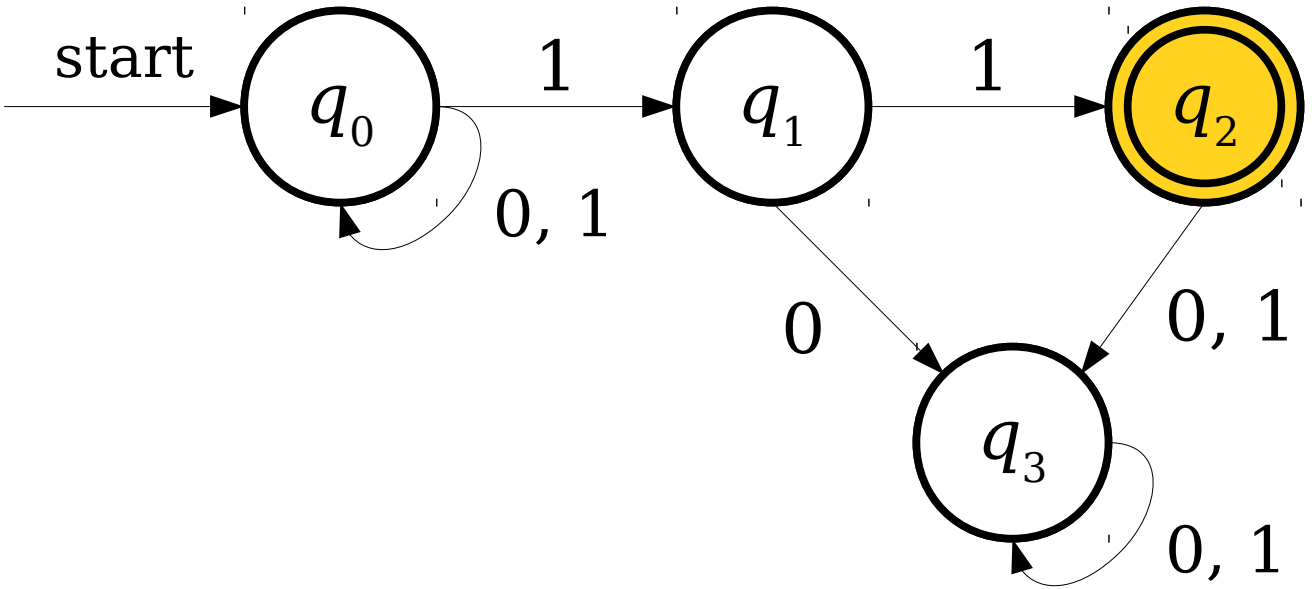




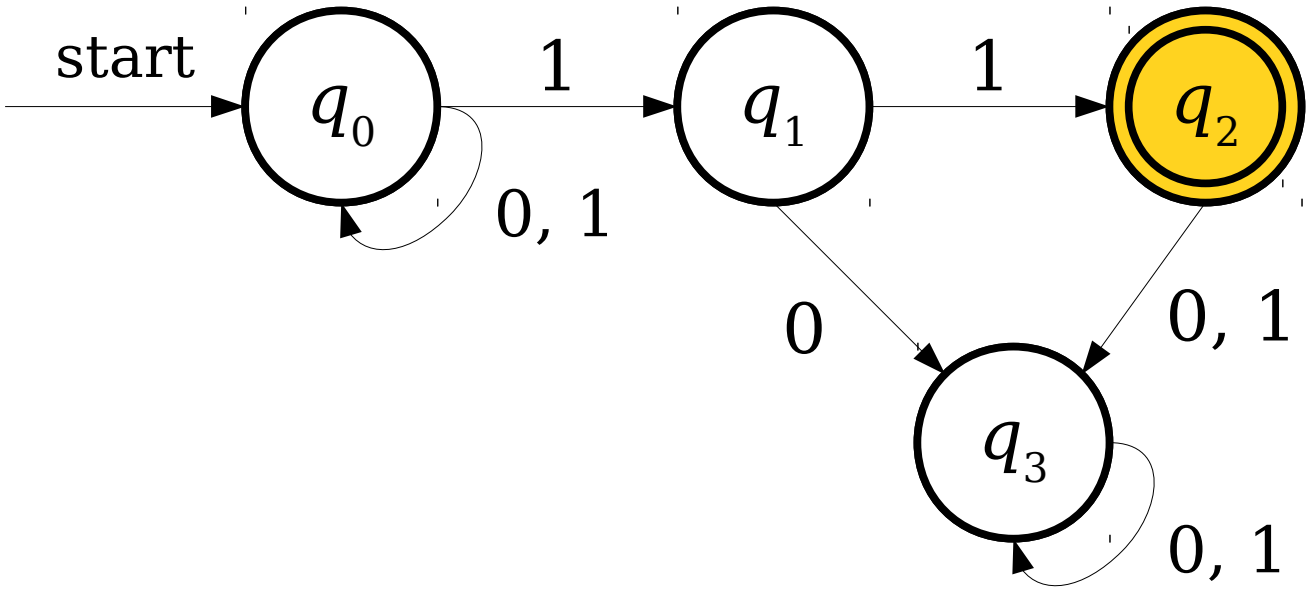
A Simple NFA



A Simple NFA

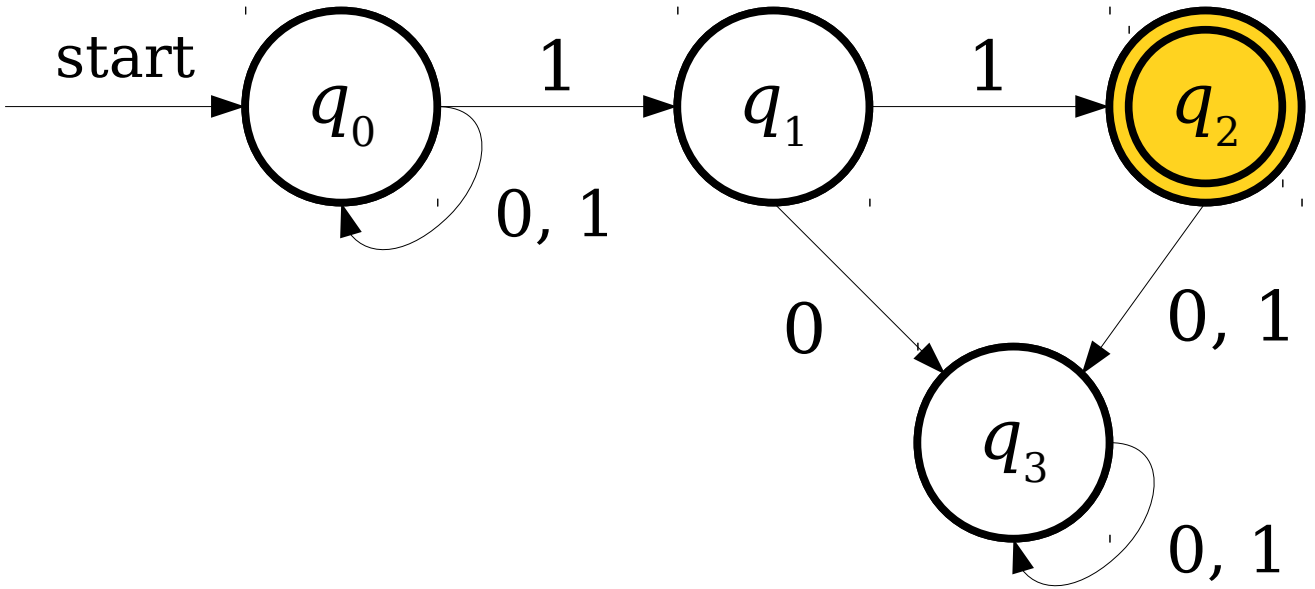


A Simple NFA



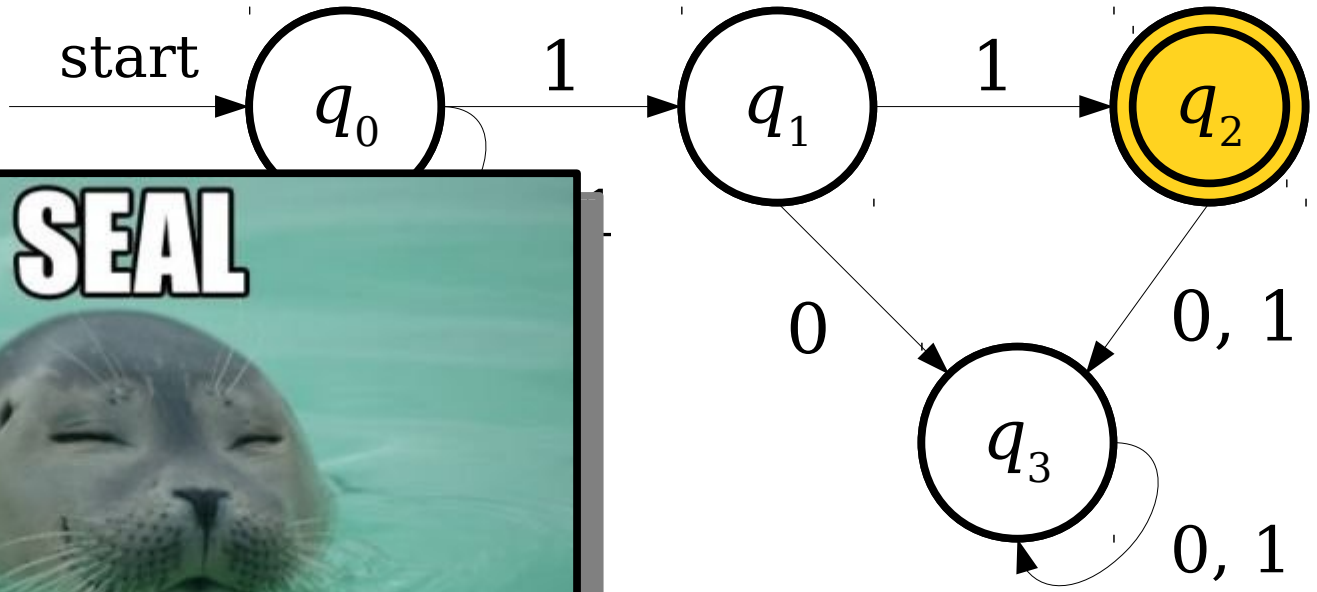
0 1 0 1 1

A Simple NFA



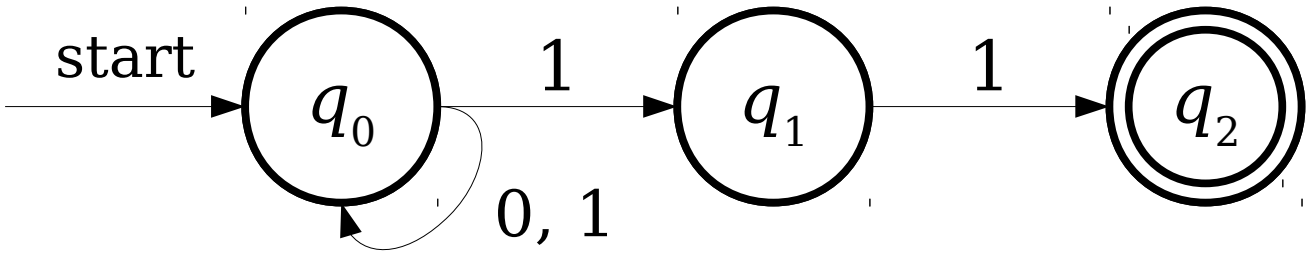
0 1 0 1 1

A Simple NFA

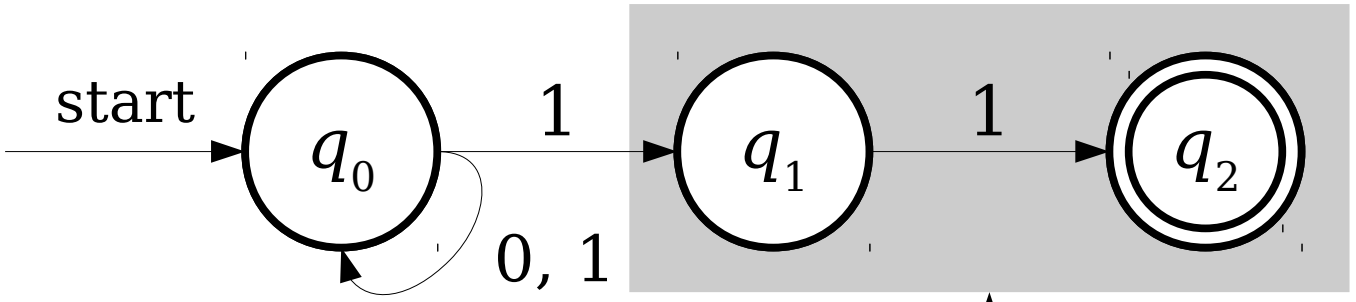


0 1 0 1 1

A More Complex NFA

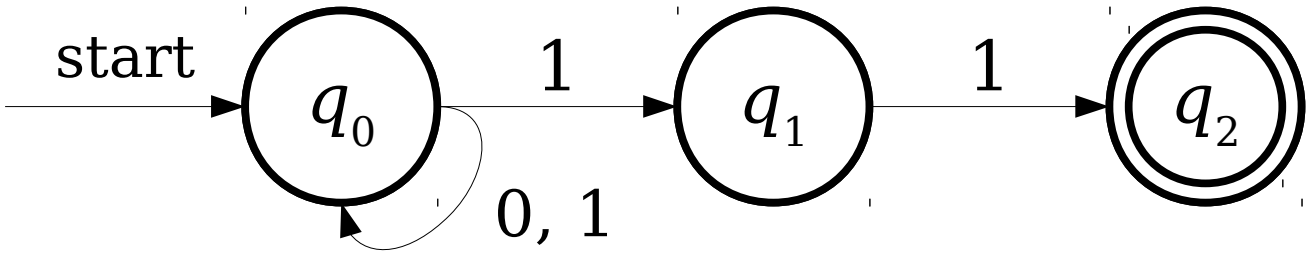


A More Complex NFA



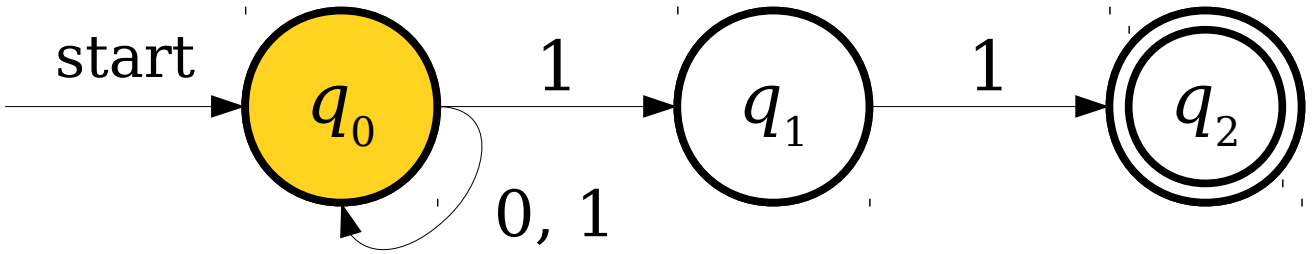
If a NFA needs to make a transition when no transition exists, the automaton **dies** and that particular path does not accept.

A More Complex NFA



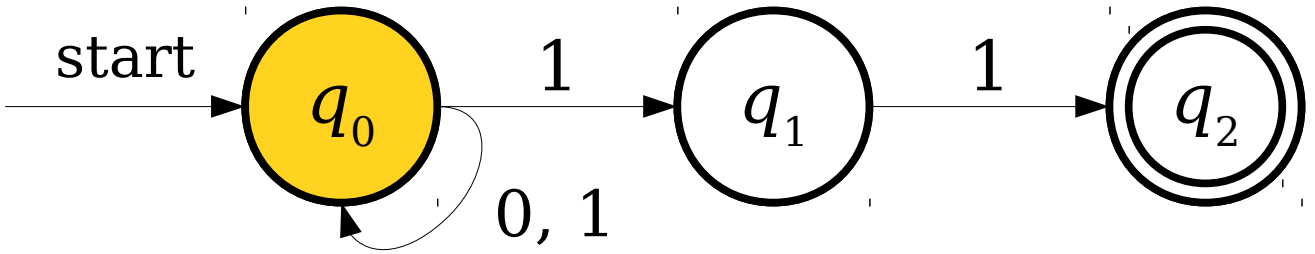
0 1 0 1 1

A More Complex NFA

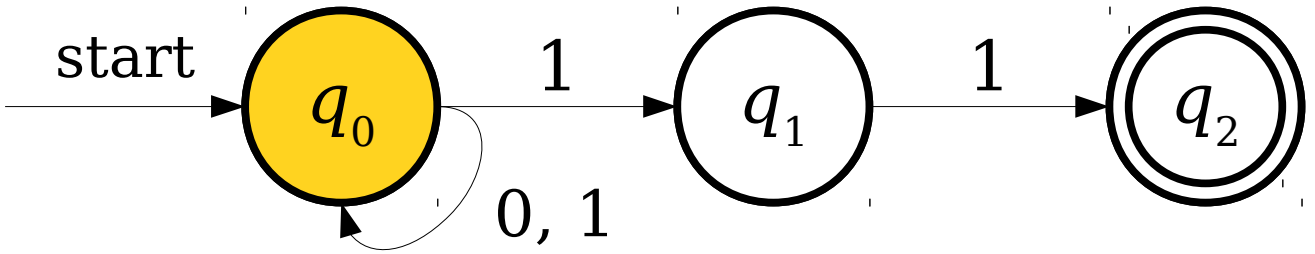


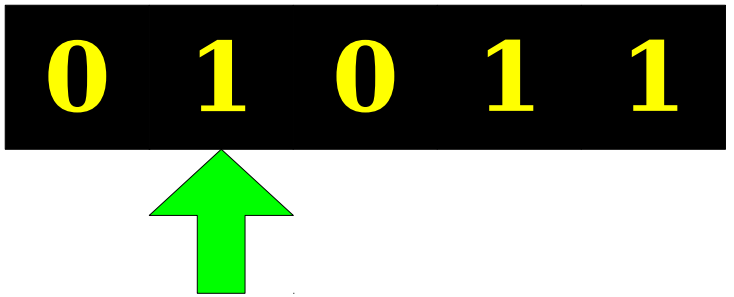
0 1 0 1 1

A More Complex NFA

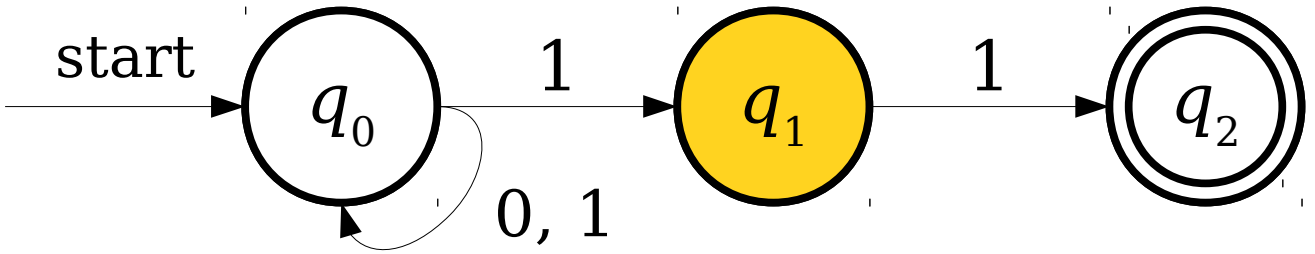


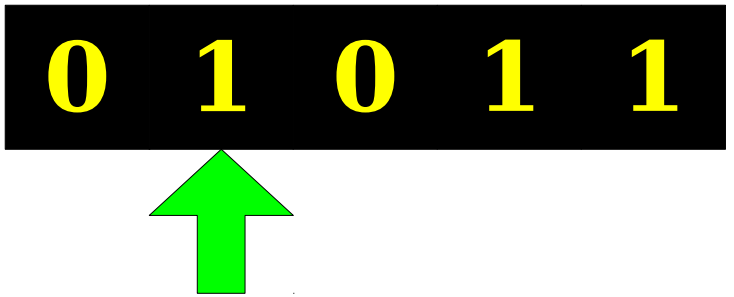
A More Complex NFA



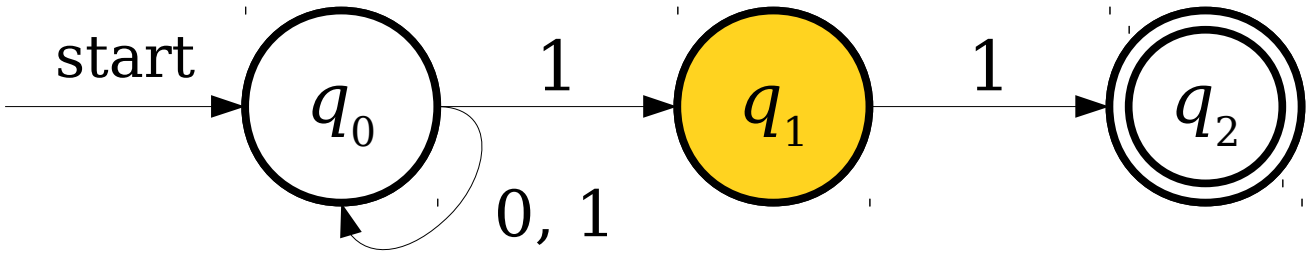


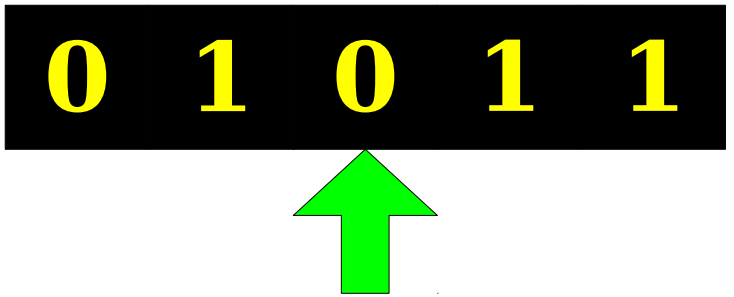
A More Complex NFA



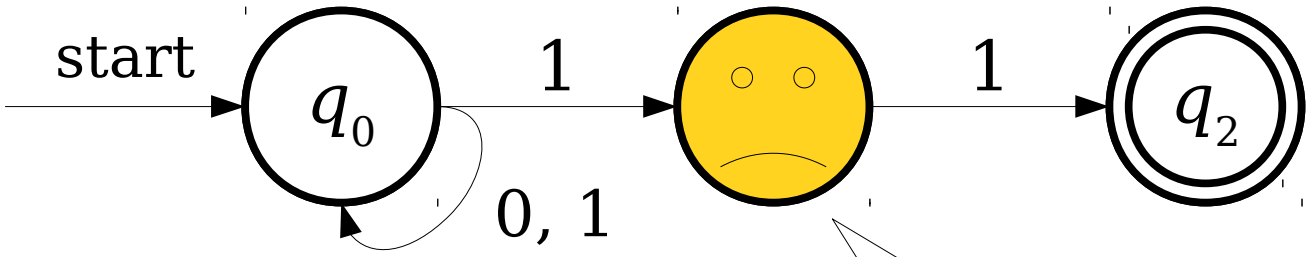


A More Complex NFA

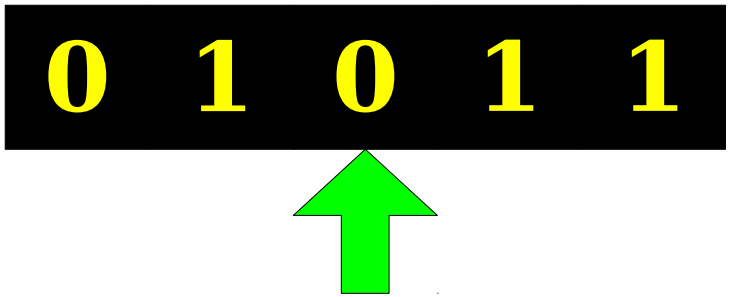




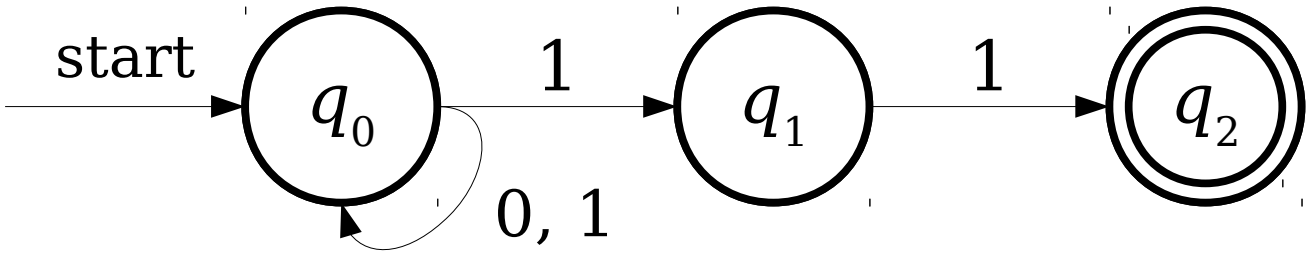
A More Complex NFA

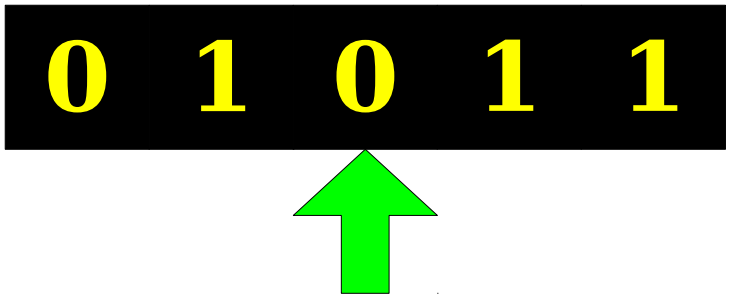


Oh no! There's no transition defined!

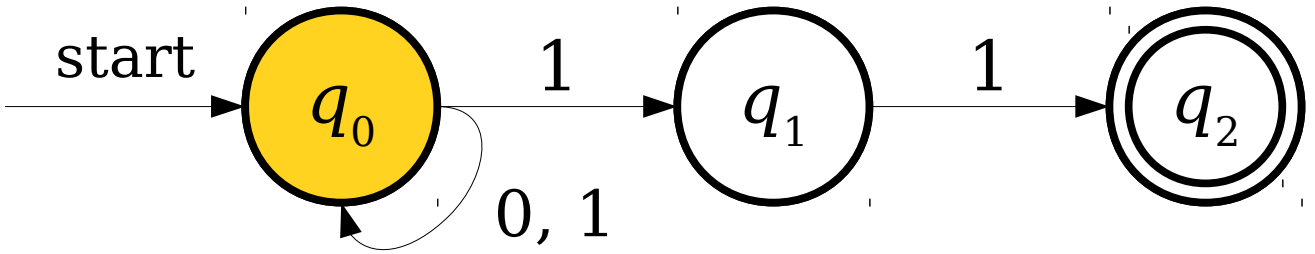


A More Complex NFA

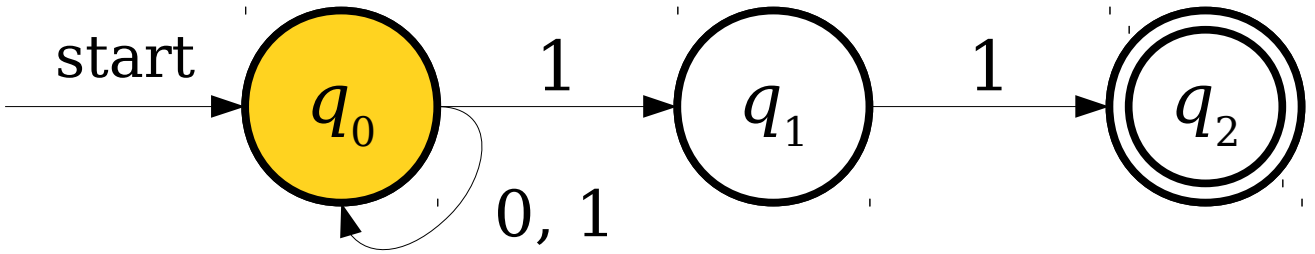


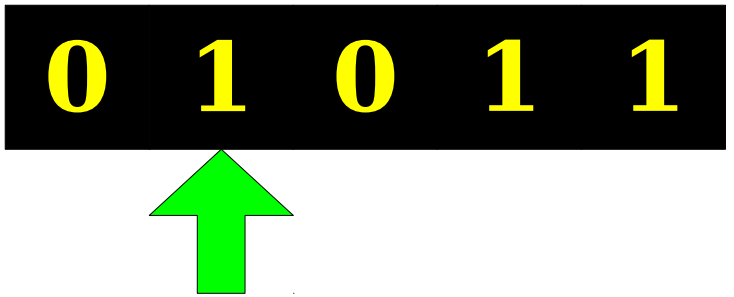


A More Complex NFA

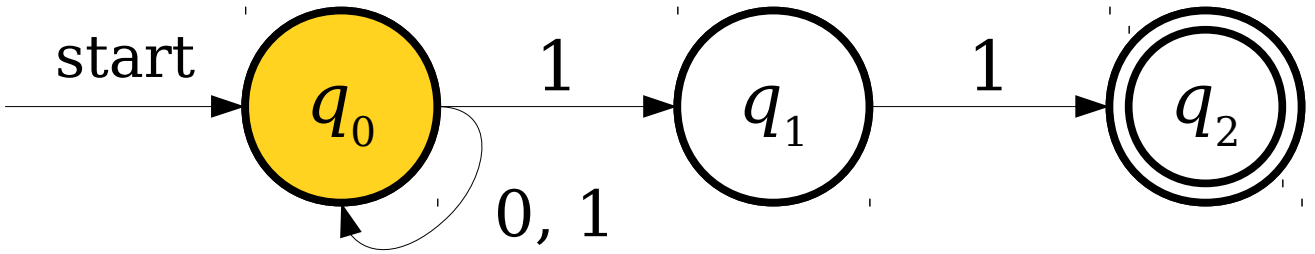


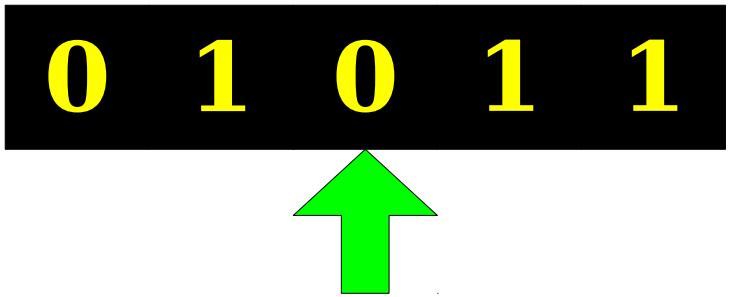
A More Complex NFA



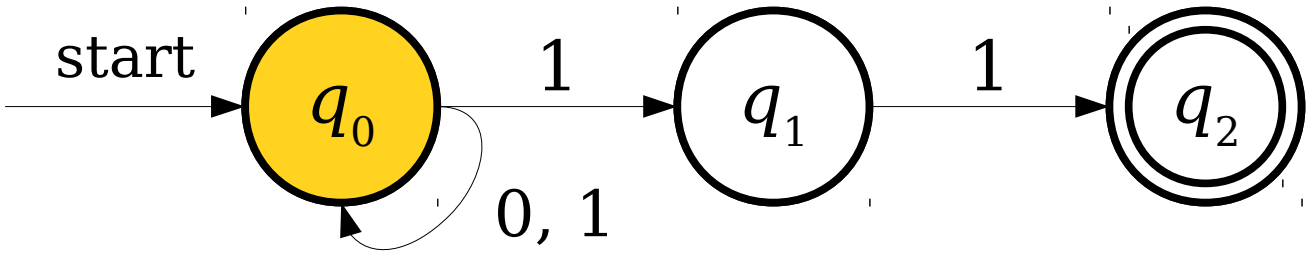


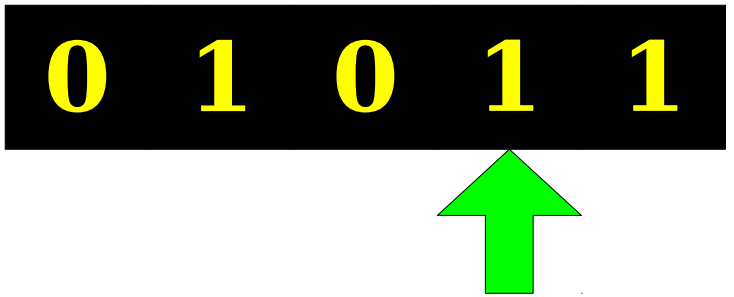
A More Complex NFA



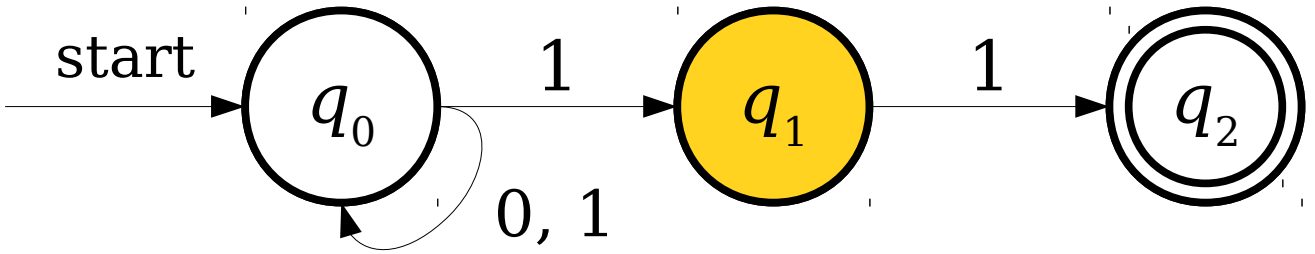


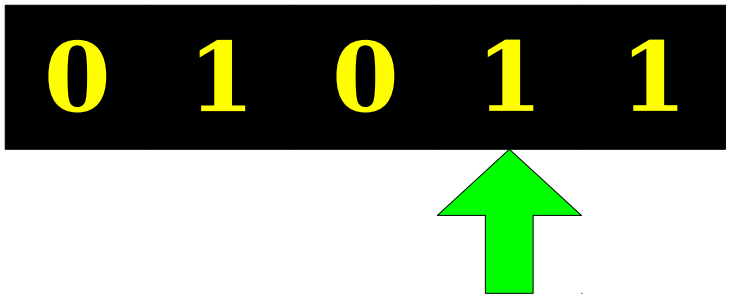
A More Complex NFA



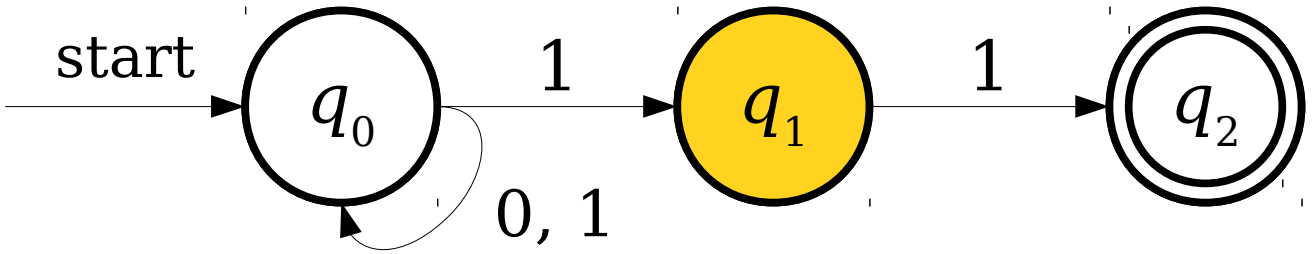


A More Complex NFA

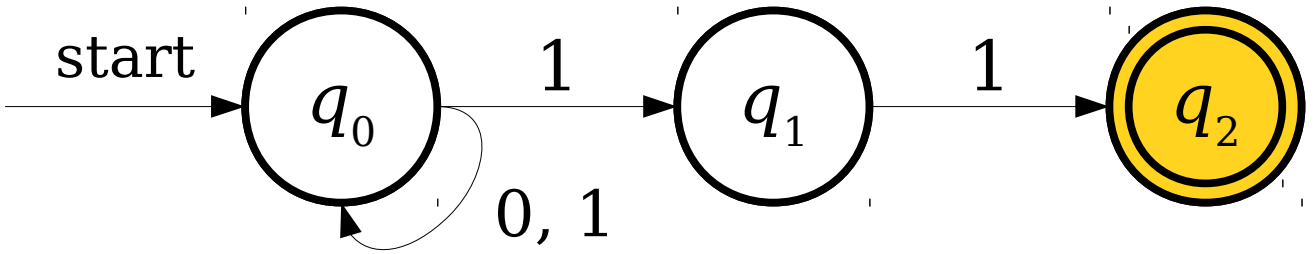




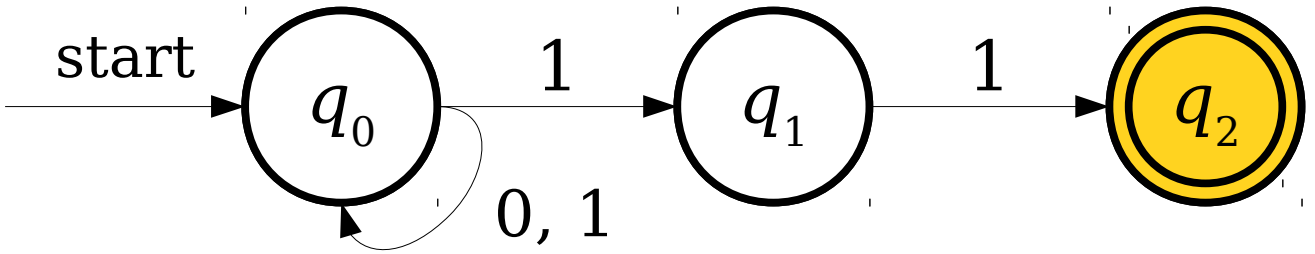
A More Complex NFA



A More Complex NFA

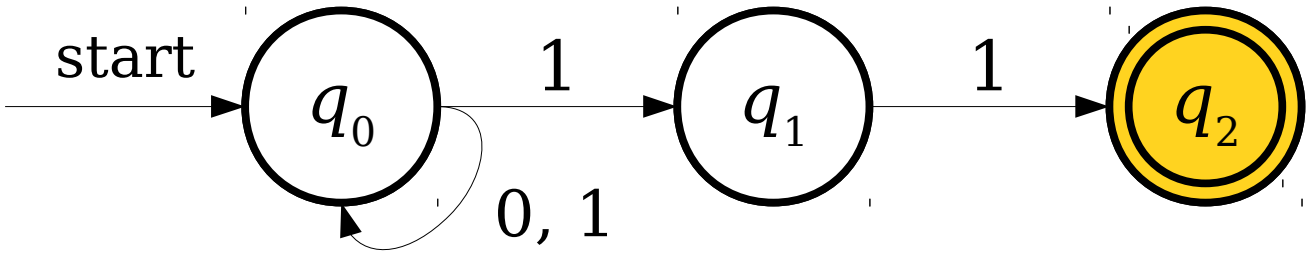


A More Complex NFA



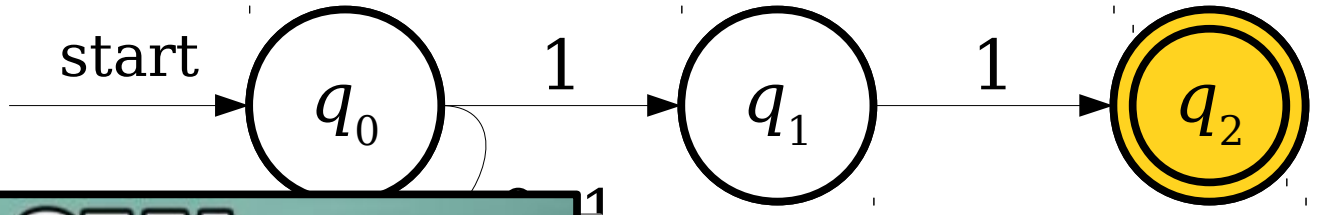
0 1 0 1 1

A More Complex NFA

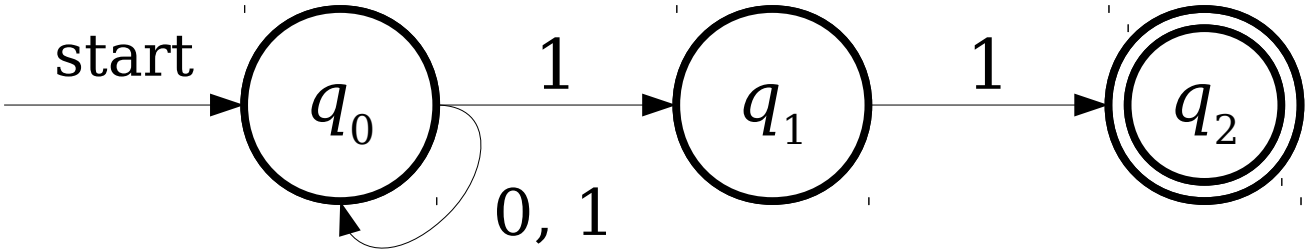


0 1 0 1 1

A More Complex NFA



0 1 1



As with DFAs, the language of an NFA N is the set of strings that N accepts:

$$\mathscr{L}(N) = \{ w \in \Sigma^* \mid N \text{ accepts } w \}.$$

What is the language of the NFA shown above?

A. { **01011** }
B. { $w \in \{$**0**, **1**$\}^*$ | w contains at least two **1**s }
D. { $w \in \{$**0**, **1**$\}^*$ | w ends with **1** }
C. { $w \in \{$**0**, **1**$\}^*$ | w ends with **11** }
E. { w $\in \{$**0**, **1**$\}^*$ | w ends with **111** }
F. **None** of these, or **two or more** of these.

Answer at **PollEv.com/cs103** or
text **CS103** to **22333** once to join, then ***A***, ..., or ***F***.

NFA Acceptance

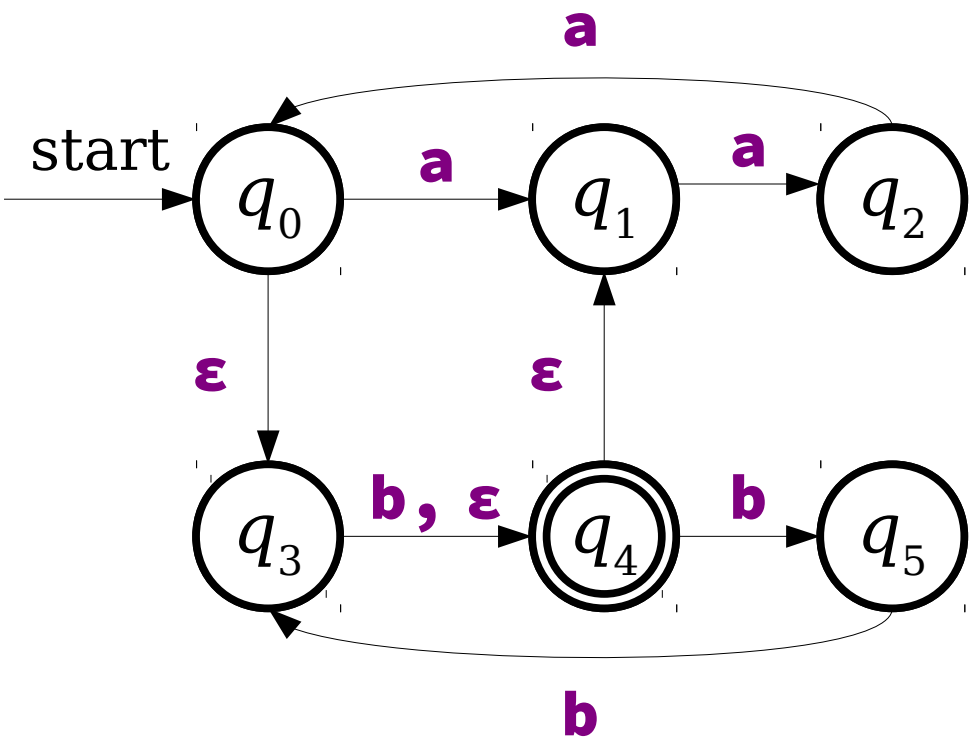
- An NFA N accepts a string w if there is some series of choices that lead to an accepting state.
- Consequently, an NFA N rejects a string w if *no possible* series of choices lead it into an accepting state.
- It's easier to show that an NFA does accept something than to show that it doesn't.

ε-Transitions

- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.

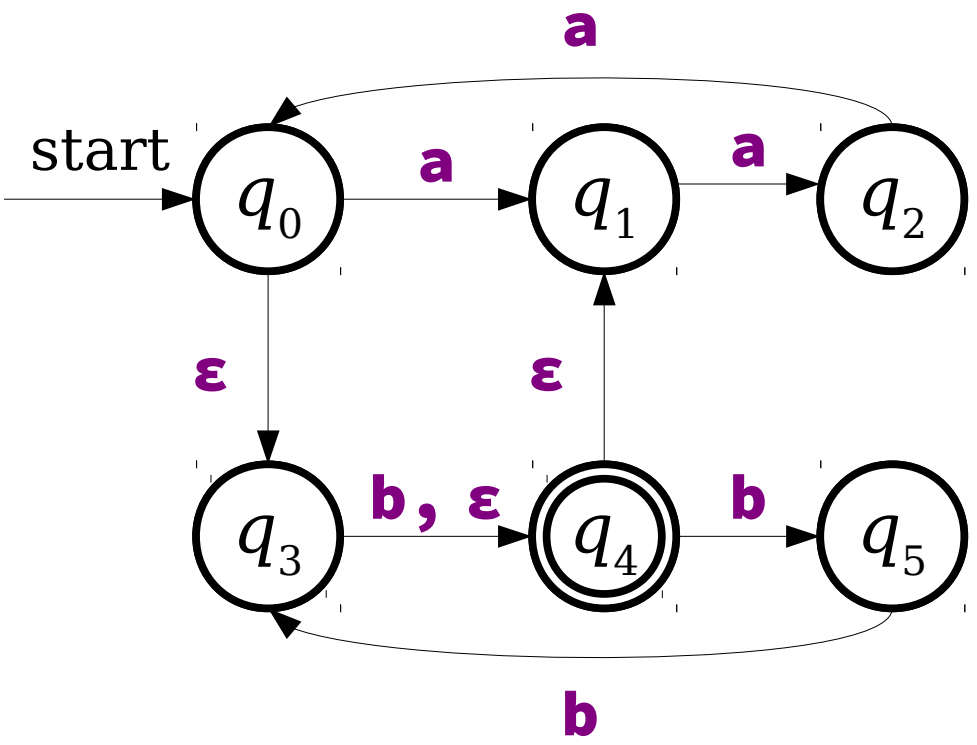
ε-Transitions

- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



ε-Transitions

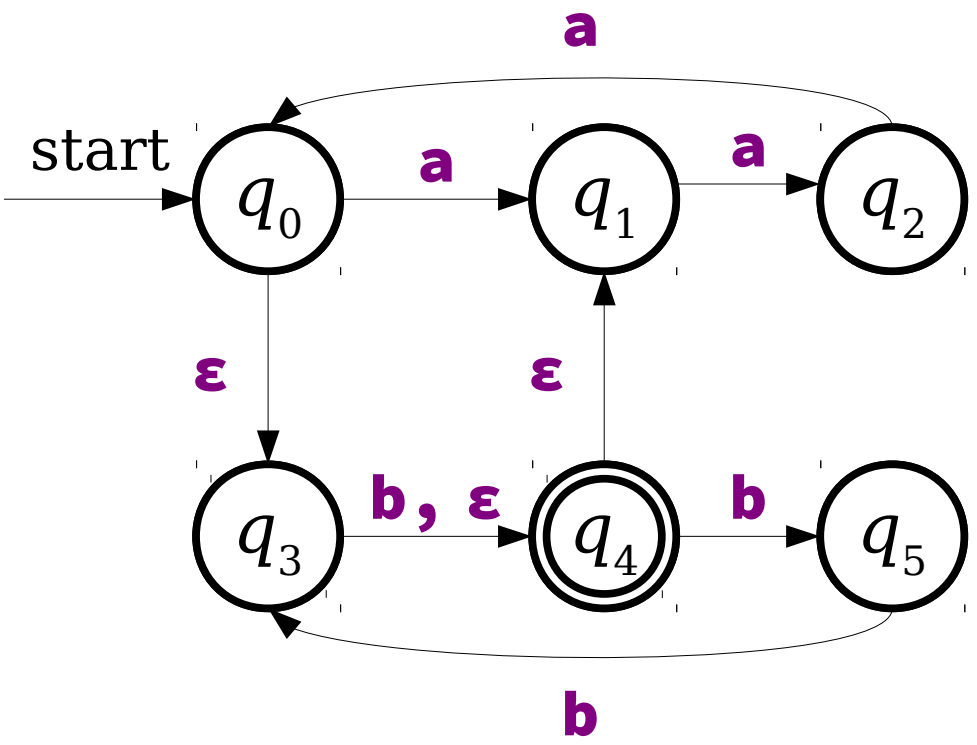
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



b a a b b

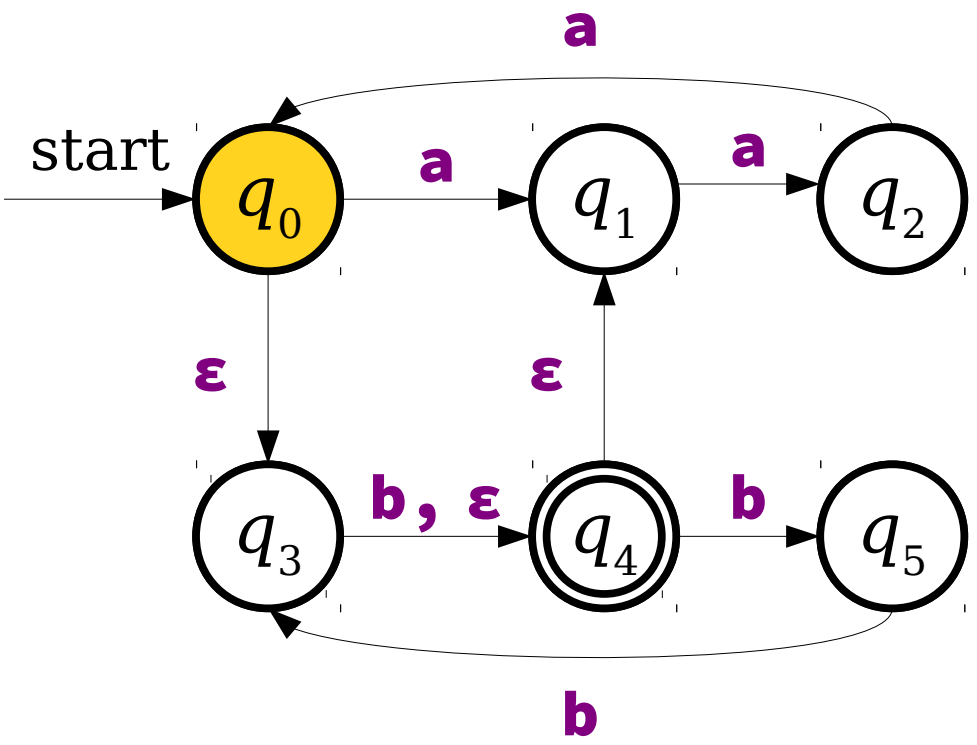
ε-Transitions

- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



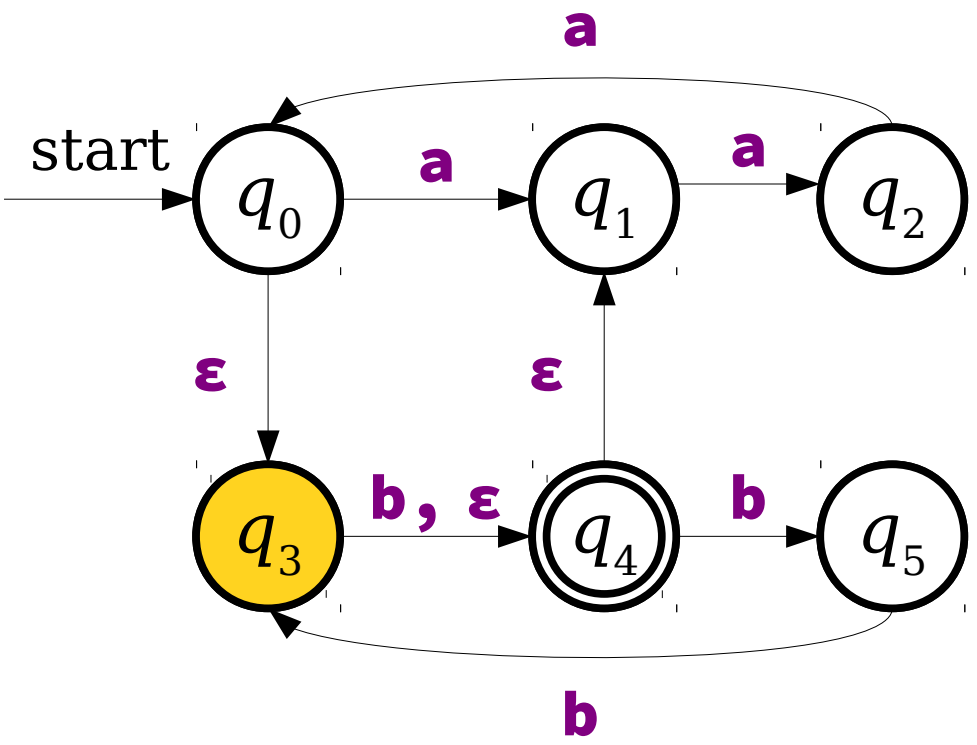
ε-Transitions

- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



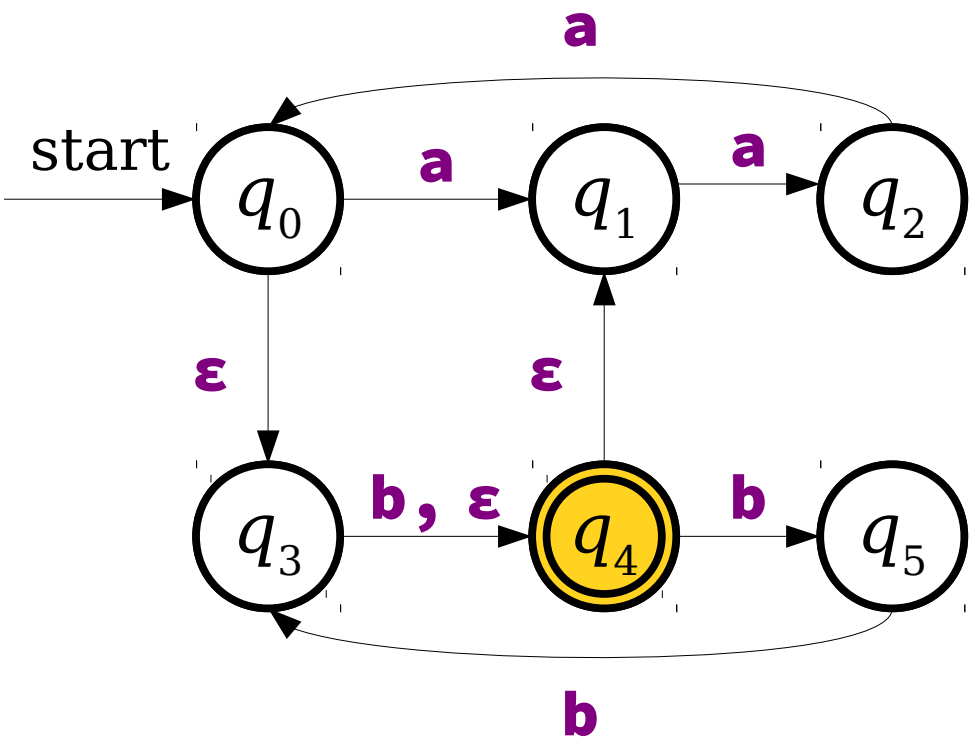
ε-Transitions

- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



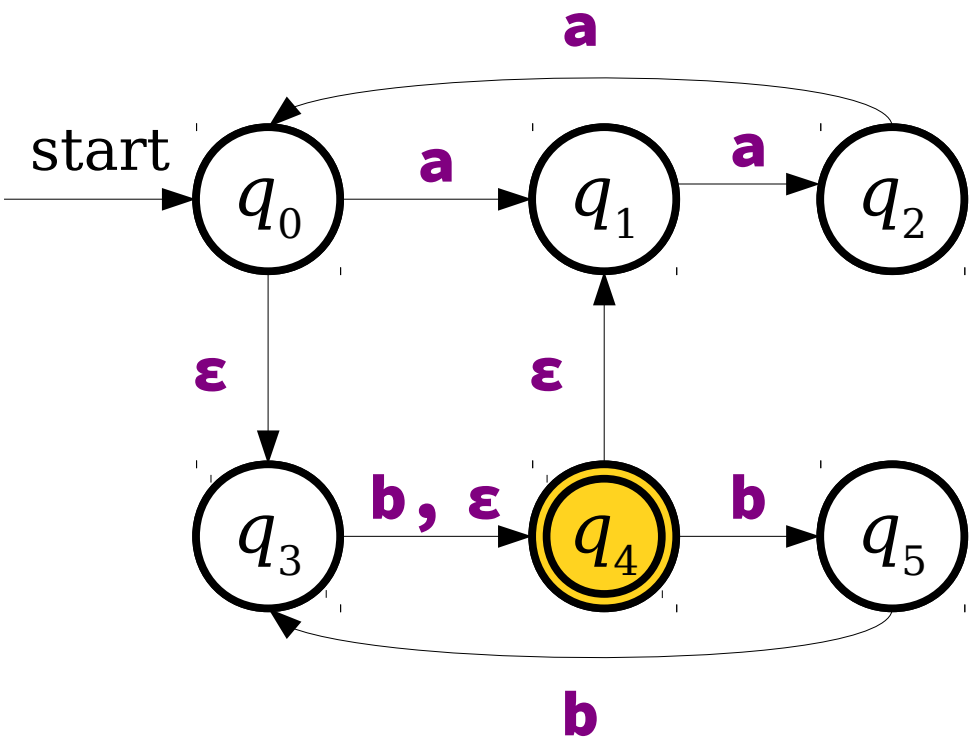
ε-Transitions

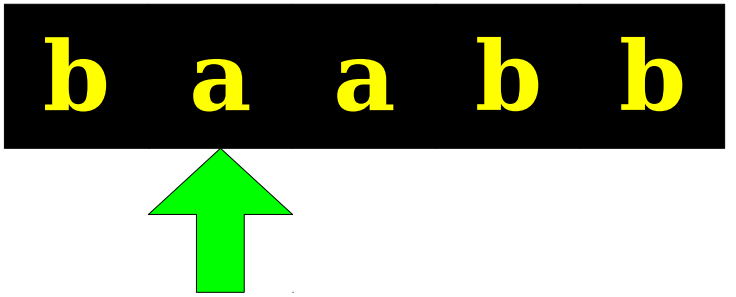
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



ε-Transitions

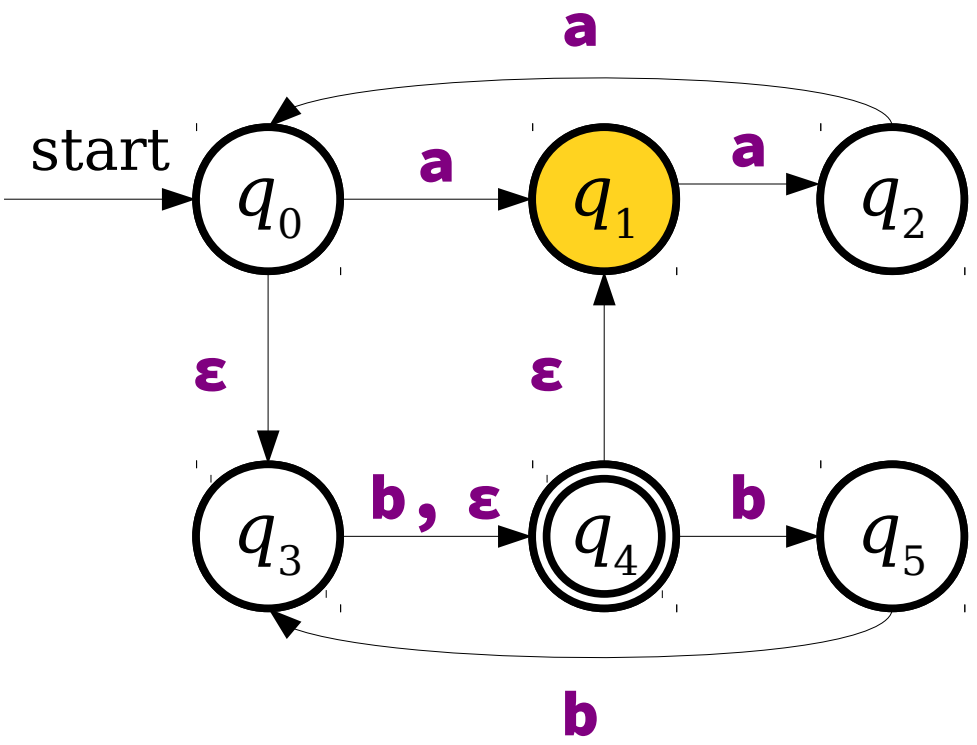
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.

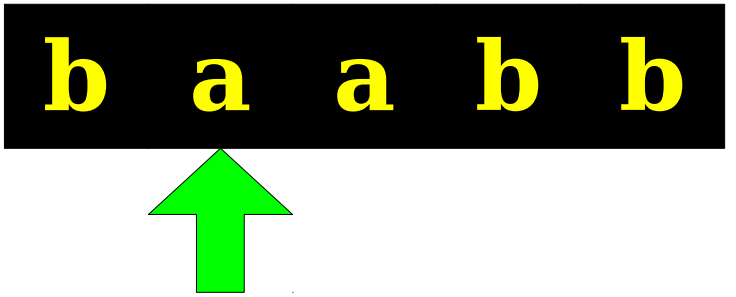




ε-Transitions

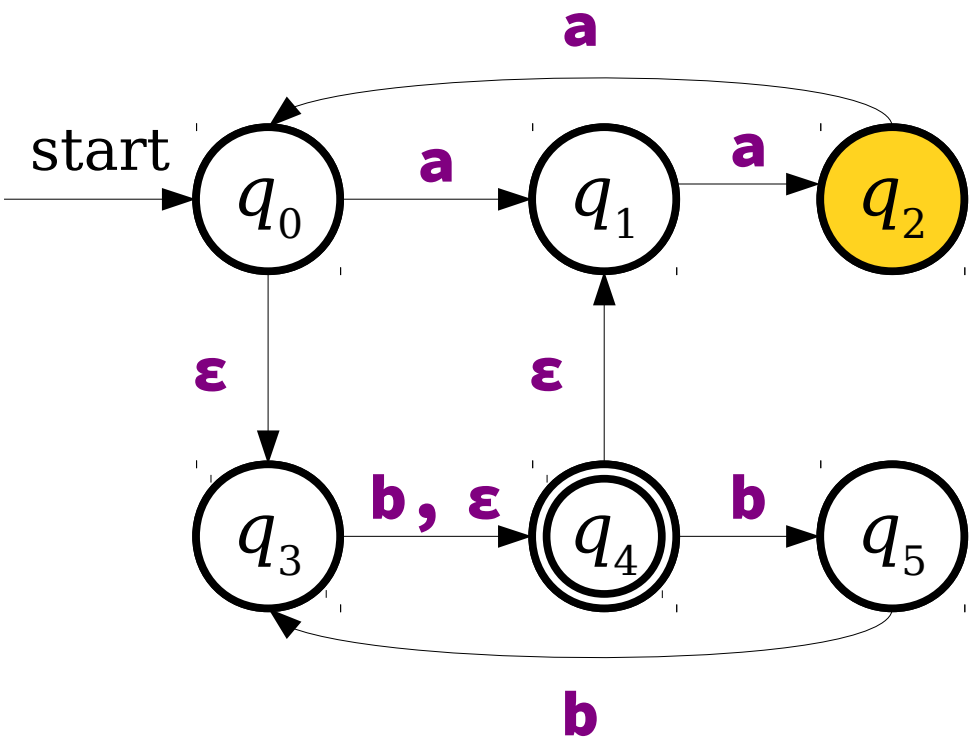
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.

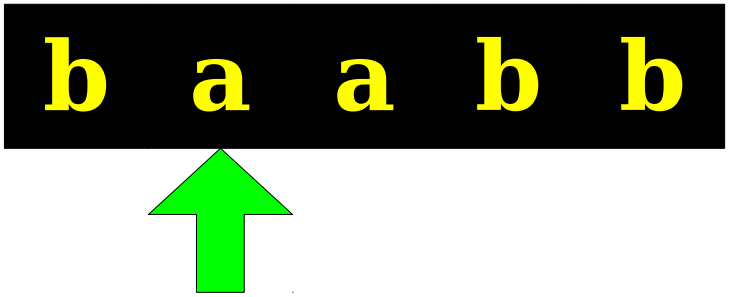




ε-Transitions

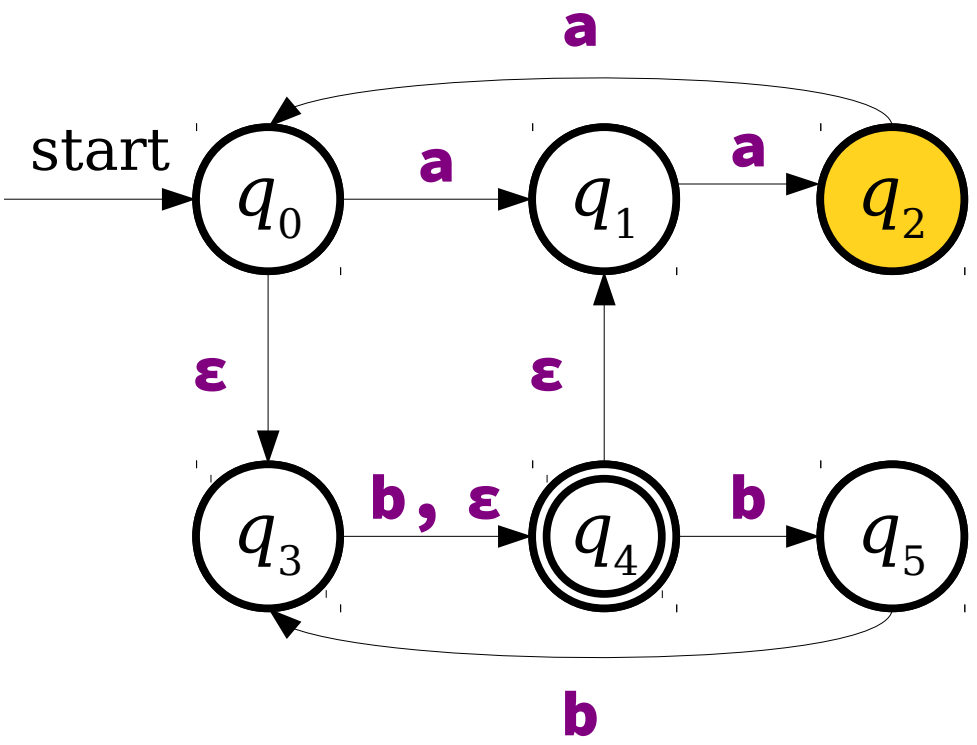
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.

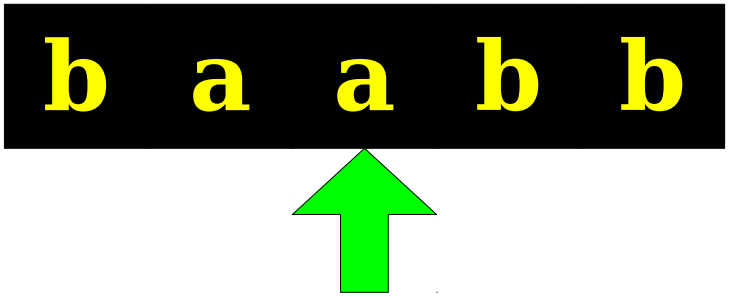




ε-Transitions

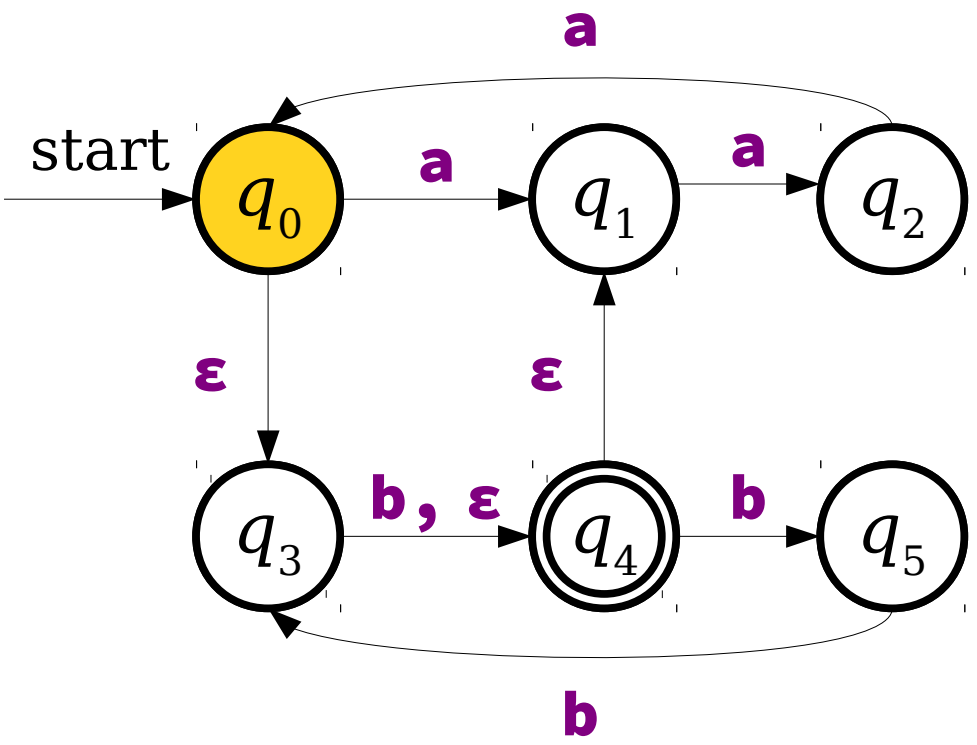
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.

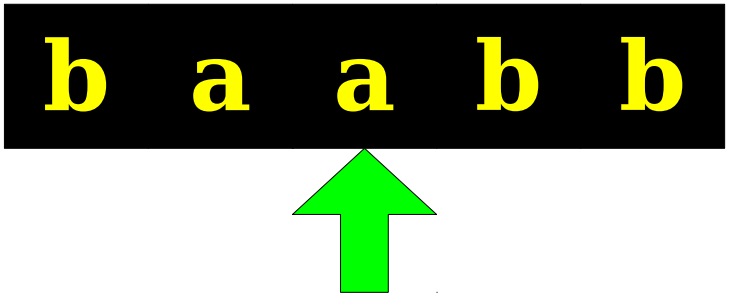




ε-Transitions

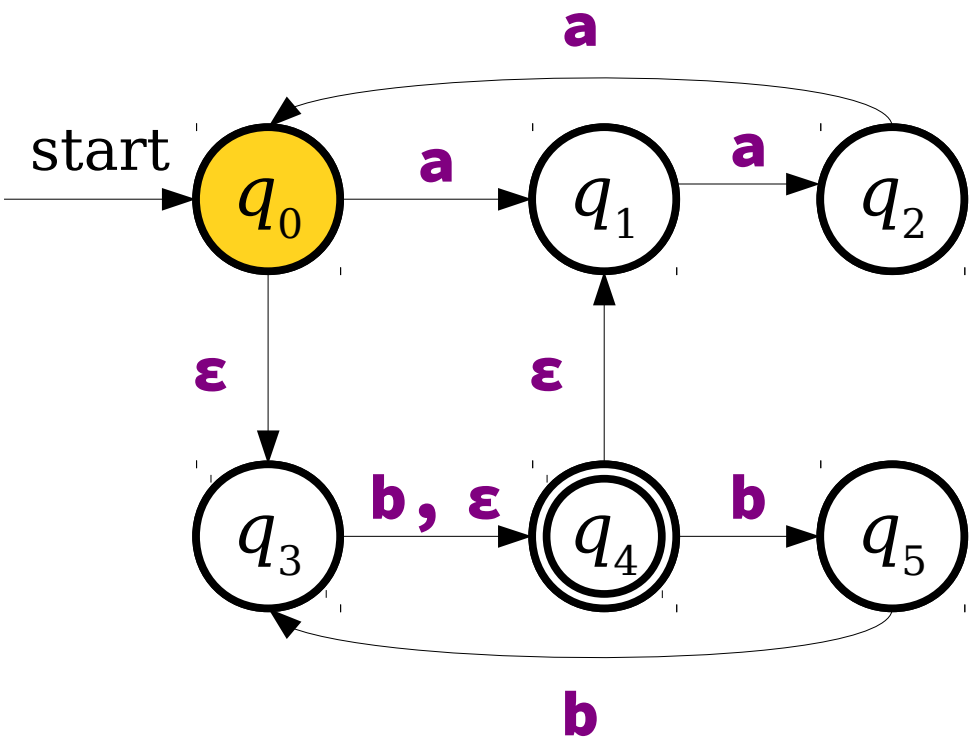
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.

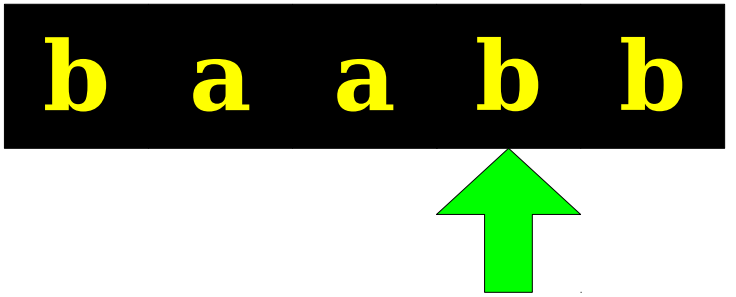




ε-Transitions

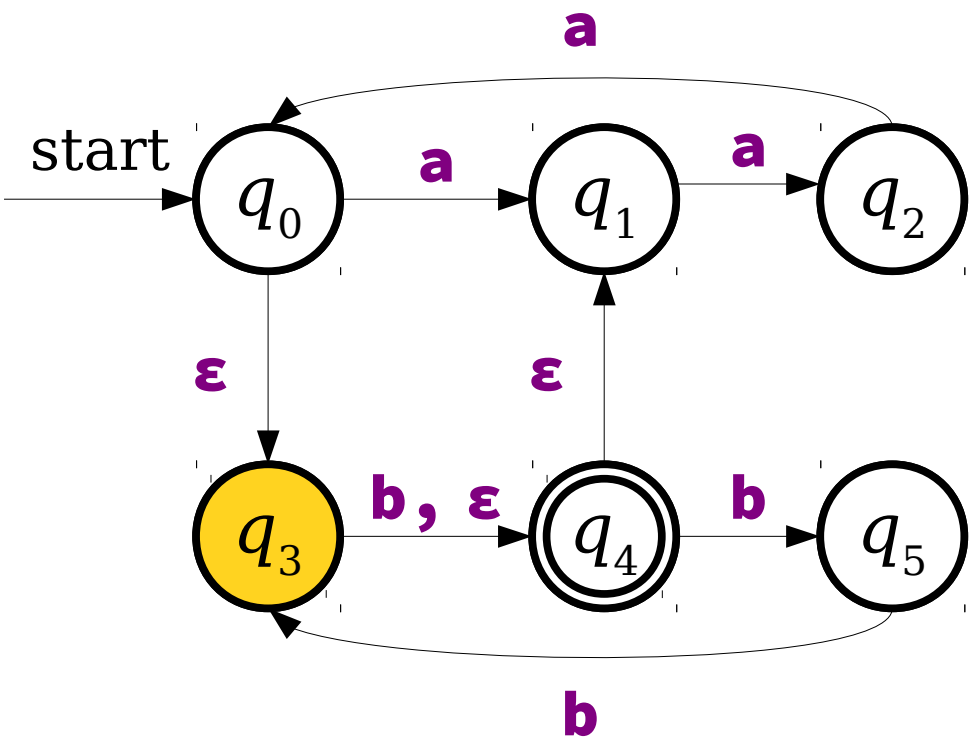
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.

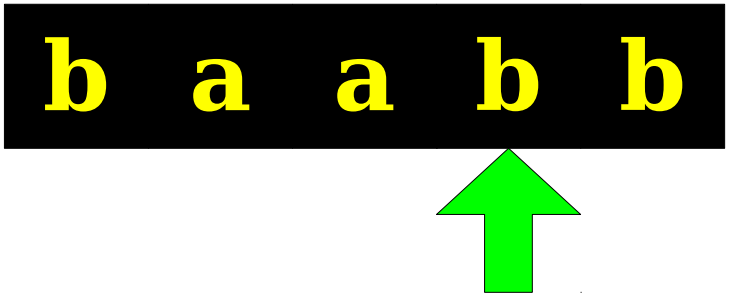




ε-Transitions

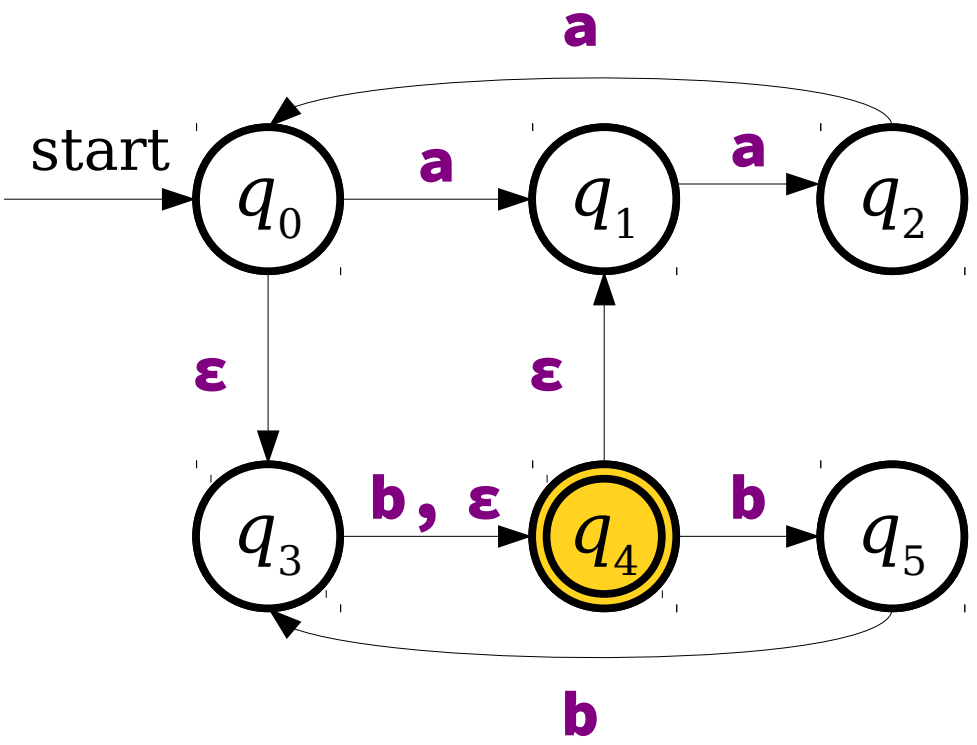
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.

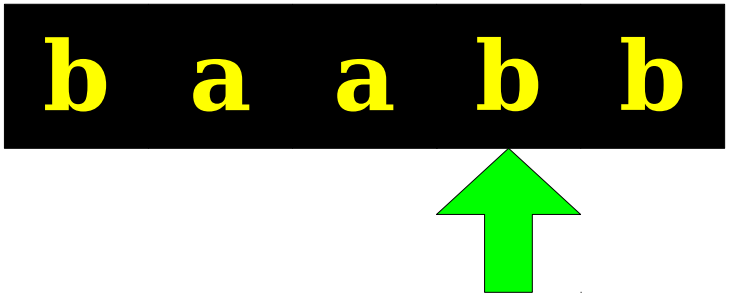




ε-Transitions

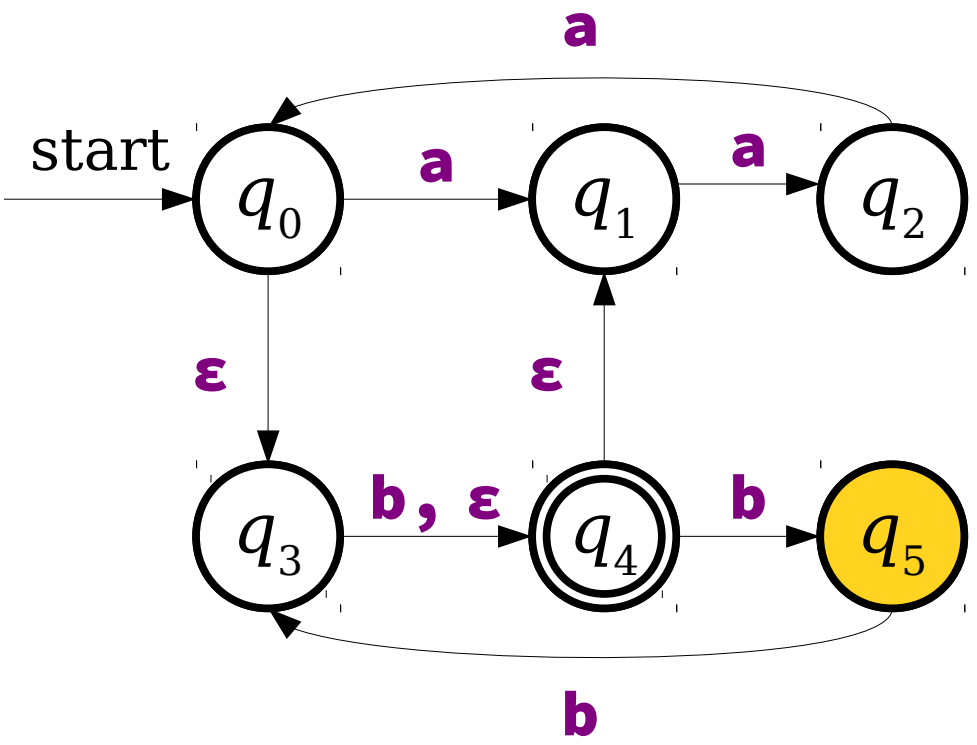
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.

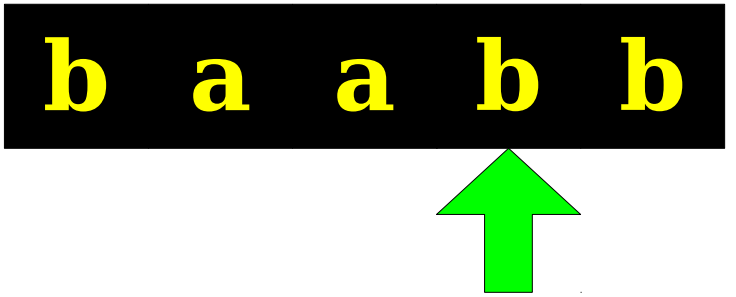




ε-Transitions

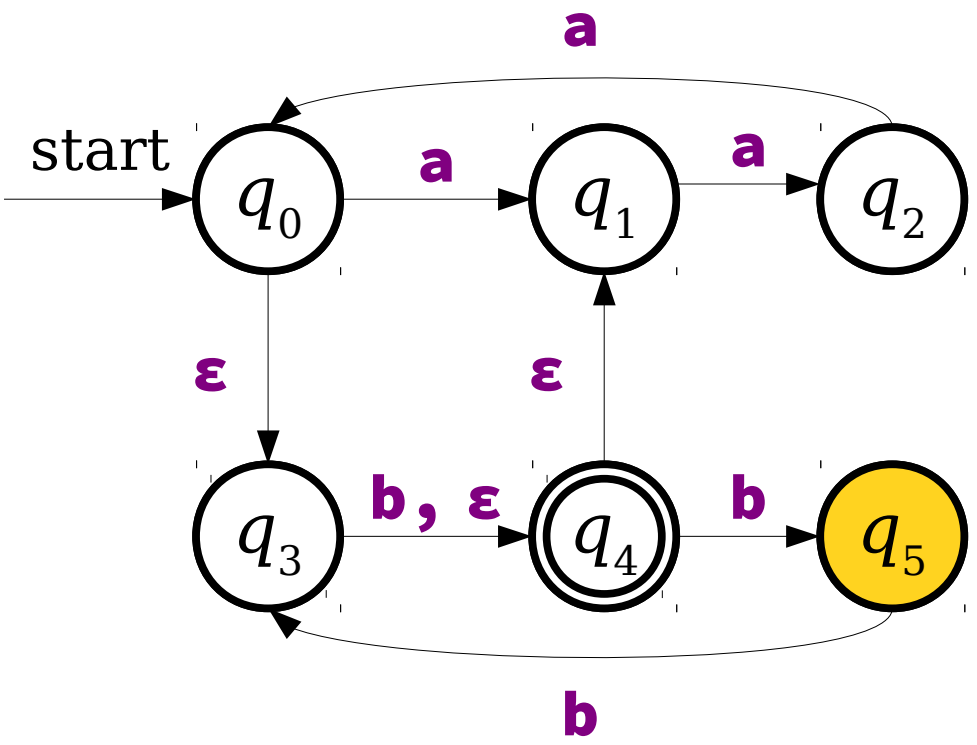
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.





ε-Transitions

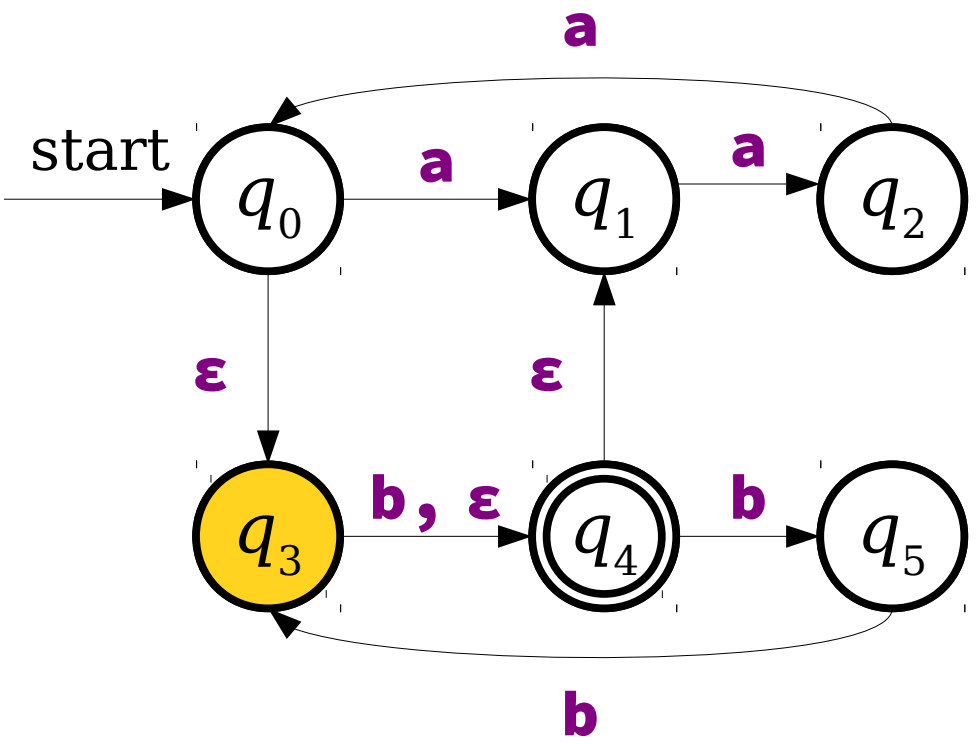
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



b a a b b

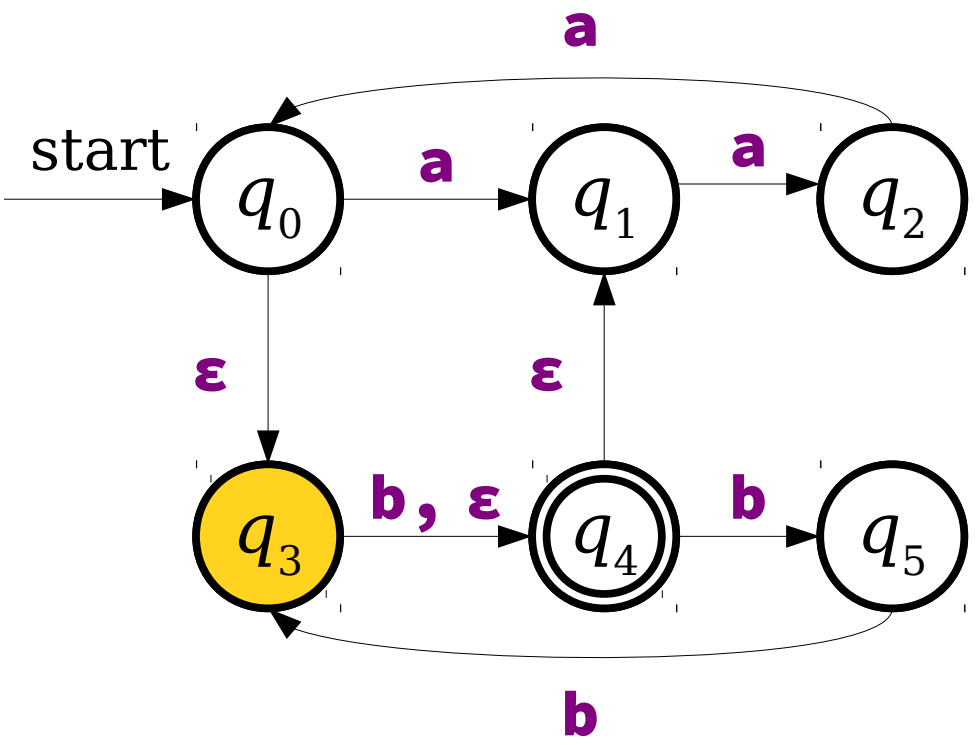
ε-Transitions

- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



ε-Transitions

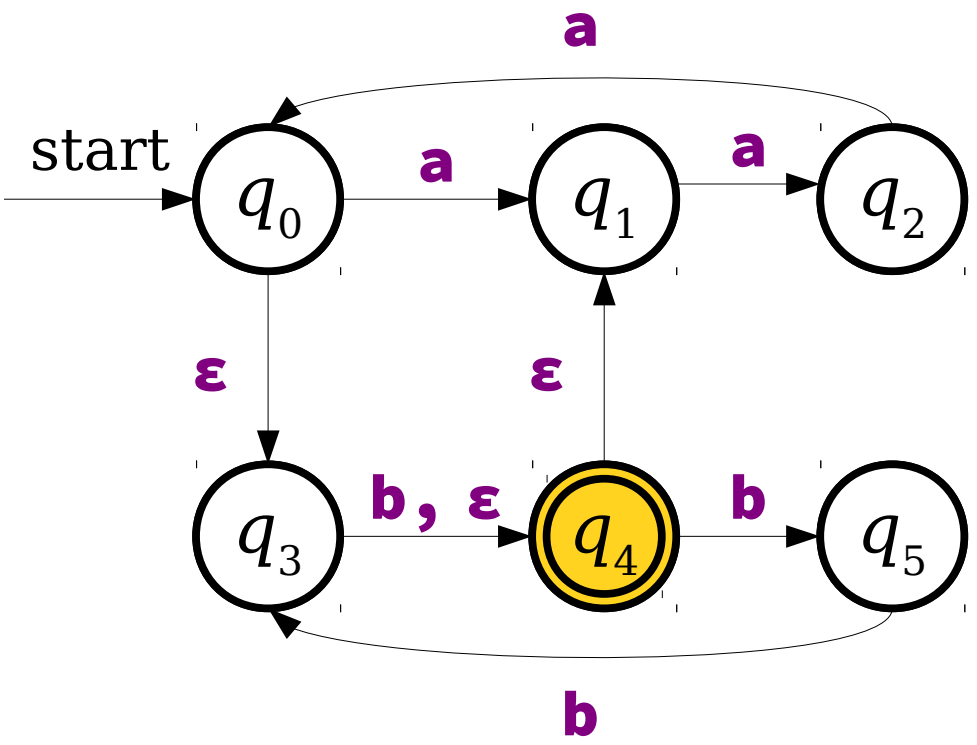
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



b a a b b

ε-Transitions

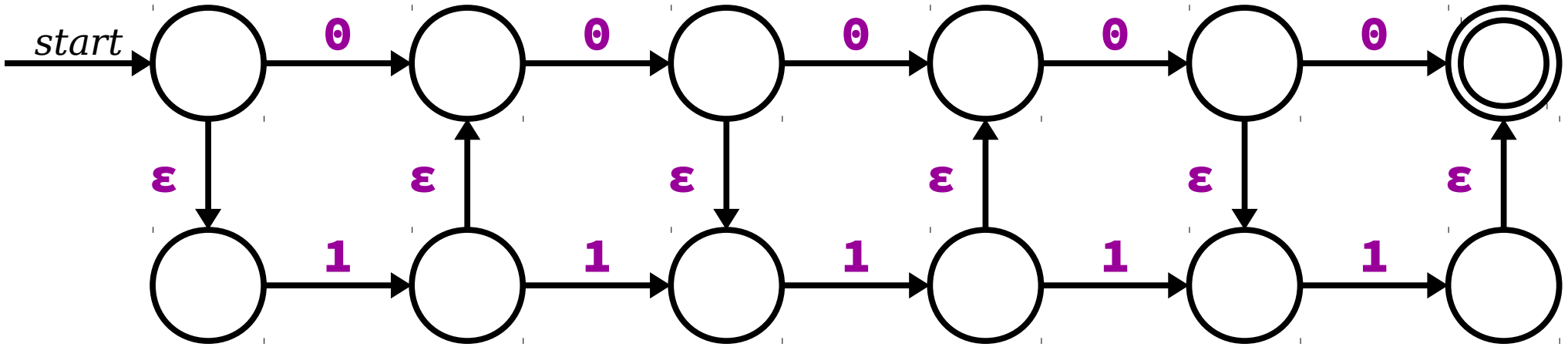
- NFAs have a special type of transition called the **ε-transition**.
- An NFA may follow any number of ε-transitions at any time without consuming any input.



b a a b b

ε-Transitions

- NFAs have a special type of transition called the **ε-transition**.
- An NFA *may* follow any number of ε-transitions at any time without consuming any input.
- NFAs are not *required* to follow ε-transitions every time one is available. It's simply another option at the machine's disposal (stay or move).



Suppose we run the above NFA on the string **10110**. How many of the following statements are true?

- There is at least one computation that finishes in an accepting state.
- There is at least one computation that finishes in a rejecting state.
- There is at least one computation that dies.
- This NFA accepts **10110**.
- This NFA rejects **10110**.

Answer at **PollEv.com/cs103** or
text **CS103** to **22333** once to join, then **a number**.