Formal Languages, Automata and Codes

Oleg Gutik

Lecture 6

We now come to a fundamental question. In what sense are DFA's and NFA's different? Obviously, there is a difference in their definition, but this does not imply that there is any essential distinction between them. To explore this question, we introduce the concept of equivalence between automata.

Definition 2.7

Two finite accepters, M_1 and M_2, are said to be equivalent if

$$L(M_1) = L(M_2),$$

that is, if they both accept the same language.

As mentioned, there are generally many accepters for a given language, so any DFA or NFA has many equivalent accepters.

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The DFA shown in the following Figure

is equivalent to the NFA in the Figure

because they both accept the language $\{(10)^n : n \geqslant 0\}$.

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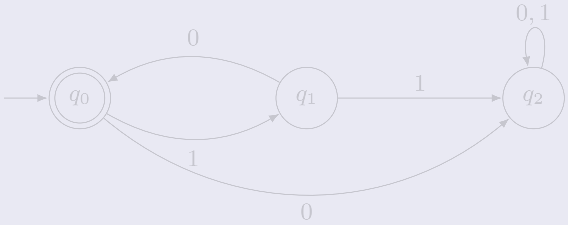

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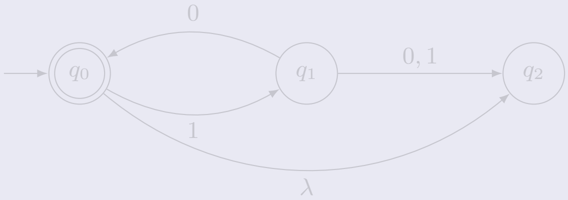

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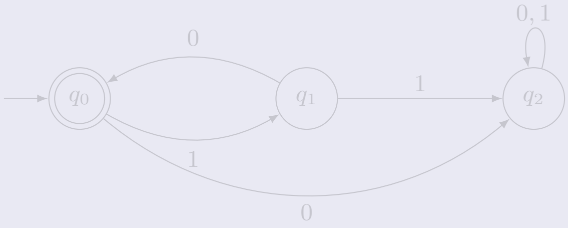

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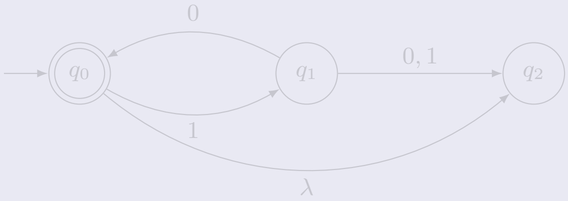

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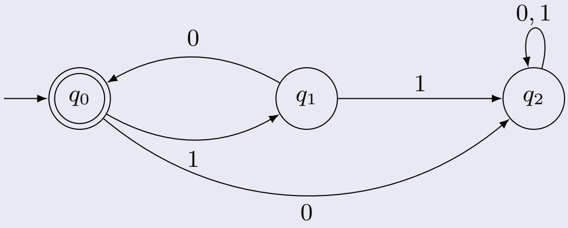

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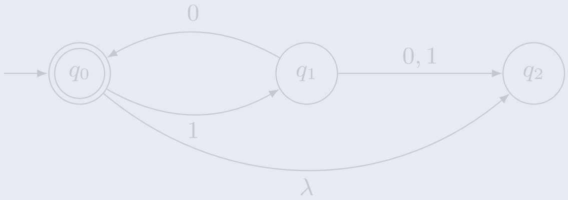

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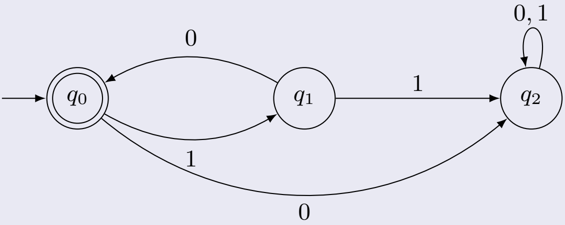

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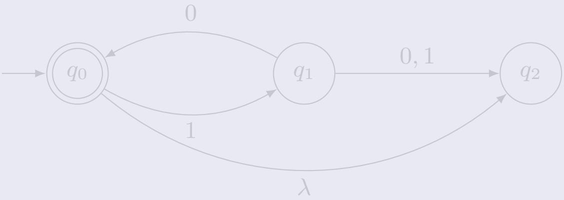

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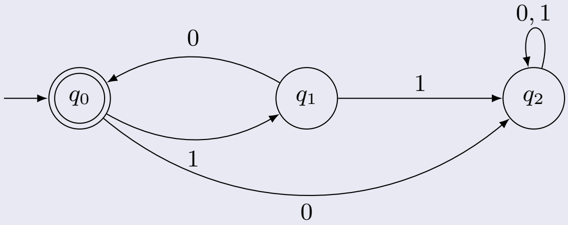

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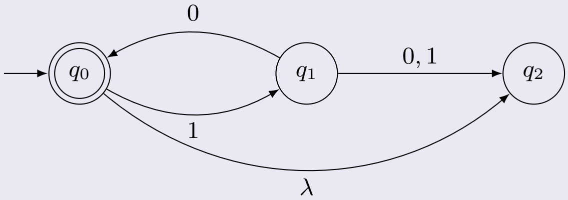

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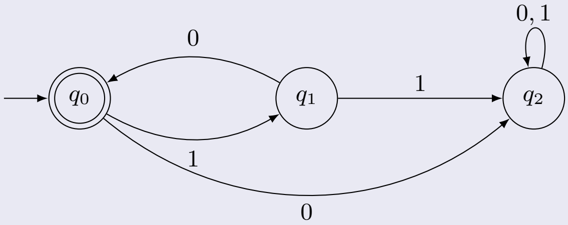

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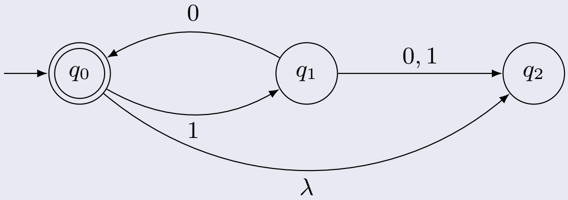

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This result is not obvious and certainly has to be demonstrated. The argument, like most arguments in this book, will be constructive. This means that we can actually give a way of converting any NFA into an equivalent DFA. The construction is not hard to understand; once the idea is clear it becomes the starting point for a rigorous argument. The rationale for the construction is the following. After an NFA has read a string w, we may not know exactly what state it will be in, but we can say that it must be in one state of a set of possible states, say $\{q_i, q_j, \ldots, q_k\}$. An equivalent DFA after reading the same string must be in some definite state. How can we make these two situations correspond? The answer is a nice trick: Label the states of the DFA with a set of states in such a way that, after reading w, the equivalent DFA will be in a single state labeled $\{q_i, q_j, \ldots, q_k\}$. Since for a set of $|Q|$ states there are exactly $2^{|Q|}$ subsets, the corresponding DFA will have a finite number of states.

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Convert the NFA in the following Figure to an equivalent DFA.

The NFA starts in state q_0, so the initial state of the DFA will be labeled $\{q_0\}$. After reading a symbol a, the NFA can be in state q_1 or, by making a λ-transition, in state q_2. Therefore, the corresponding DFA must have a state labeled $\{q_1, q_2\}$ and a transition

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

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$$\delta(\{q_0\}, b) = \varnothing.$$

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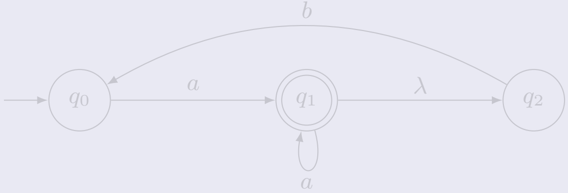

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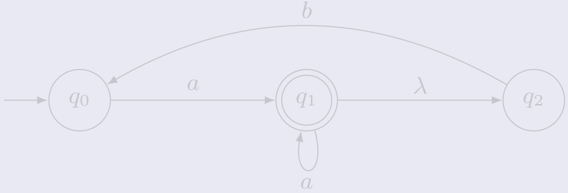

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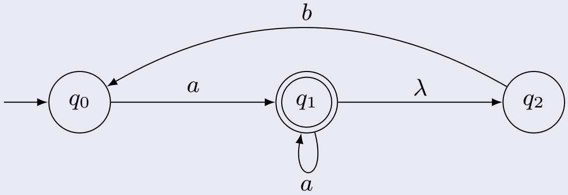

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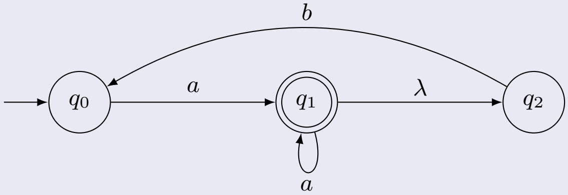

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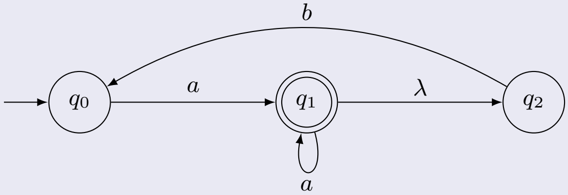

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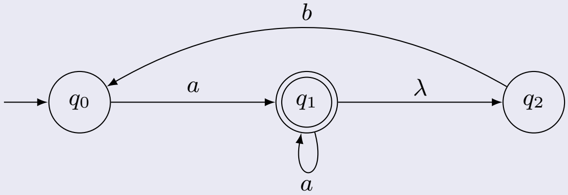

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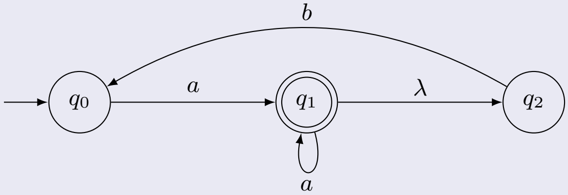

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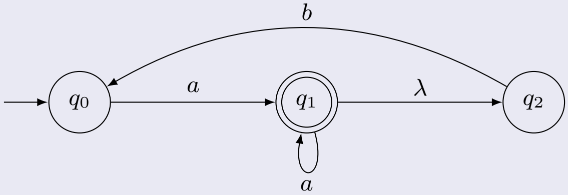

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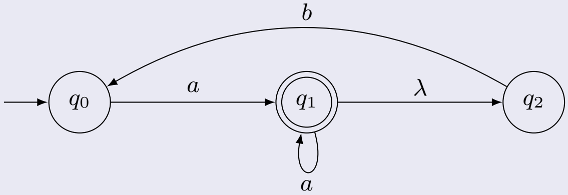

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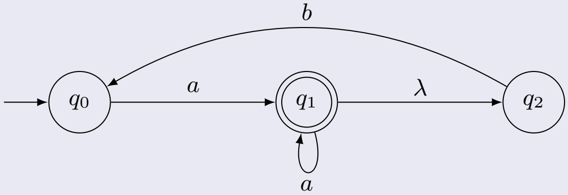

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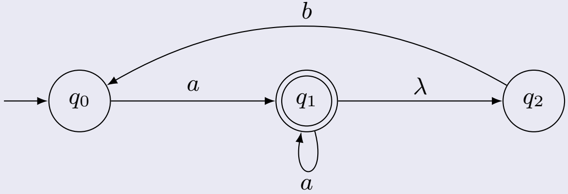

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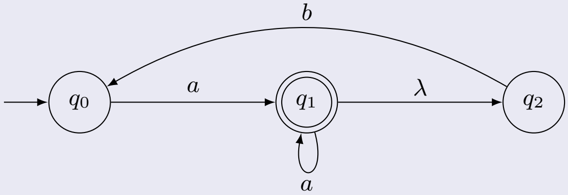

The NFA starts in state q_0, so the initial state of the DFA will be labeled $\{q_0\}$. After reading a symbol a, the NFA can be in state q_1 or, by making a λ-transition, in state q_2. Therefore, the corresponding DFA must have a state labeled $\{q_1, q_2\}$ and a transition

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

In state q_0, the NFA has no specified transition when the input is b; therefore,

$$\delta(\{q_0\}, b) = \varnothing.$$

A state labeled $\varnothing$ represents an impossible move for the NFA and, therefore, means nonacceptance of the string. Consequently, this state in the DFA must be a nonfinal trap state.

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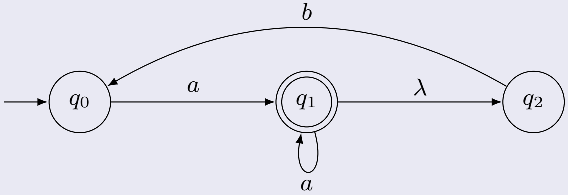

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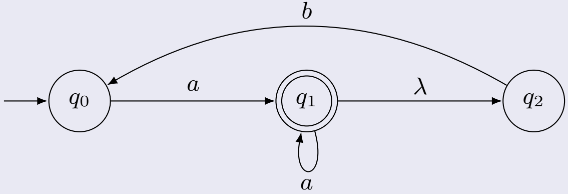

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Example 2.12 (continuation)

We have now introduced into the DFA the state $\{q_1, q_2\}$, so we need to find the transitions out of this state. Remember that this state of the DFA corresponds to two possible states of the NFA, so we must refer back to the NFA. If the NFA is in state q_1 and reads a symbol a, it can go to q_1. Furthermore, from q_1 the NFA can make a λ-transition to q_2. If, for the same input, the NFA is in state q_2, then there is no specified transition. Therefore,

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Example 2.12 (continuation)

At this point, every state has all transitions defined. The result, shown in the following Figure, is a DFA, equivalent to the NFA with which we started. The NFA in the Figure accepts any string for which $\delta^*(q_0, w)$ contains q_1. For the corresponding DFA to accept every such w, any state whose label includes q_1 must be made a final state.

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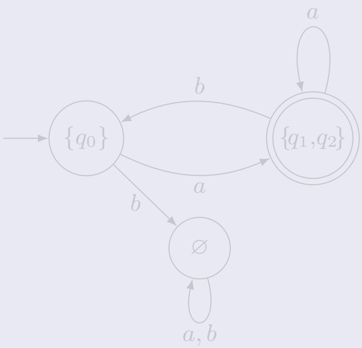

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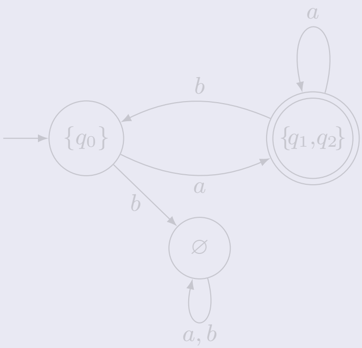

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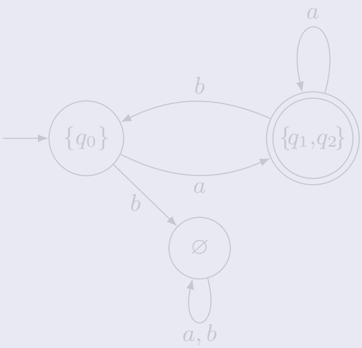

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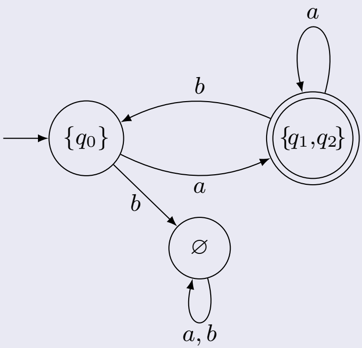

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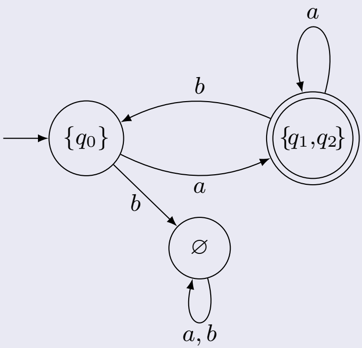

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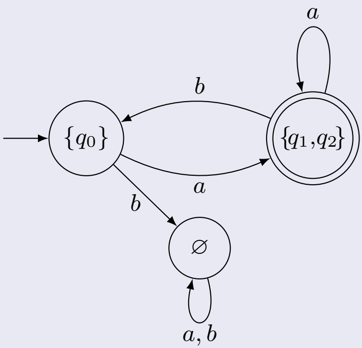

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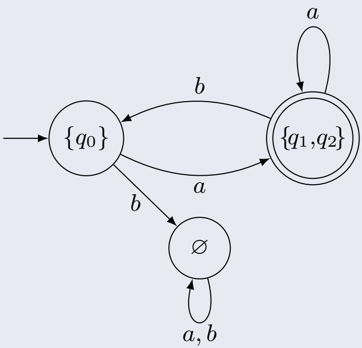

Theorem 2.2

Let L be the language accepted by a nondeterministic finite accepter $M_N = (Q_N, \Sigma, \delta_N, q_0, F_N)$. Then there exists a deterministic finite accepter $M_D = (Q_D, \Sigma, \delta_D, \{q_0\}, F_D)$ such that

$$L(M_N) = L(M_D).$$

Proof. Given M_N, we use the procedure *NFA-to-DFA* below to construct the transition graph G_D for M_D. To understand the construction, remember that G_D has to have certain properties. Every vertex must have exactly $|\Sigma|$ outgoing edges, each labeled with a different element of Σ. During the construction, some of the edges may be missing, but the procedure continues until they are all there.

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Procedure ***NFA-to-DFA***

1. Create a graph G_D with vertex $\{q_0\}$.

2. Repeat the following steps until no more edges are missing.

   Take any vertex $\{q_i, q_j, \ldots, q_k\}$ of G_D that has no outgoing edge for some $a \in \Sigma$.

   Add to G_D an edge from $\{q_i, q_j, \ldots, q_k\}$ to $\{q_l, q_m, \ldots, q_n\}$ and label it with a.

3. Every state of G_D whose label contains any $q_f \in F_N$ is identified as a final vertex.

4. If M_N accepts λ, the vertex $\{q_0\}$ in G_D is also made a final vertex.

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Procedure *NFA-to-DFA*

1. Create a graph G_D with vertex $\{q_0\}$. Identify this vertex as the initial vertex.
2. Repeat the following steps until no more edges are missing.

   Take any vertex $\{q_i, q_j, \ldots, q_k\}$ of G_D that has no outgoing edge for some $a \in \Sigma$. Compute $\delta_N^*(q_i, a)$, $\delta_N^*(q_j, a)$, ..., $\delta_N^*(q_k, a)$. If

   $$\delta_N^*(q_i, a) \cup \delta_N^*(q_j, a) \cup \cdots \cup \delta_N^*(q_k, a) = \{q_l, q_m, \ldots, q_n\},$$

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Convert the NFA in the following Figure to an equivalent DFA.

Since $\delta_N(q_0, 0) = \{q_0, q_1\}$, we introduce the state $\{q_0, q_1\}$ in G_D and add an edge labeled by 0 between $\{q_0\}$ and $\{q_0, q_1\}$. In the same way, considering $\delta_N(q_0, 1) = \{q_1\}$ gives us the new state $\{q_1\}$ and an edge labeled by 1 between it and $\{q_0\}$.

There are now a number of missing edges, so we continue, using the construction of Theorem 2.2. Looking at the state $\{q_0, q_1\}$, we see that there is no outgoing edge labeled by 0, so we compute

$$\delta_N^*(q_0, 0) \cup \delta_N^*(q_1, 0) = \{q_0, q_1, q_2\}.$$

This gives us the new state $\{q_0, q_1, q_2\}$ and the transition

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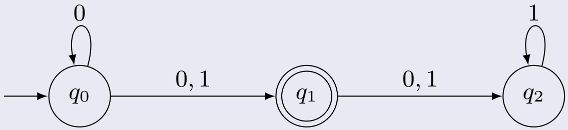

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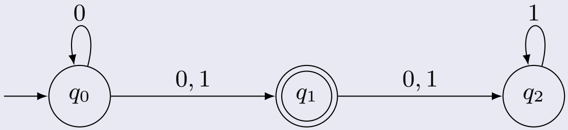

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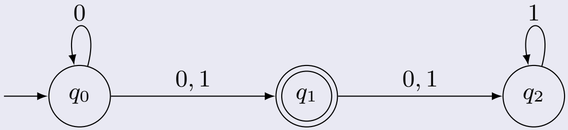

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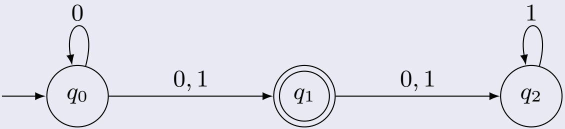

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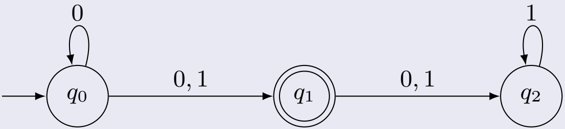

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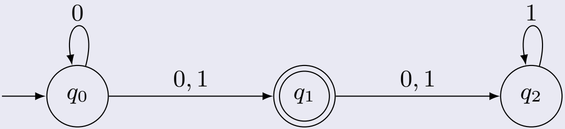

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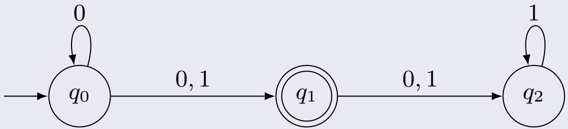

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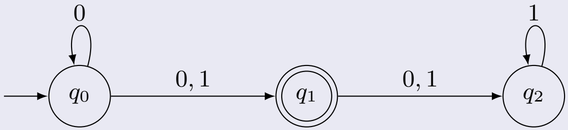

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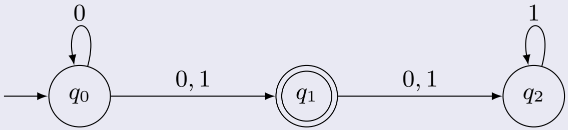

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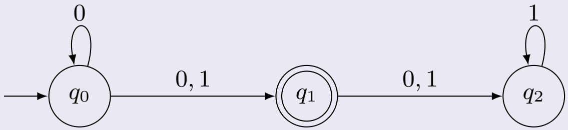

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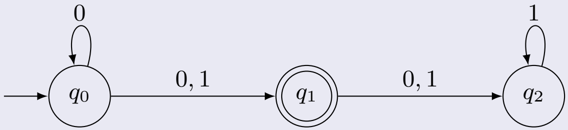

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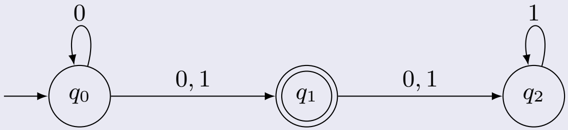

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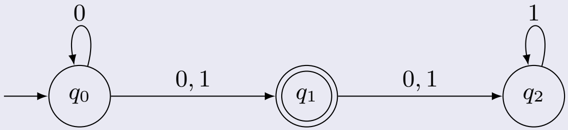

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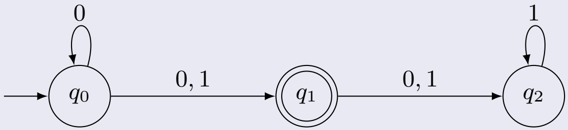

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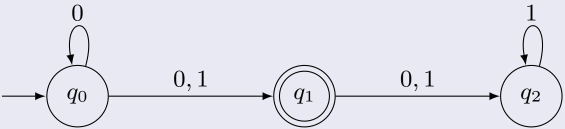

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Example 2.13 (continuation)

Then, using $a = 1$, $i = 0$, $j = 1$, $k = 2$,

$$\delta_N^*(q_0, 1) \cup \delta_N^*(q_1, 1) \cup \delta_N^*(q_2, 1) = \{q_1, q_2\}$$

makes it necessary to introduce yet another state $\{q_1, q_2\}$. At this point, we have the partially constructed automaton shown in the following Figure.

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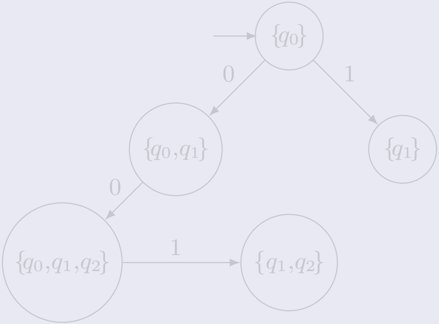

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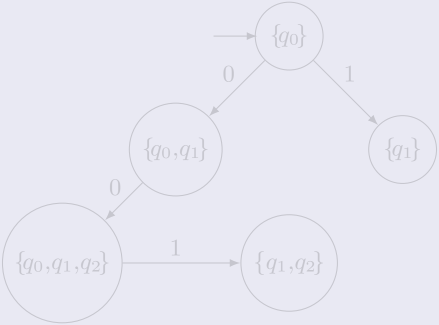

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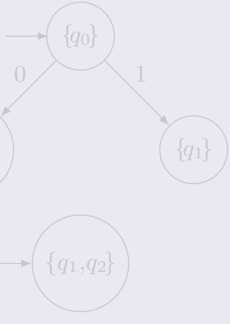

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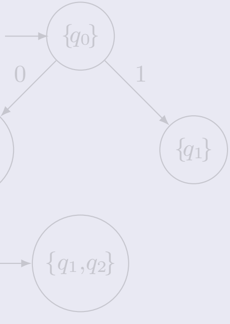

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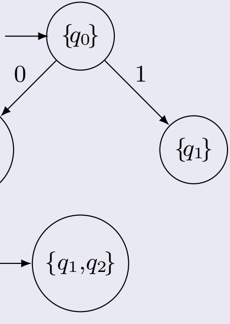

Example 2.13 (continuation)

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Example 2.13 (continuation)

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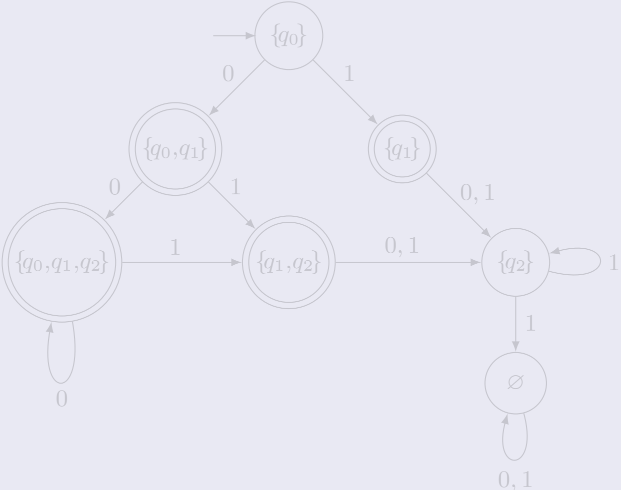

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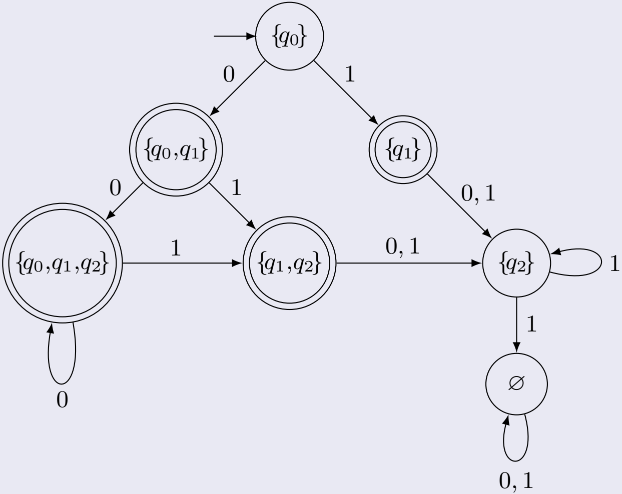

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Thank You for attention!