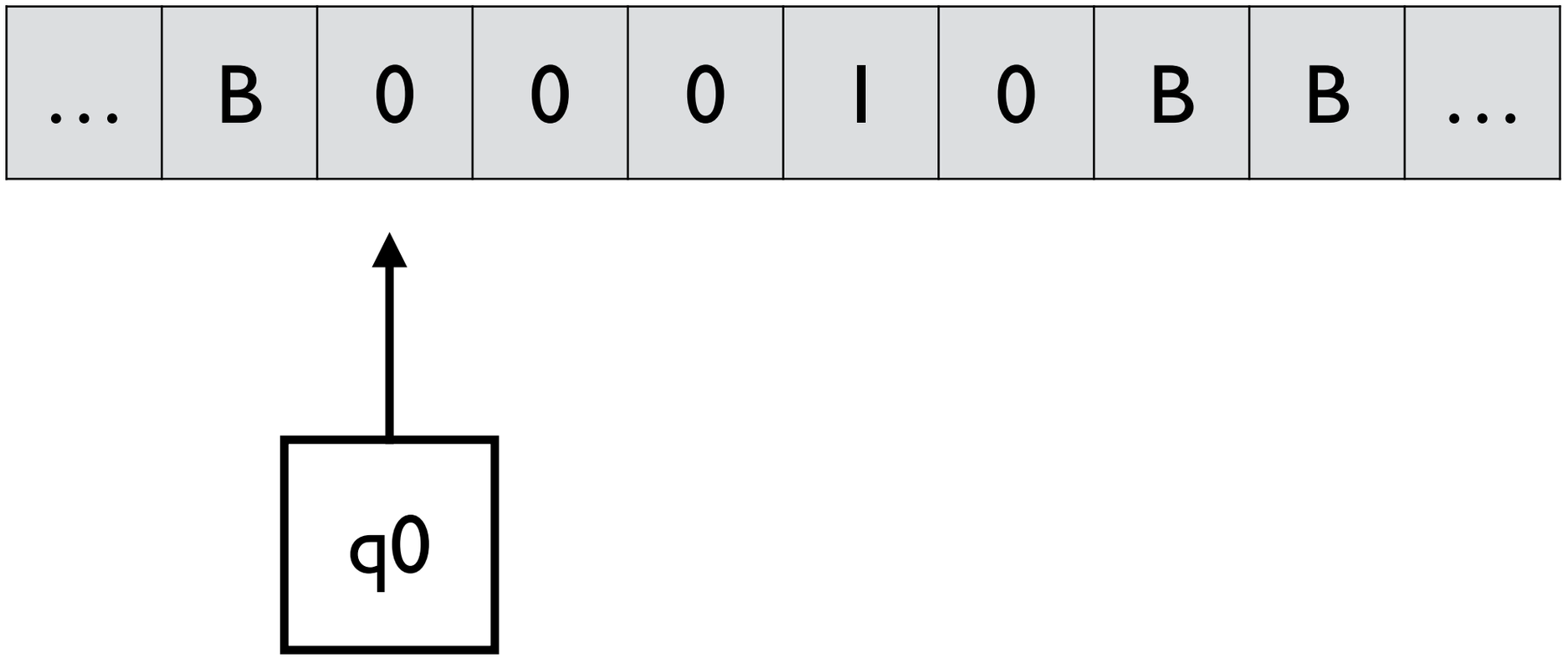
Example 4. Design a Turing machine that computes $f(m, n)$.

$$f(m, n) = max(m - n, 0) = \text{if } m \geq n \text{ then } m - n \text{ else } 0$$

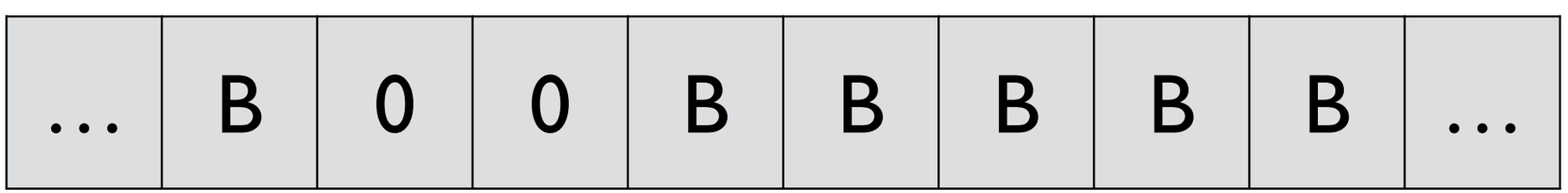
$$M = (\{q_0, q_1, \ldots, q_6\}, \{0, 1\}, \{0, 1, B\}, \delta, q_0, B, \{q_6\})$$

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

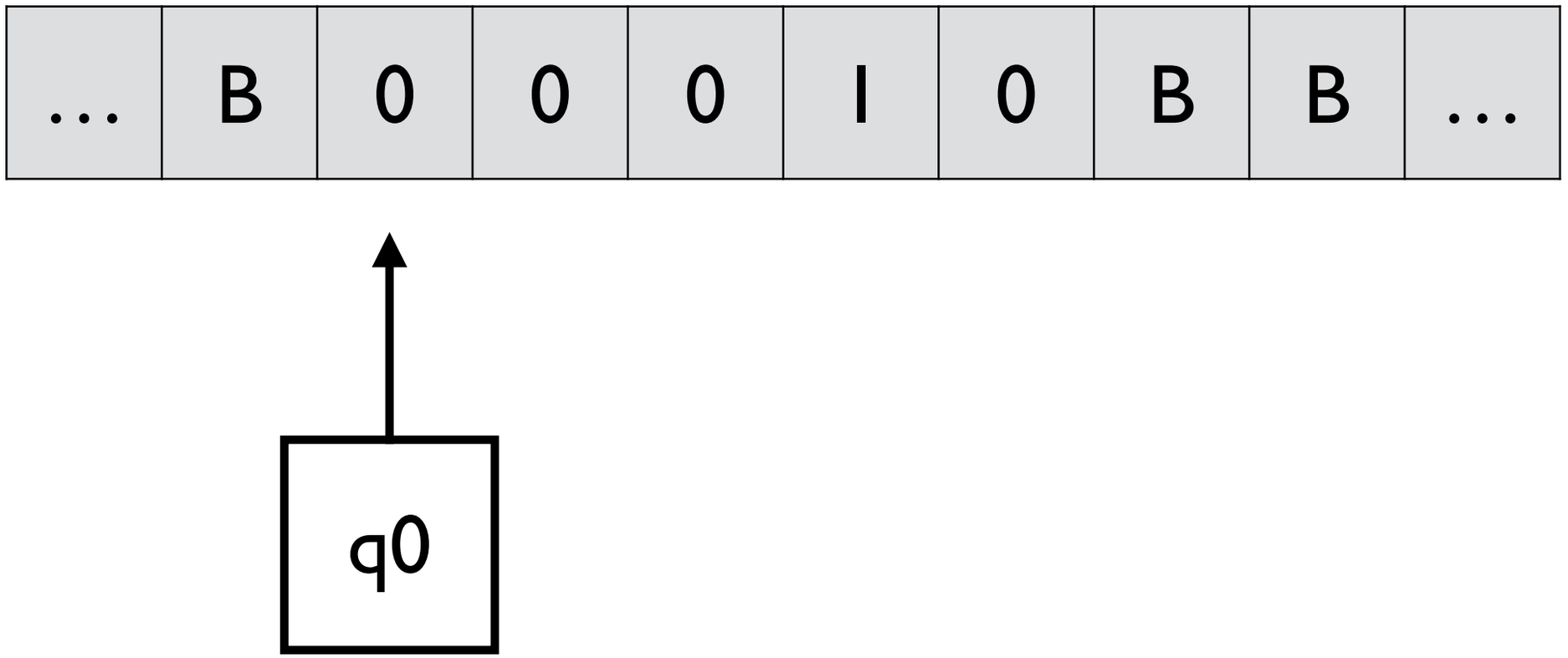
Initial machine configuration: e.g., f(3,1)



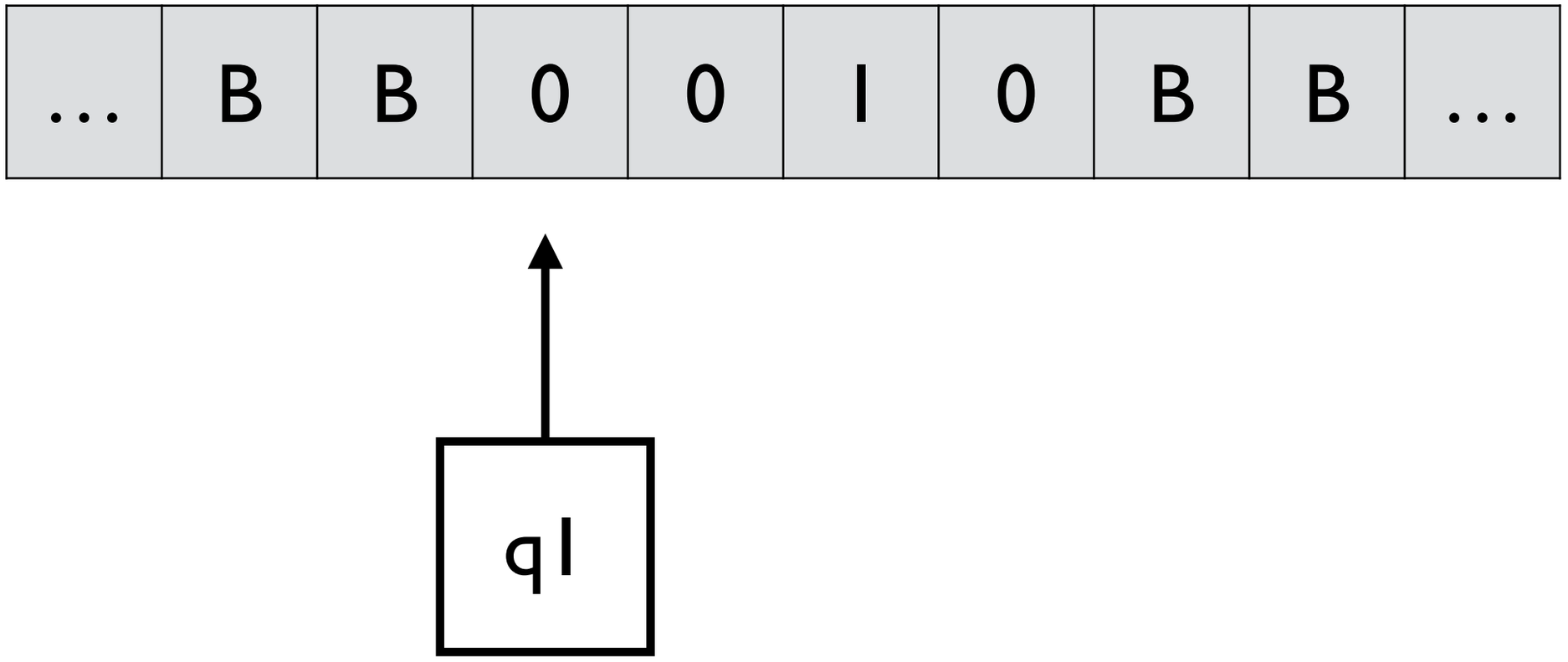
When the machine halts:



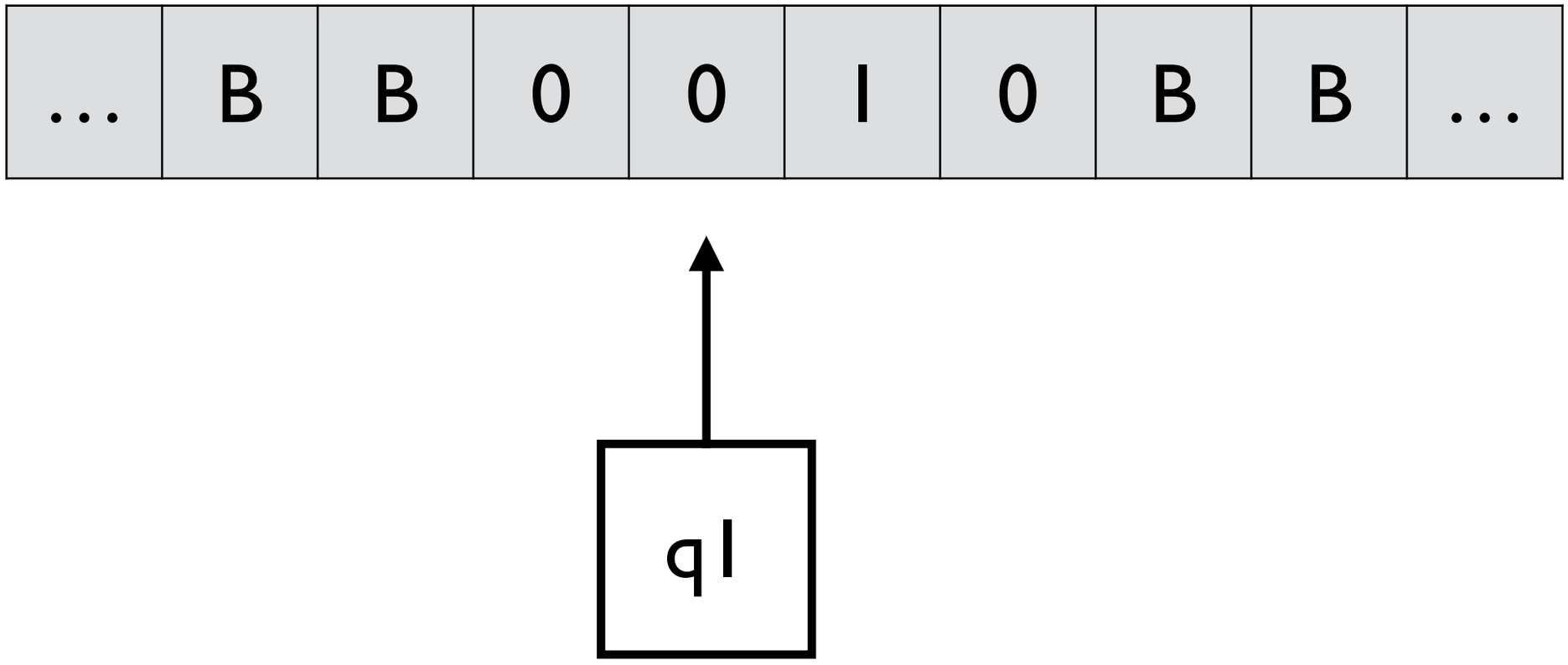
e.g., f(3,2)



	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

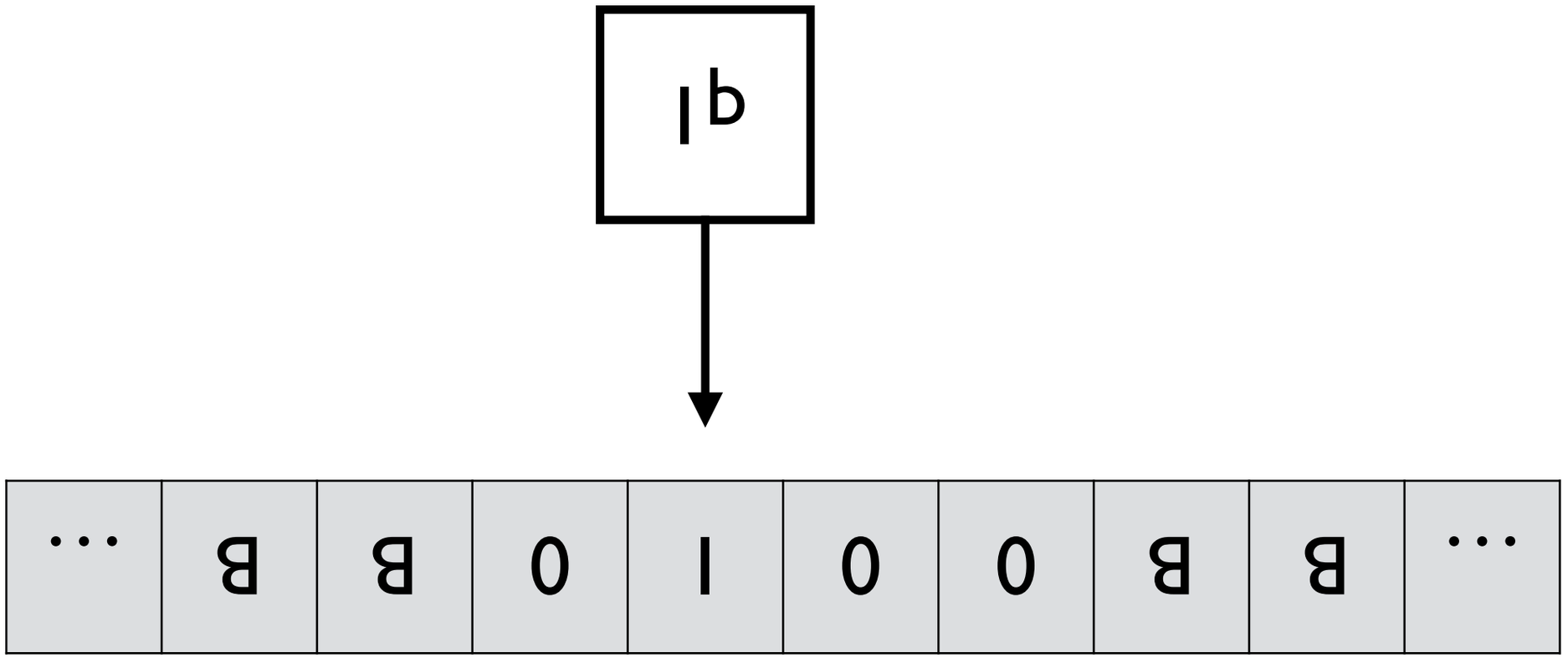


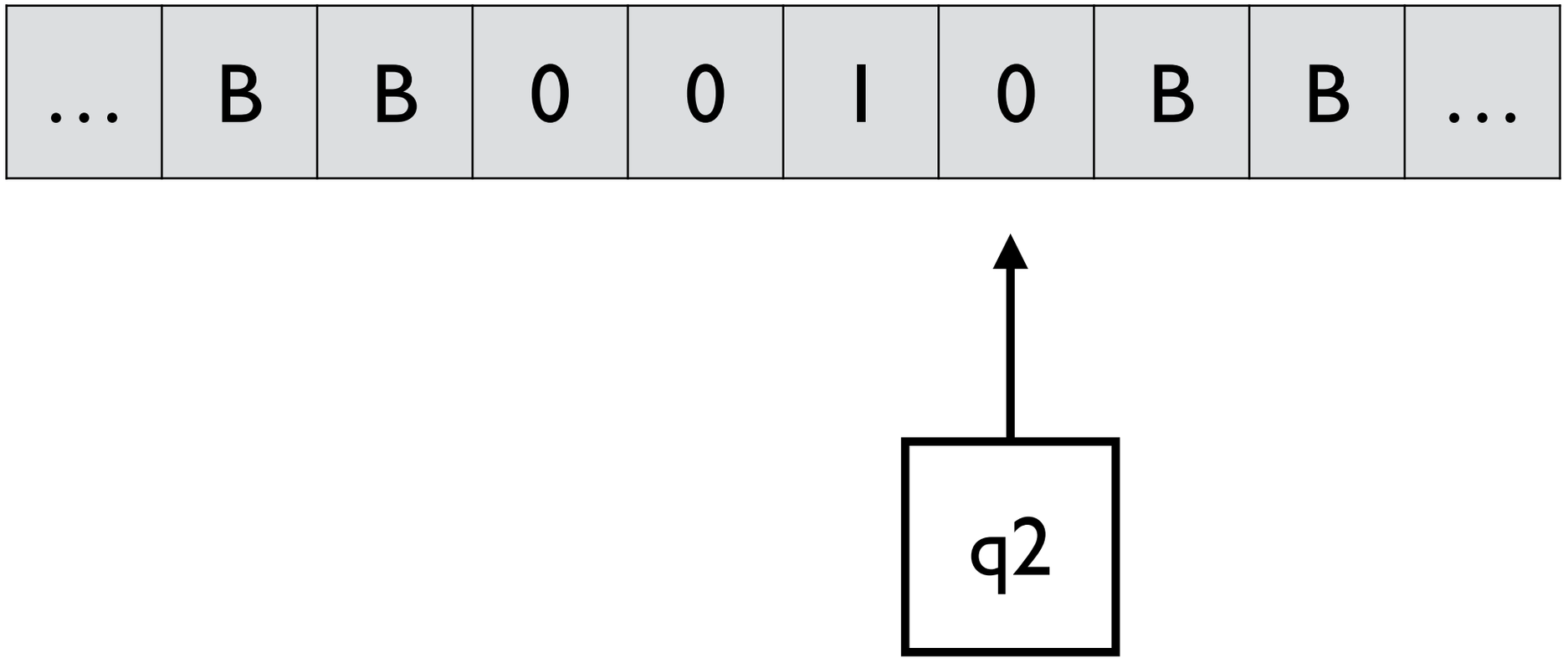
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



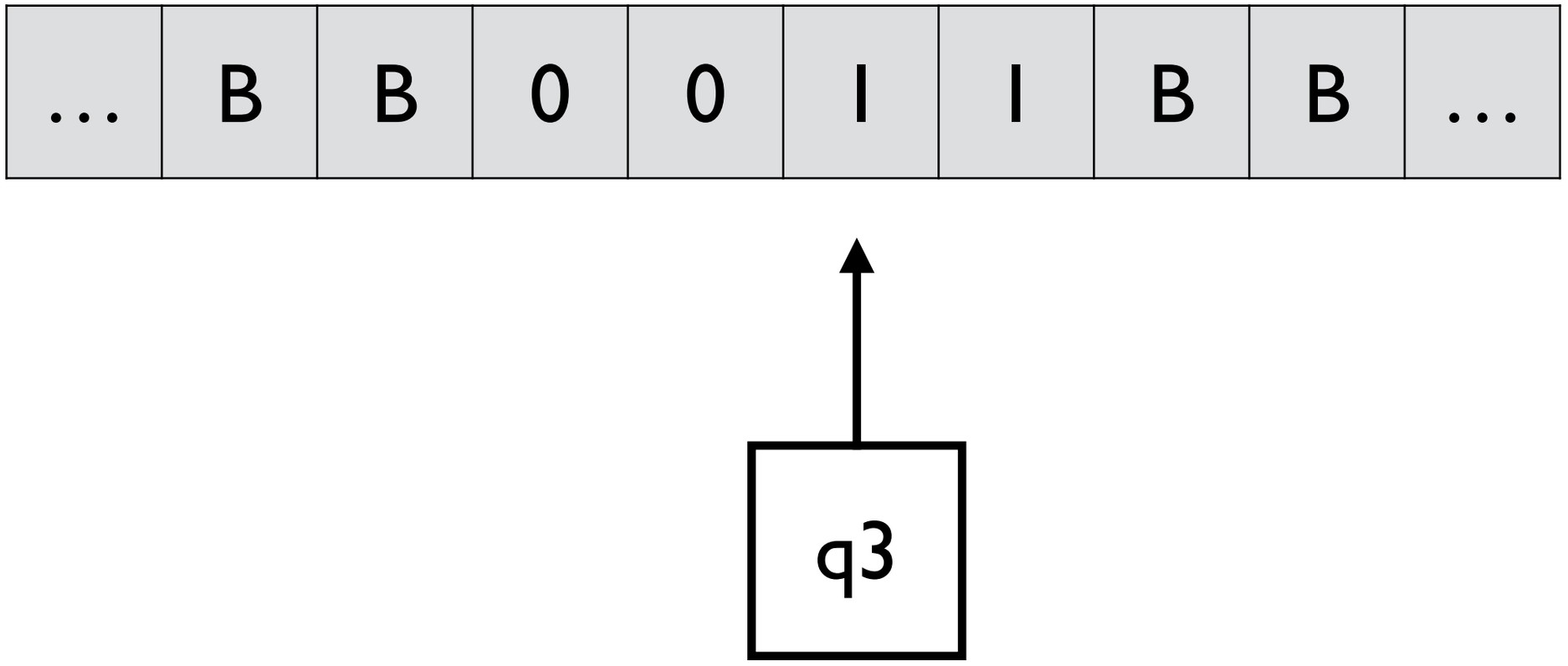
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

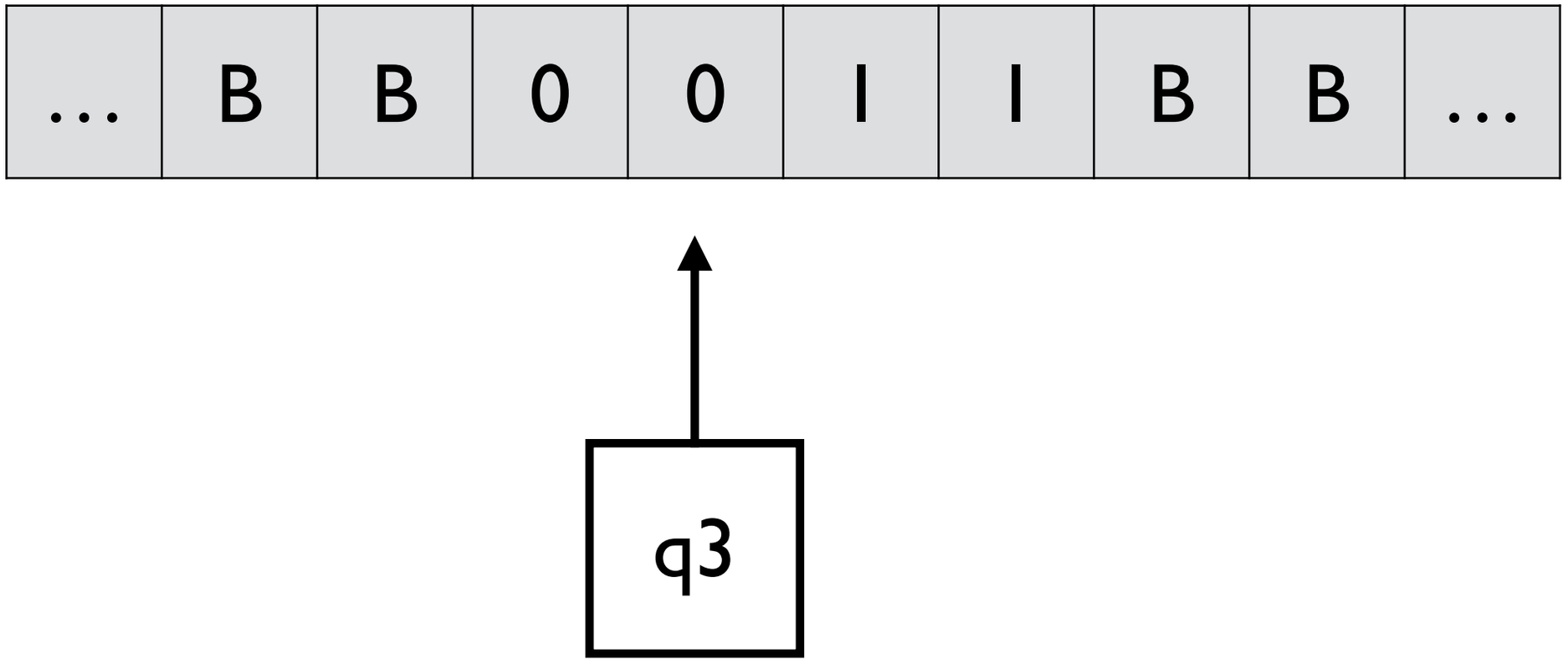




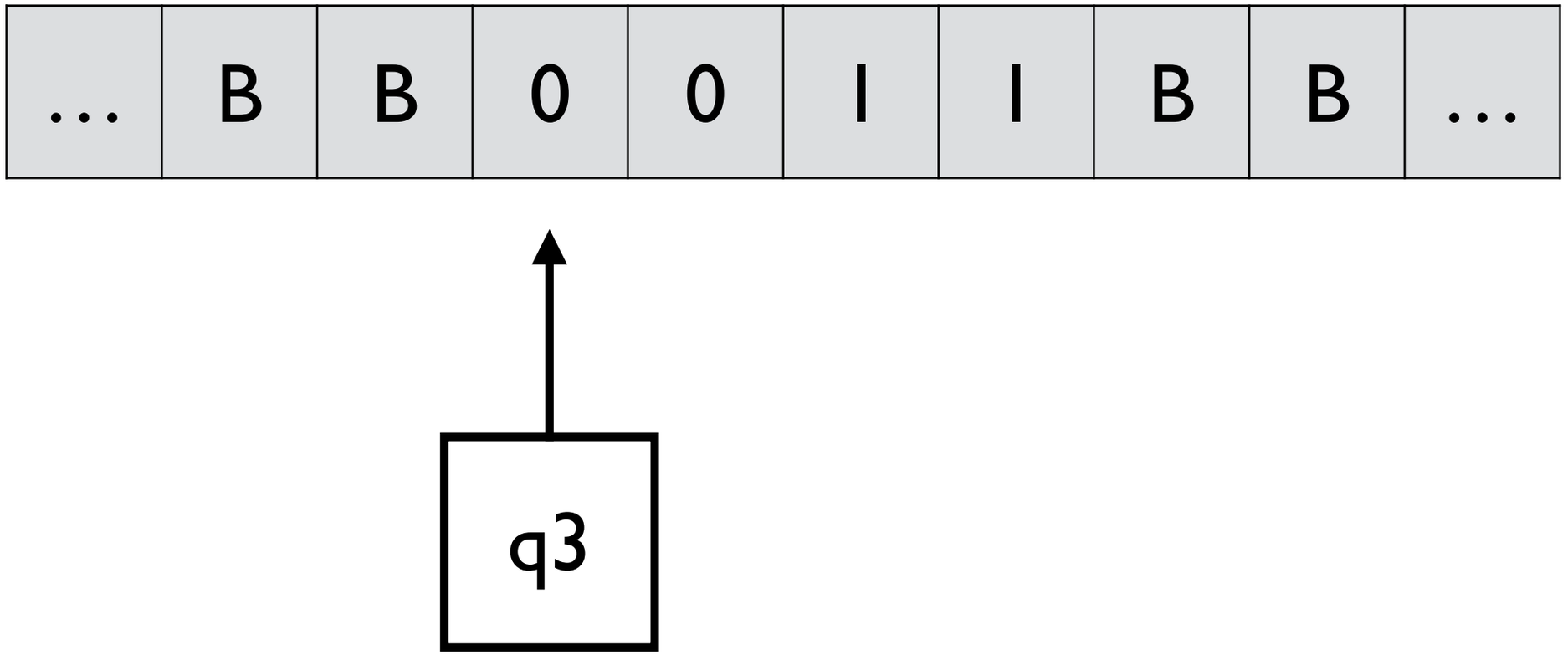
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



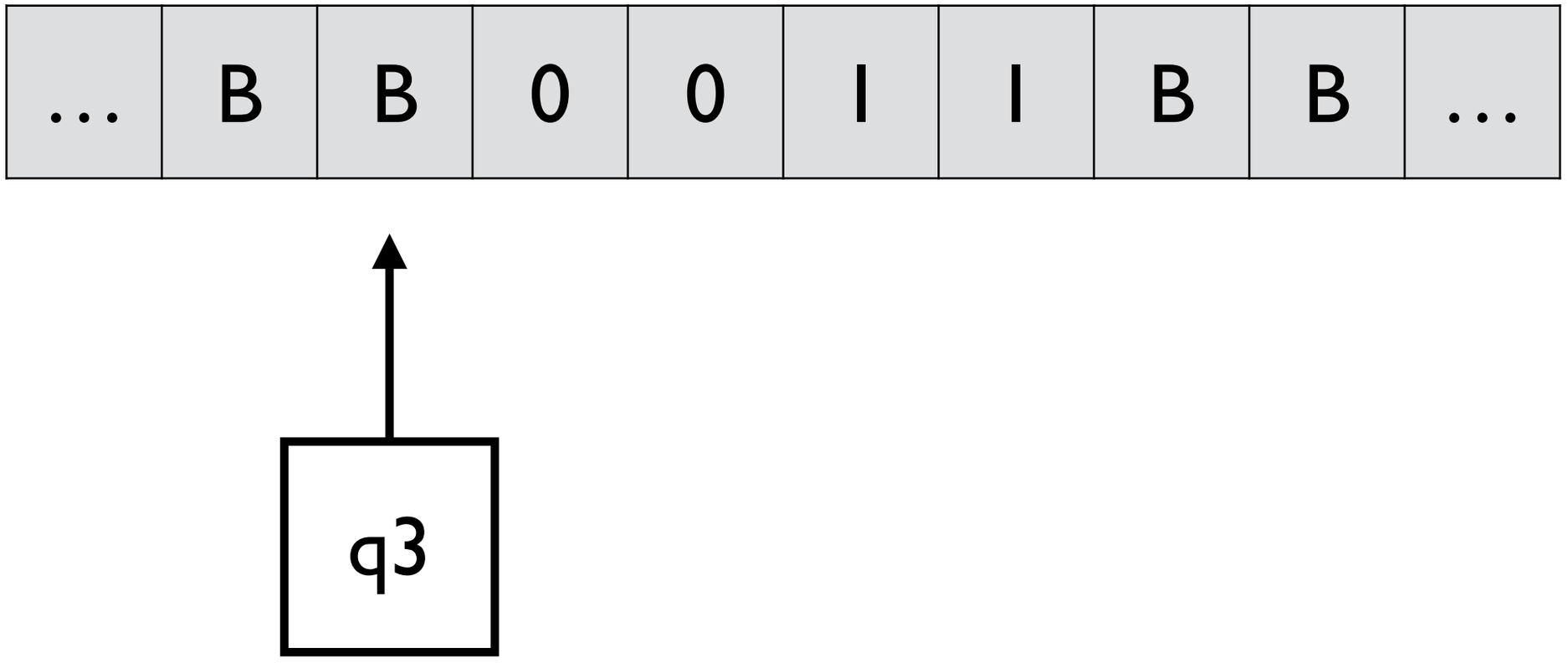
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



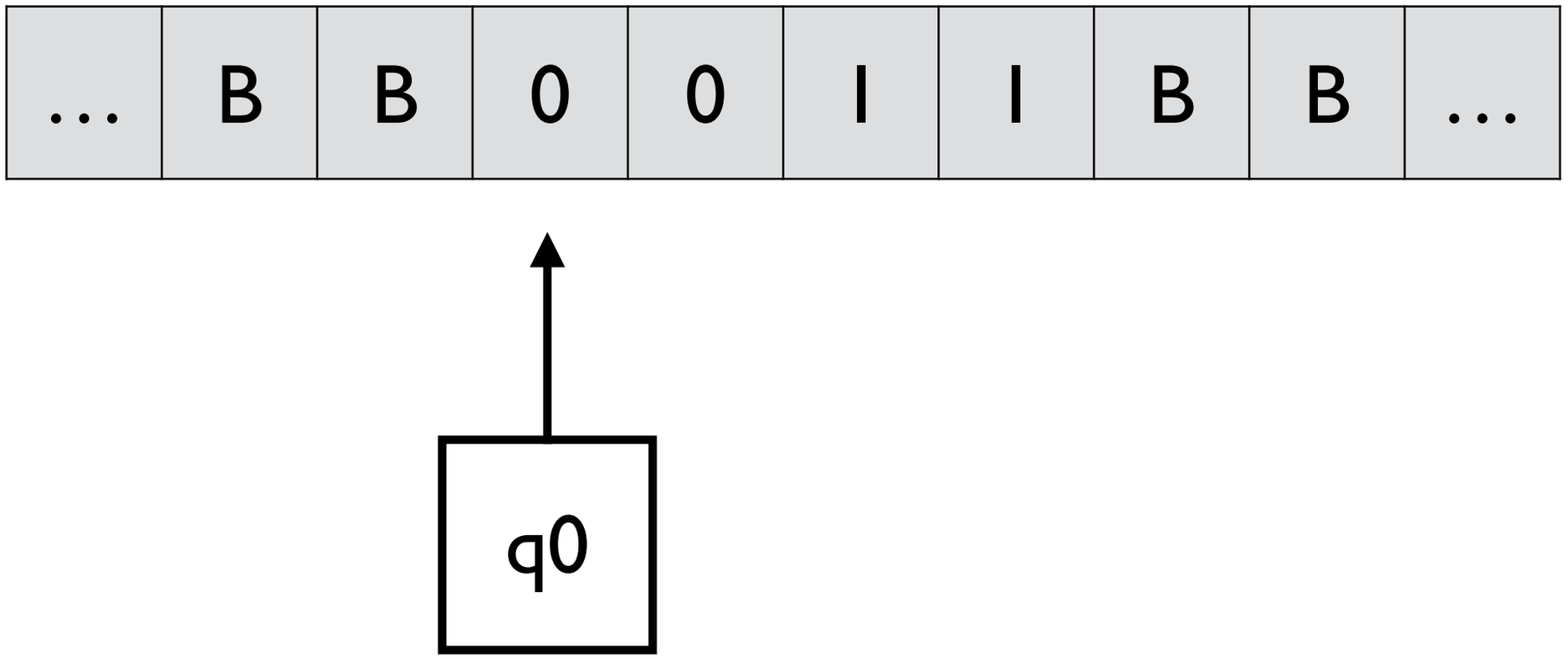
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

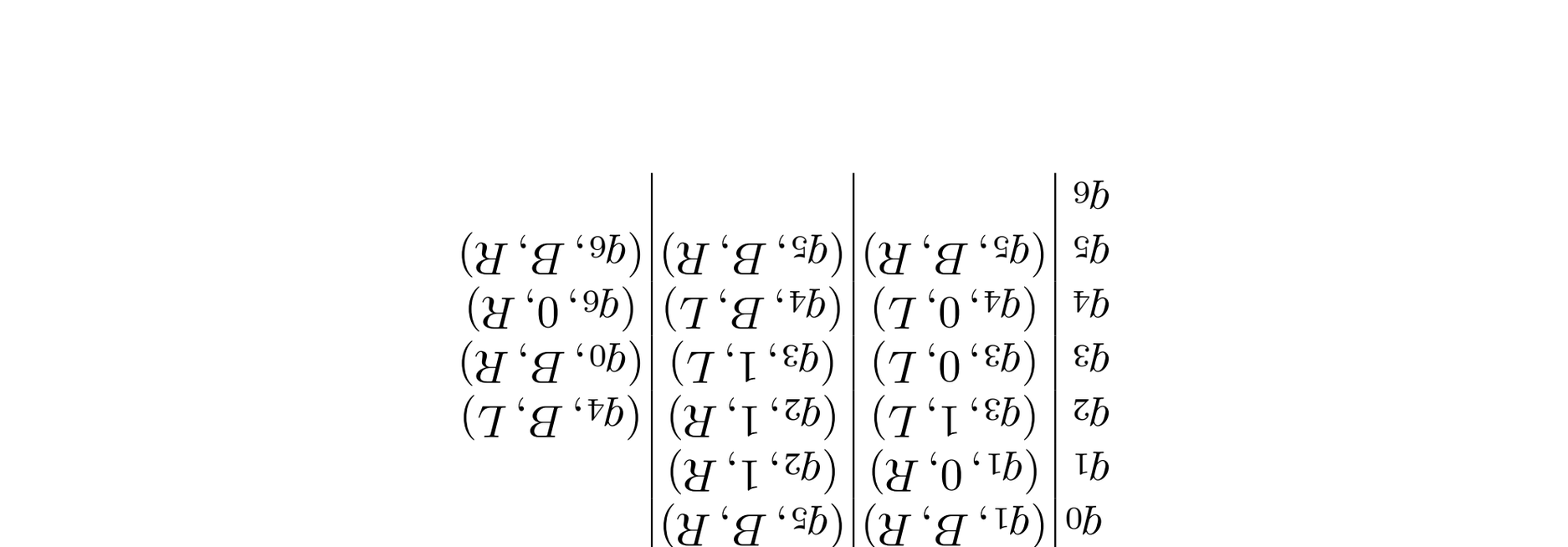


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

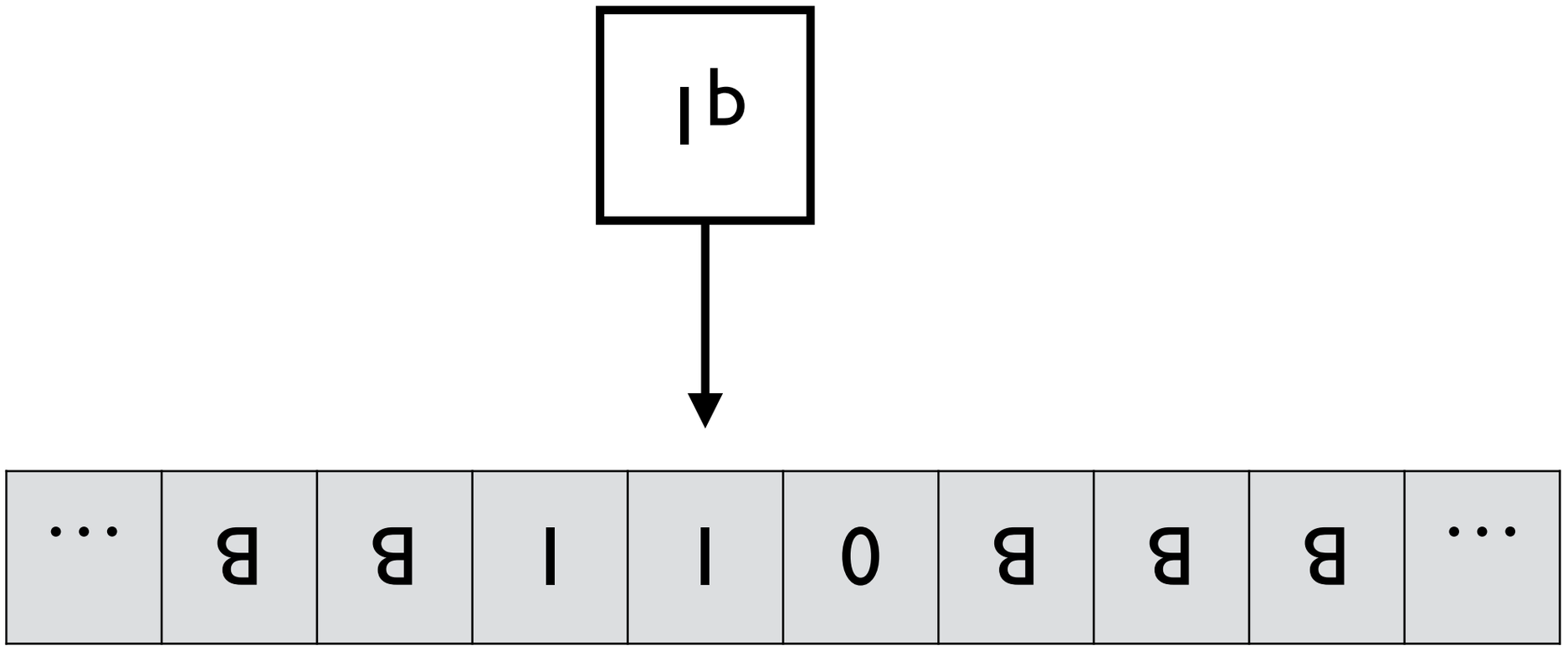


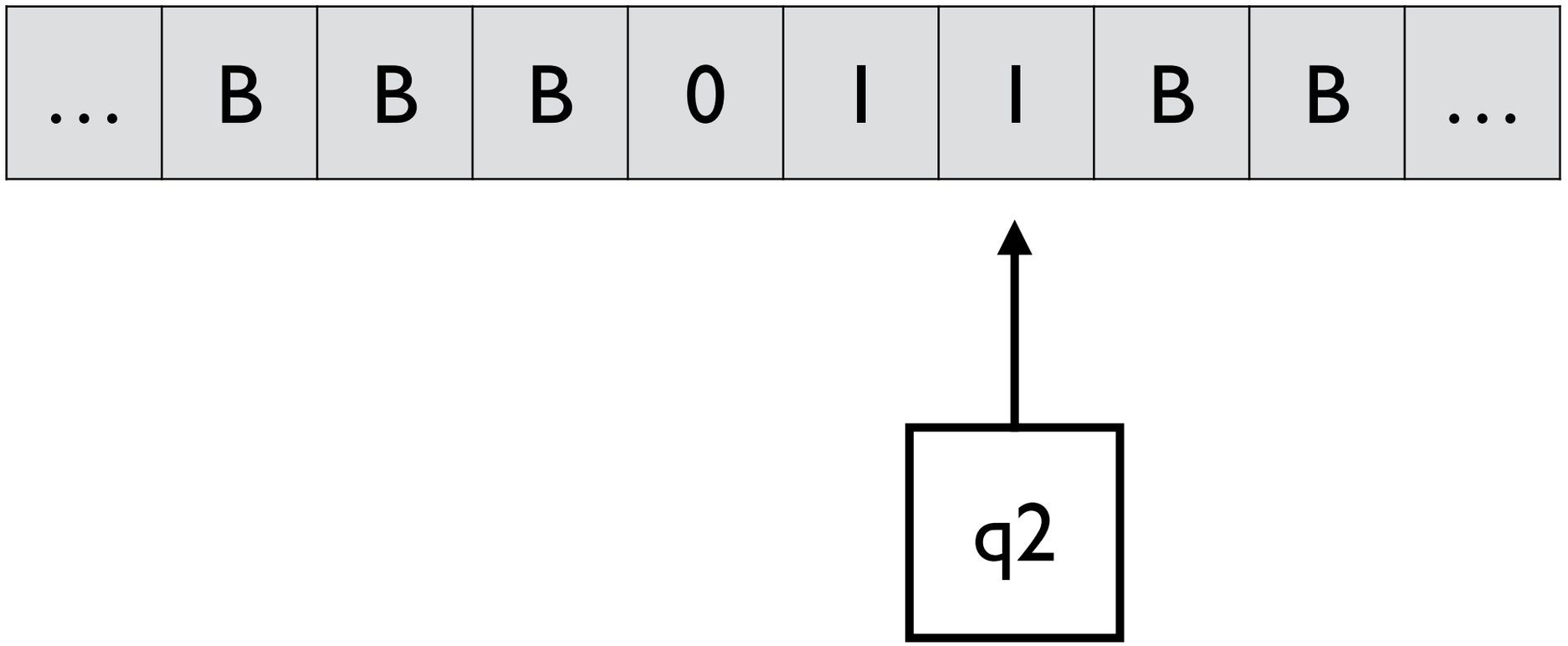
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

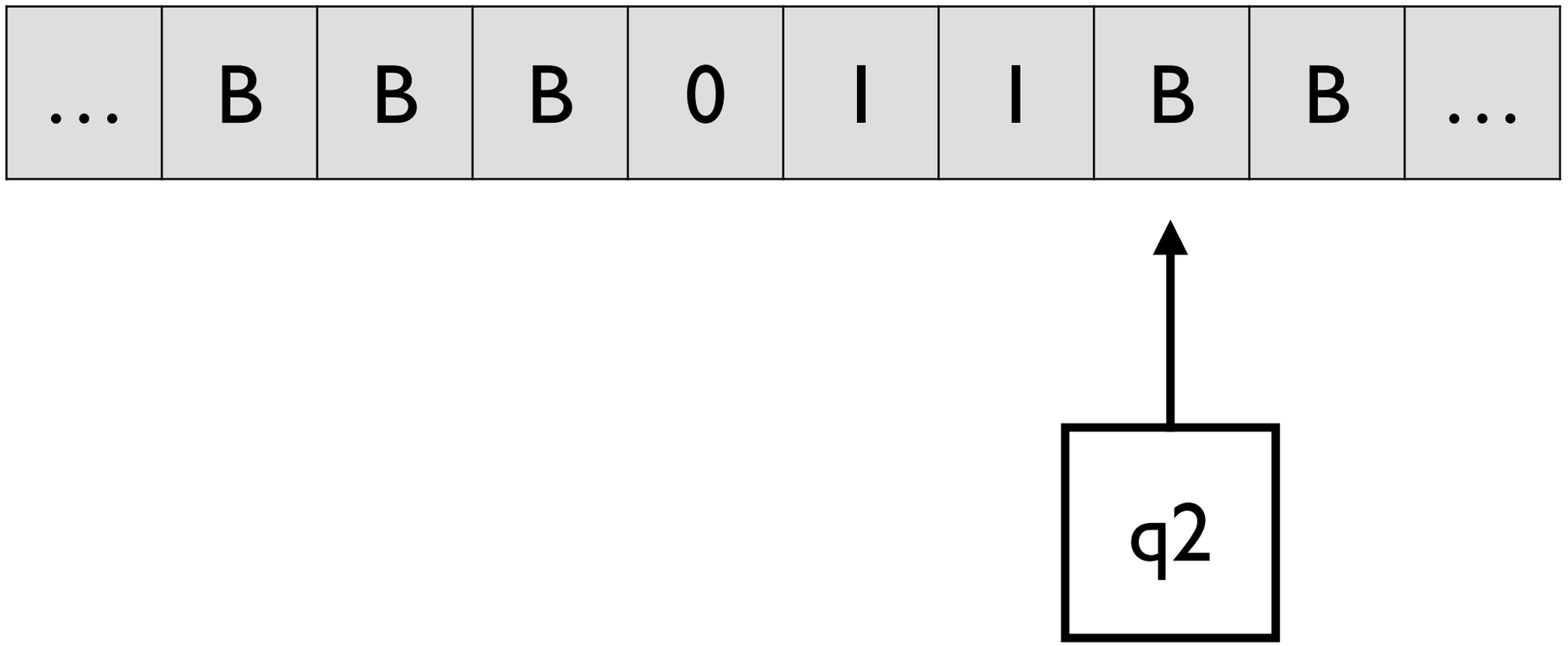


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

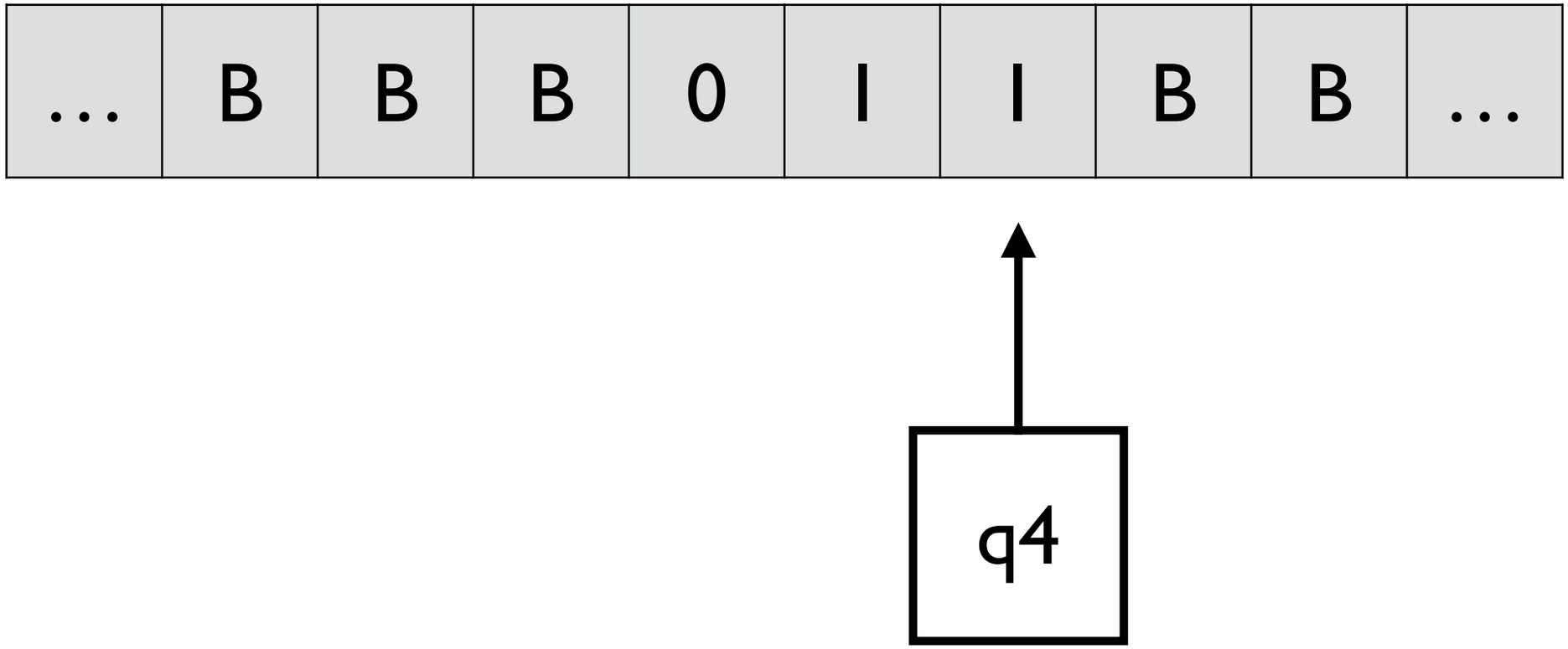




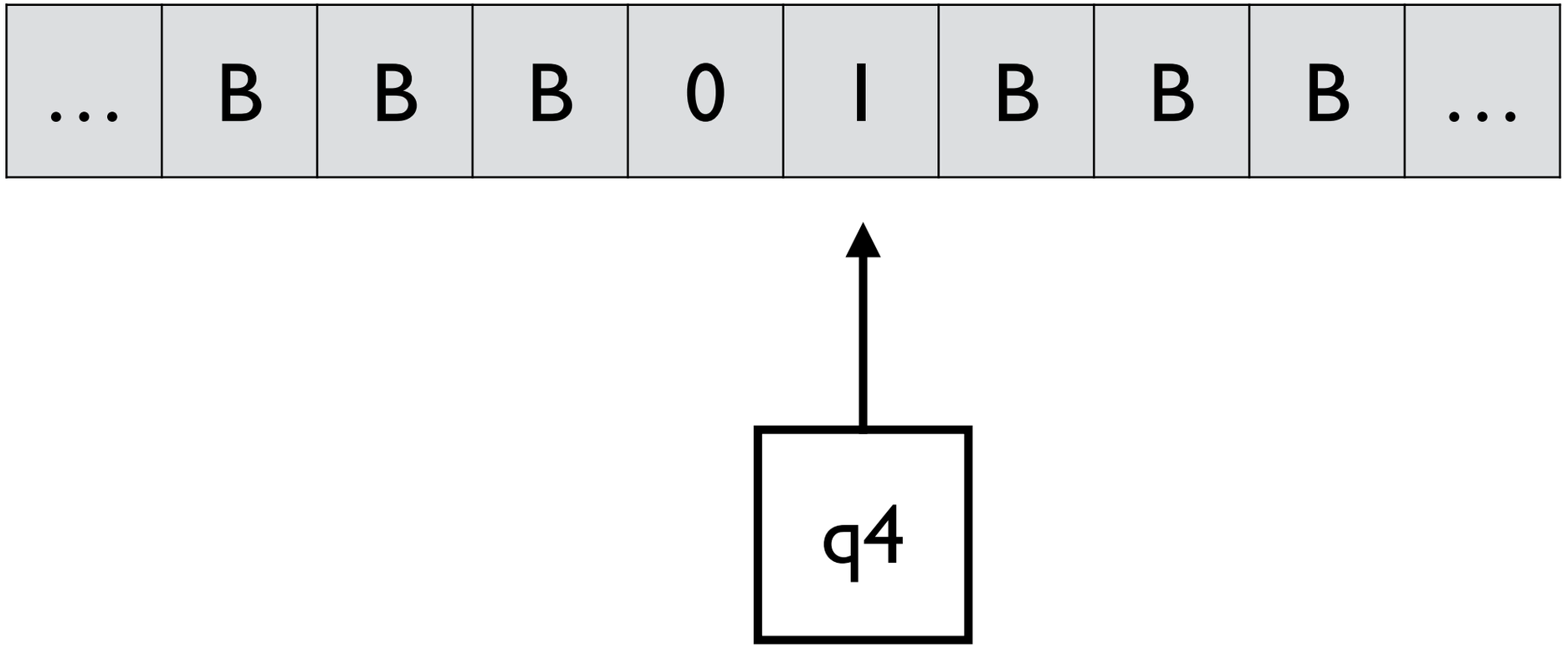
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



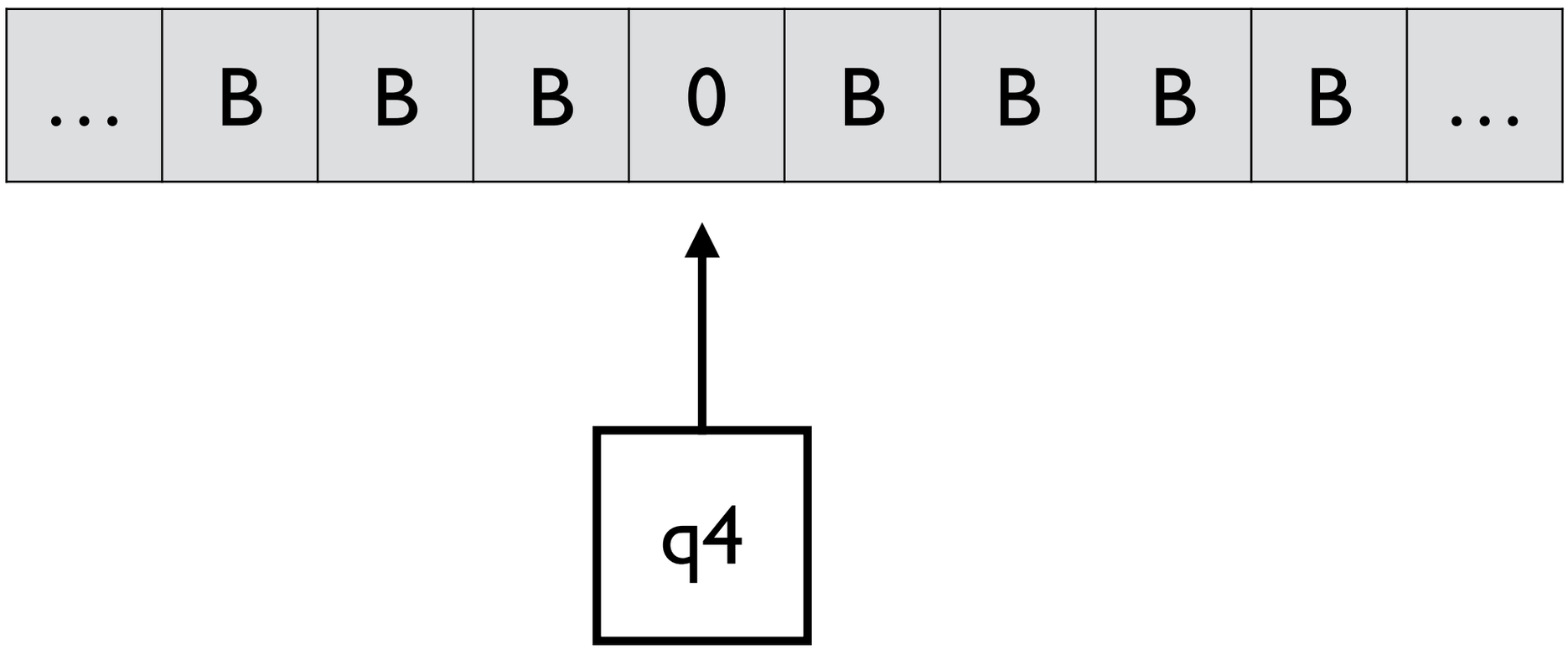
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



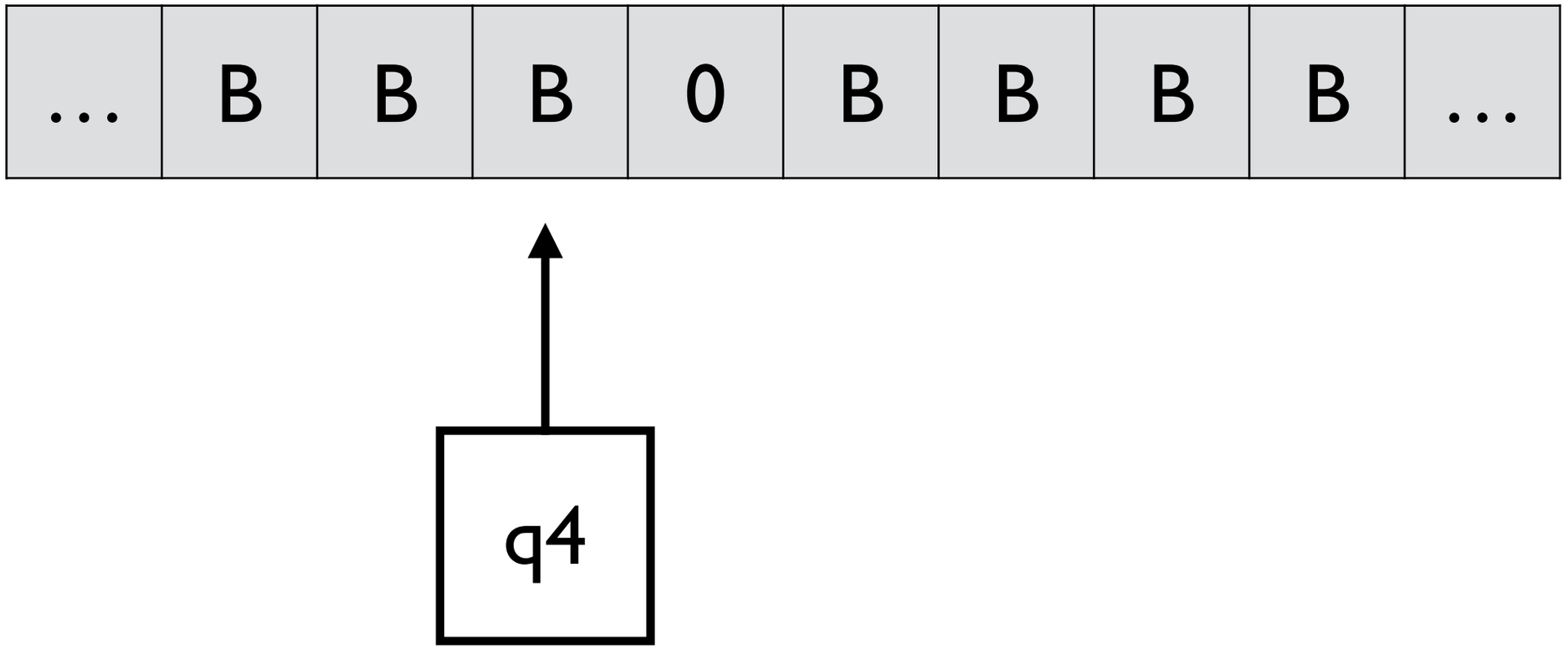
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



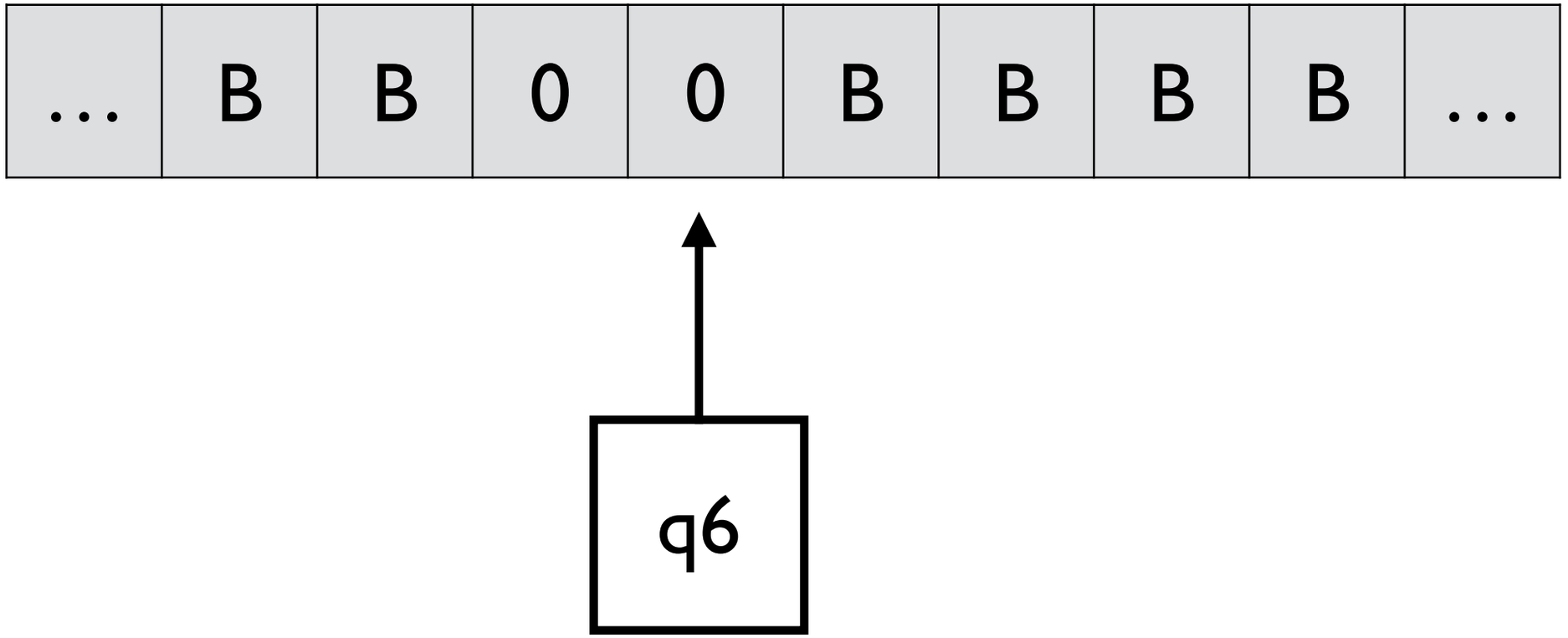
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

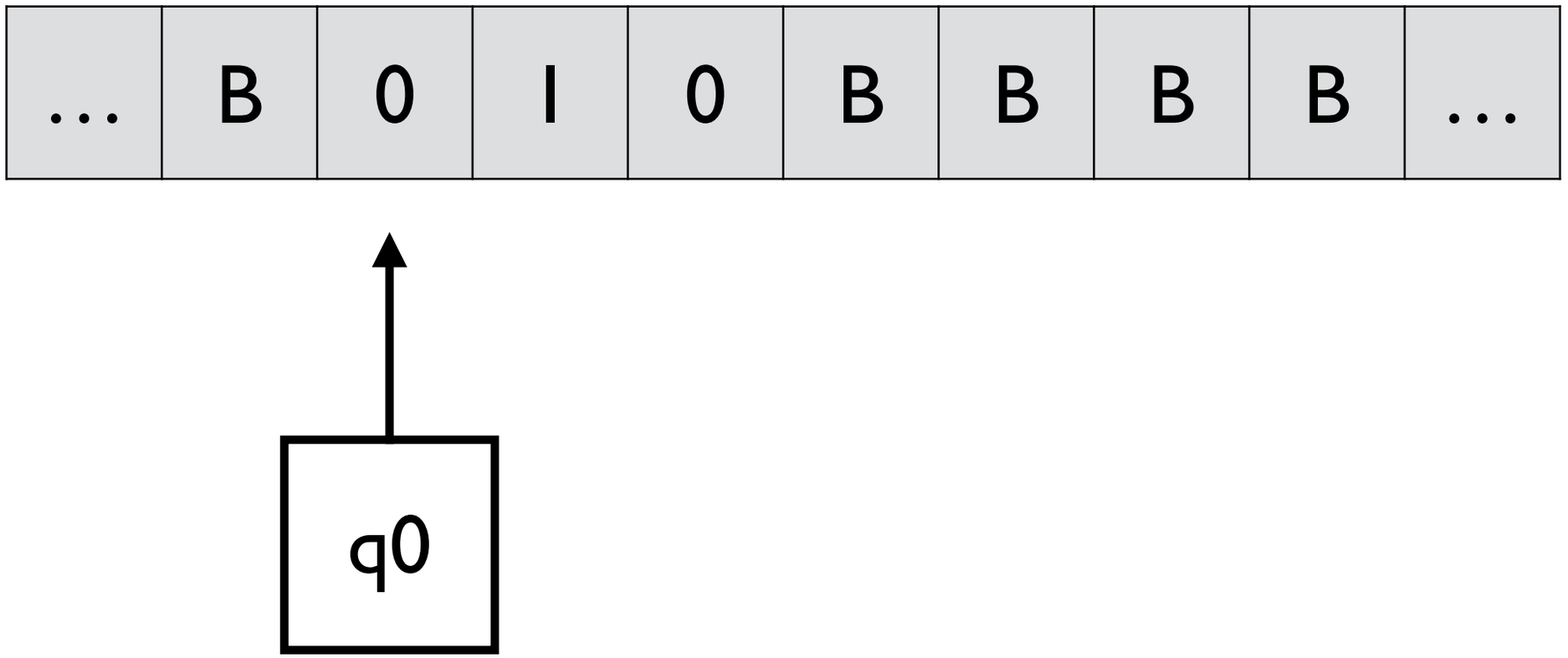


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

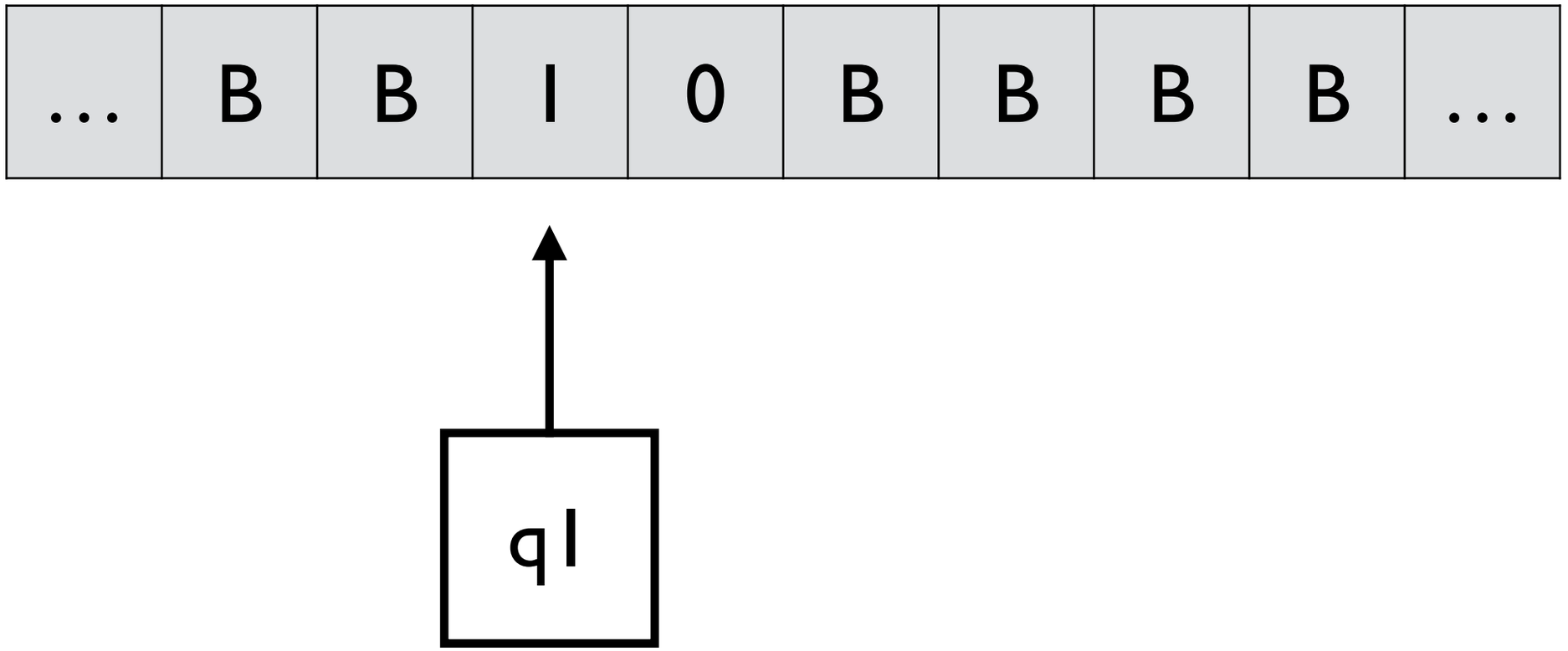


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

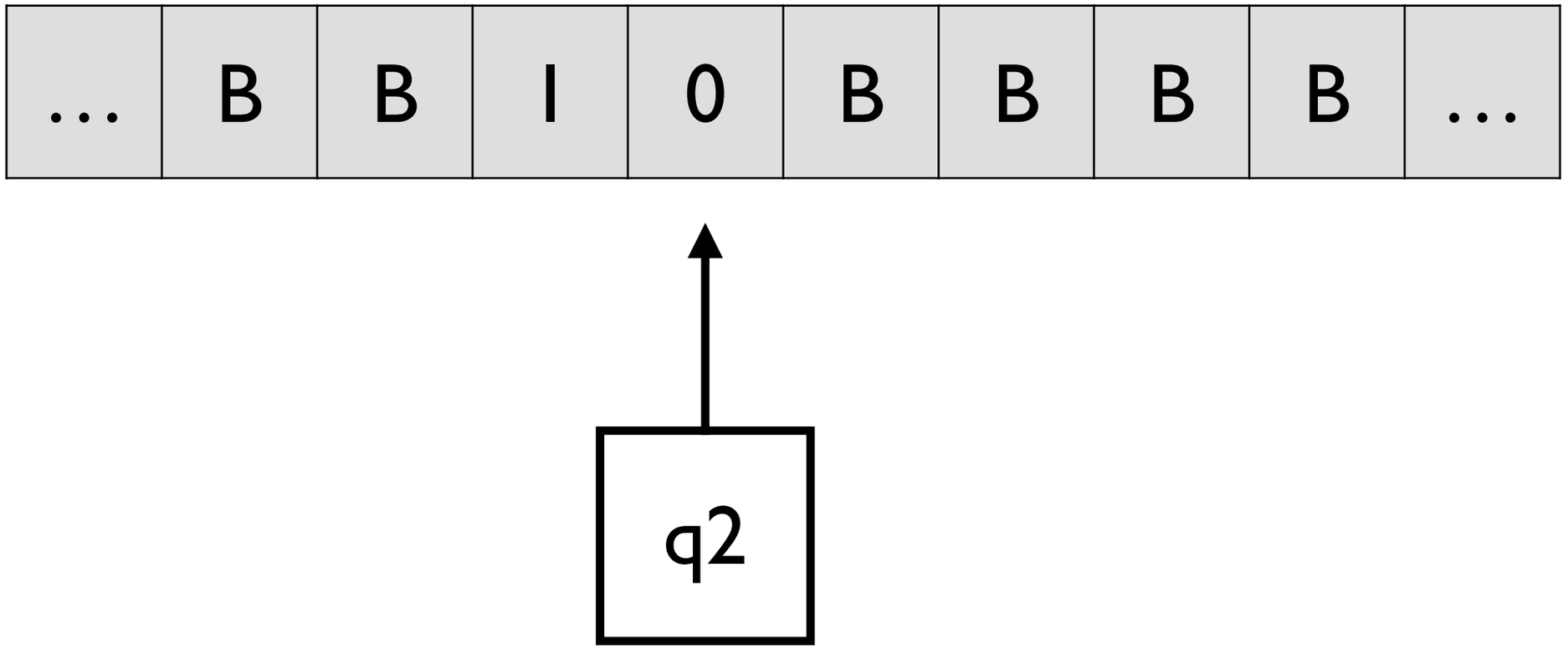
e.g., f(1,1)



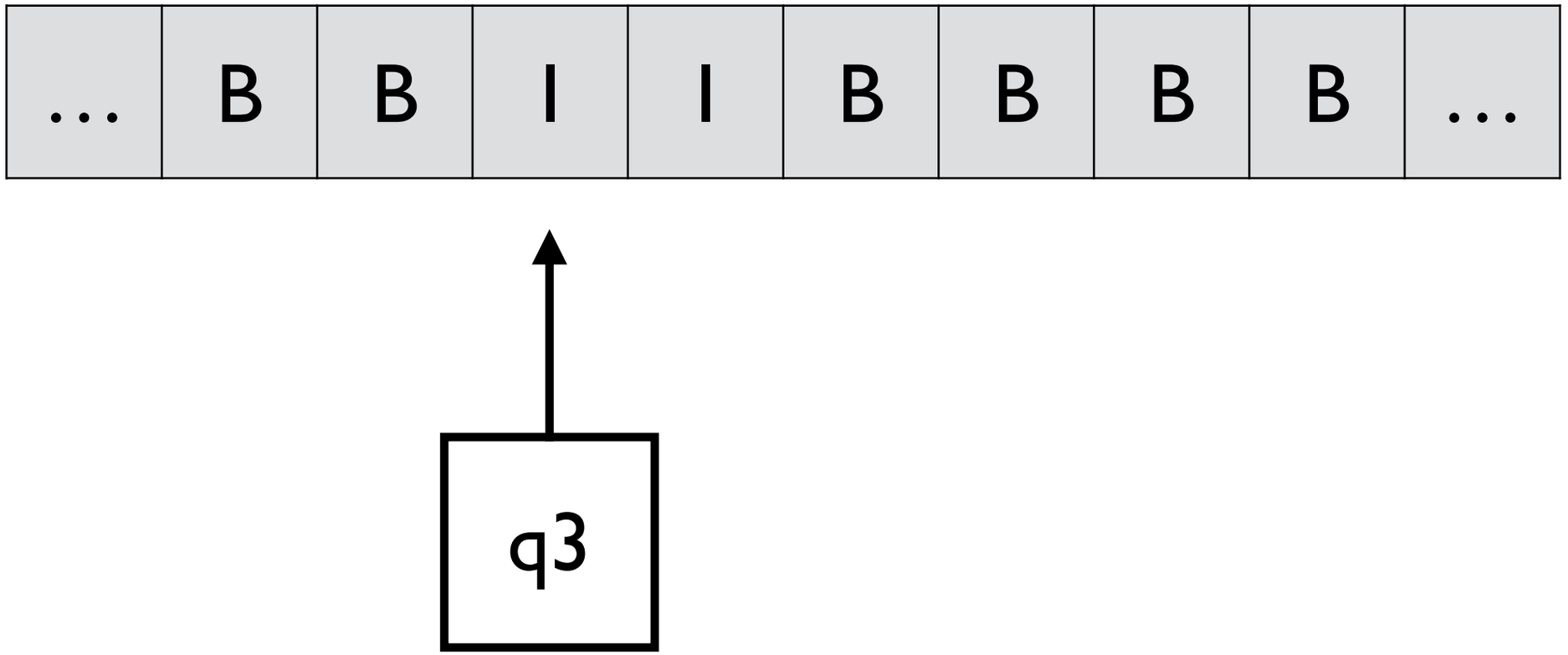
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



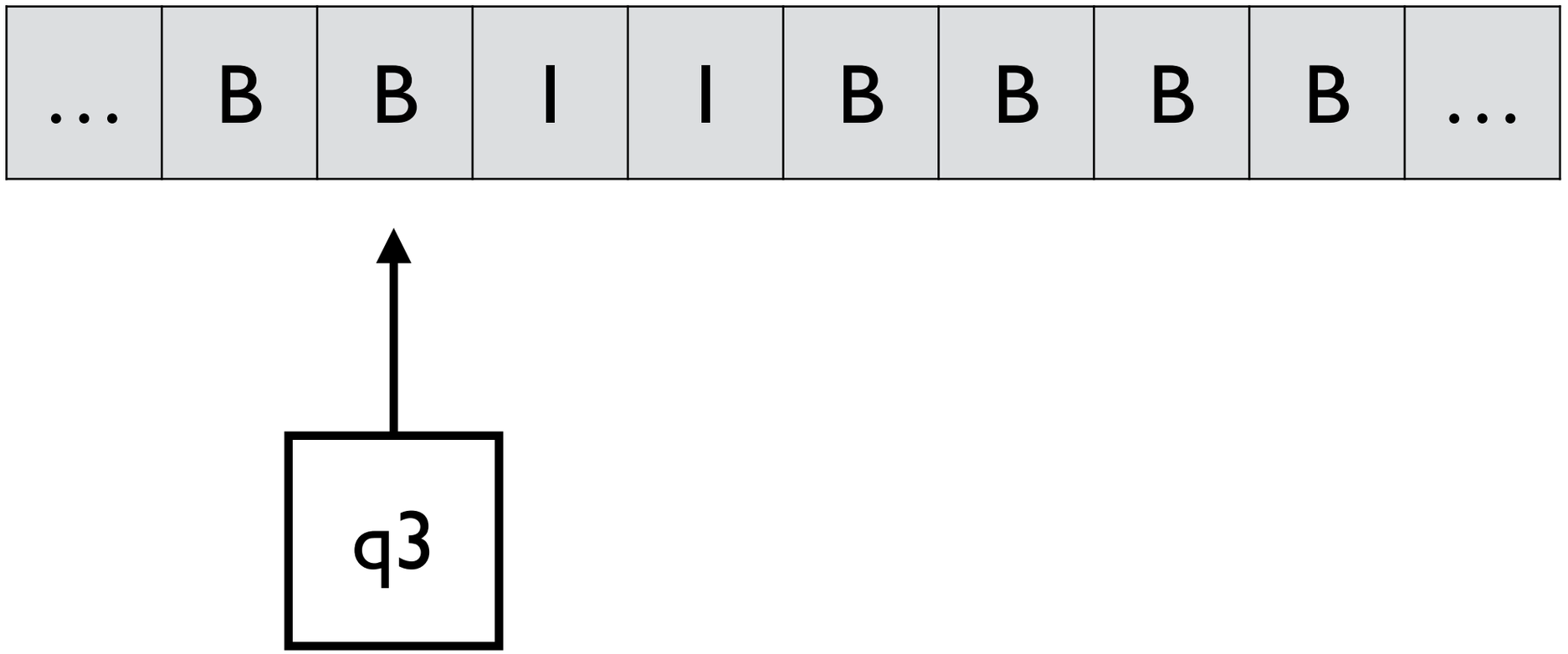
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



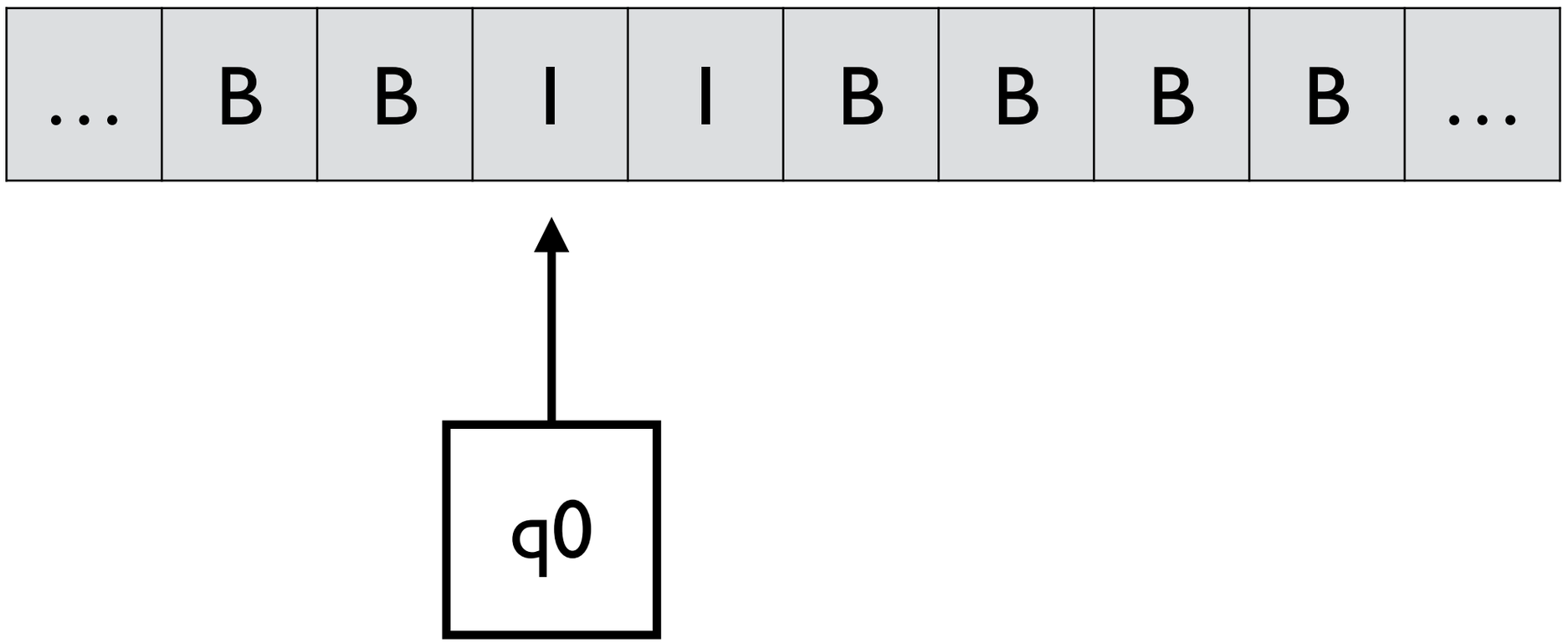
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



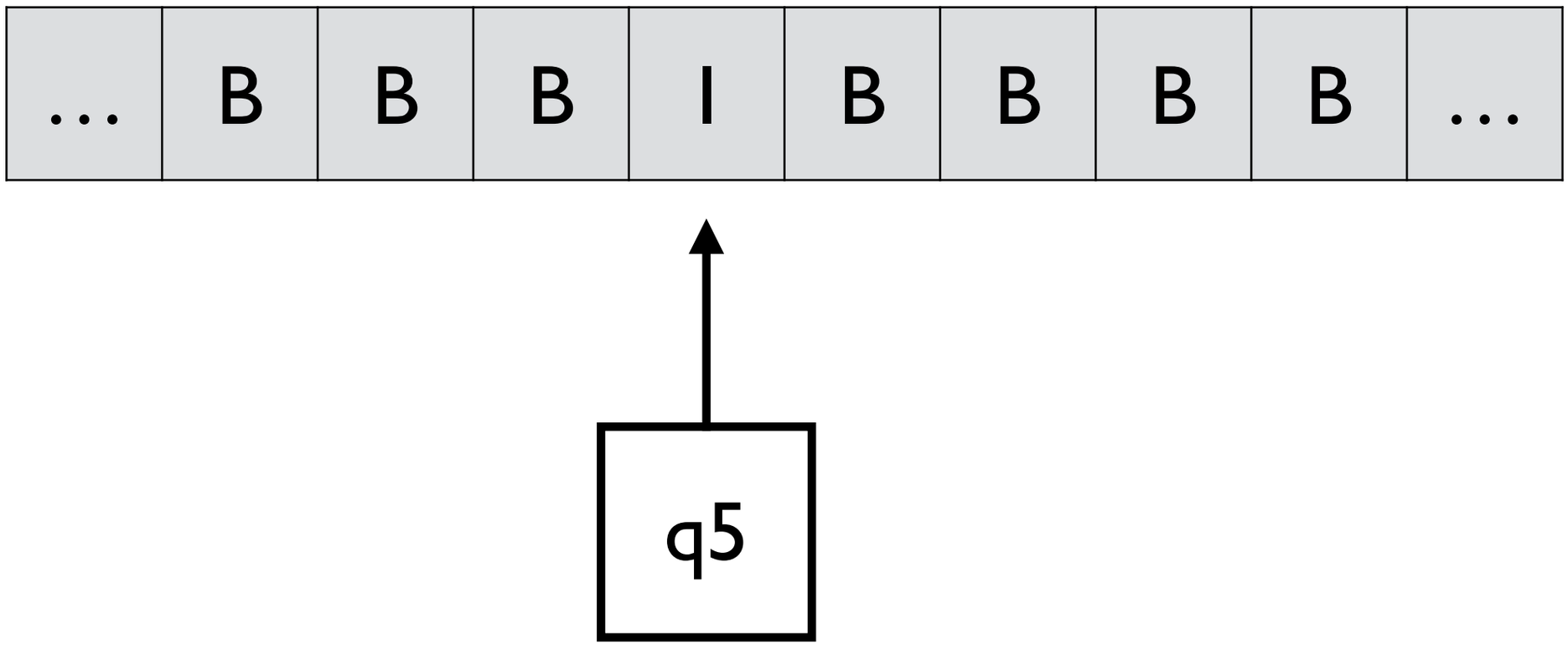
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



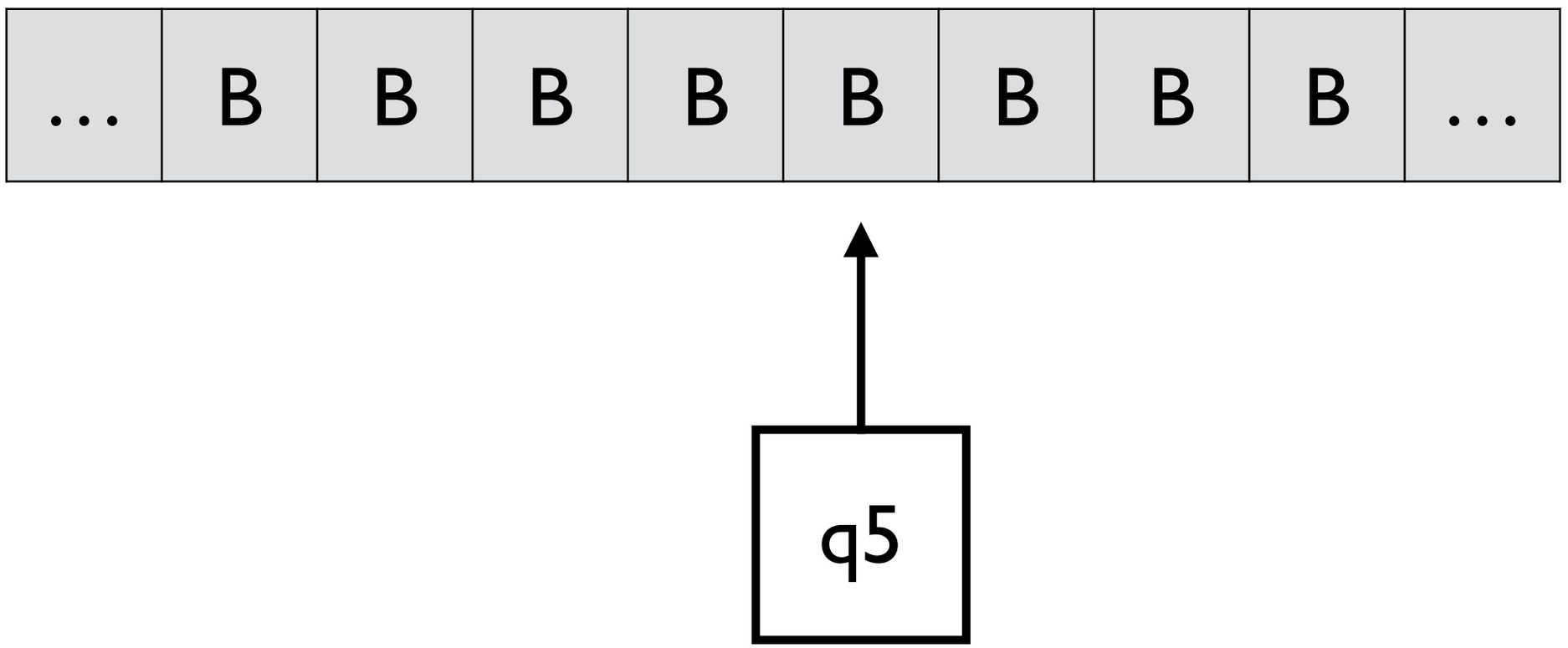
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



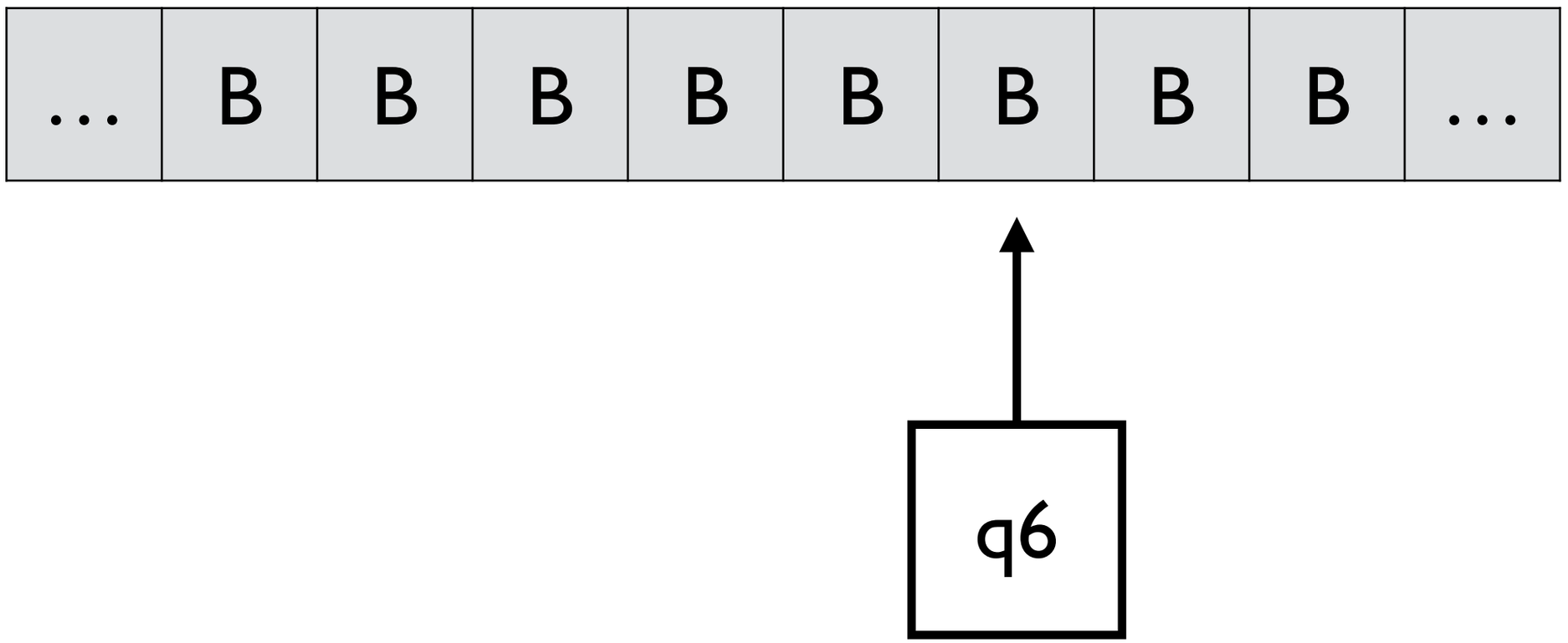
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

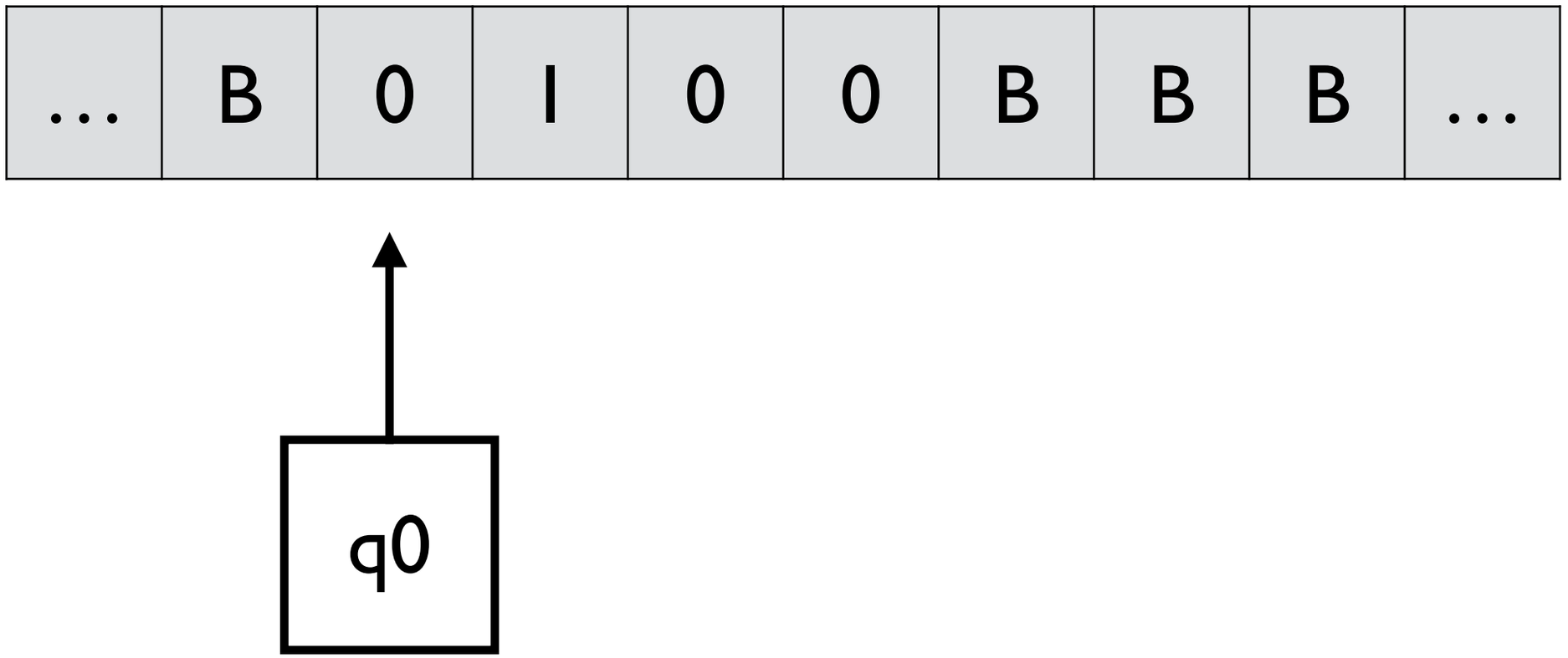


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

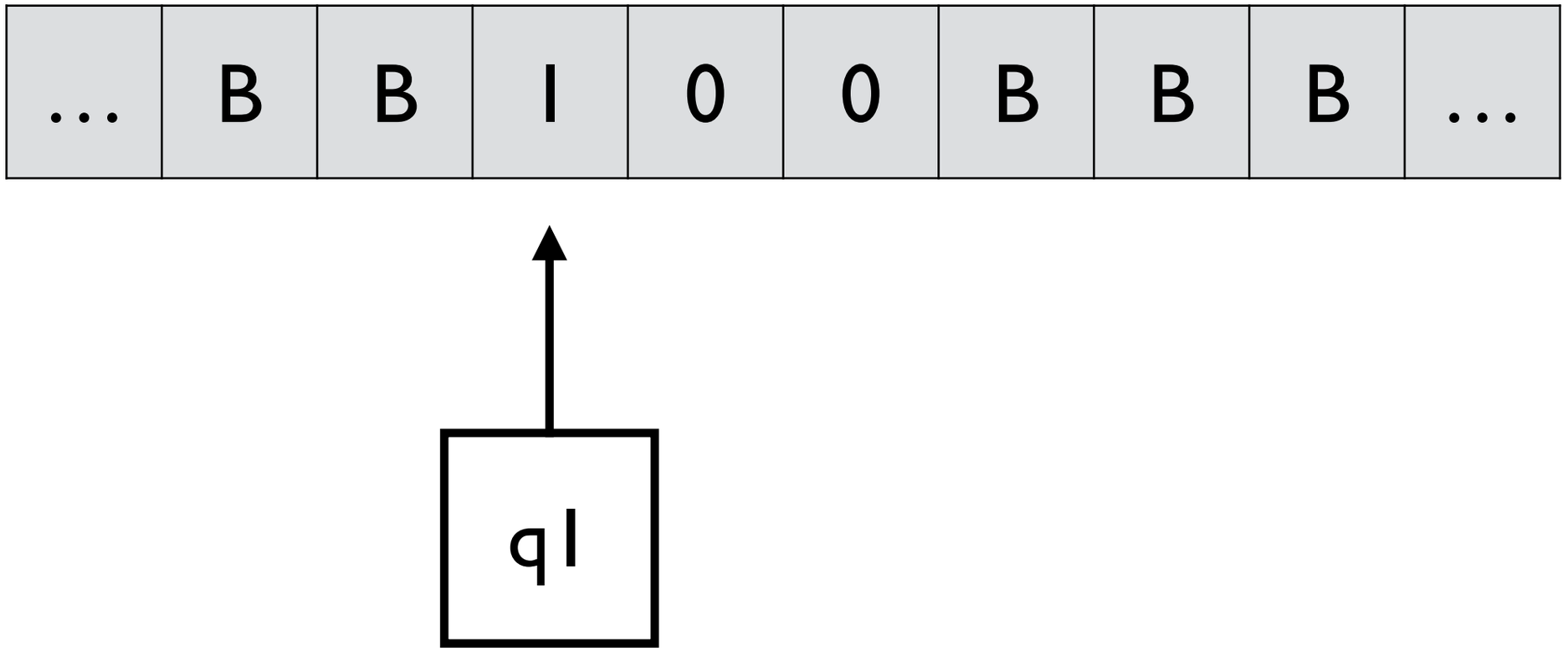


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

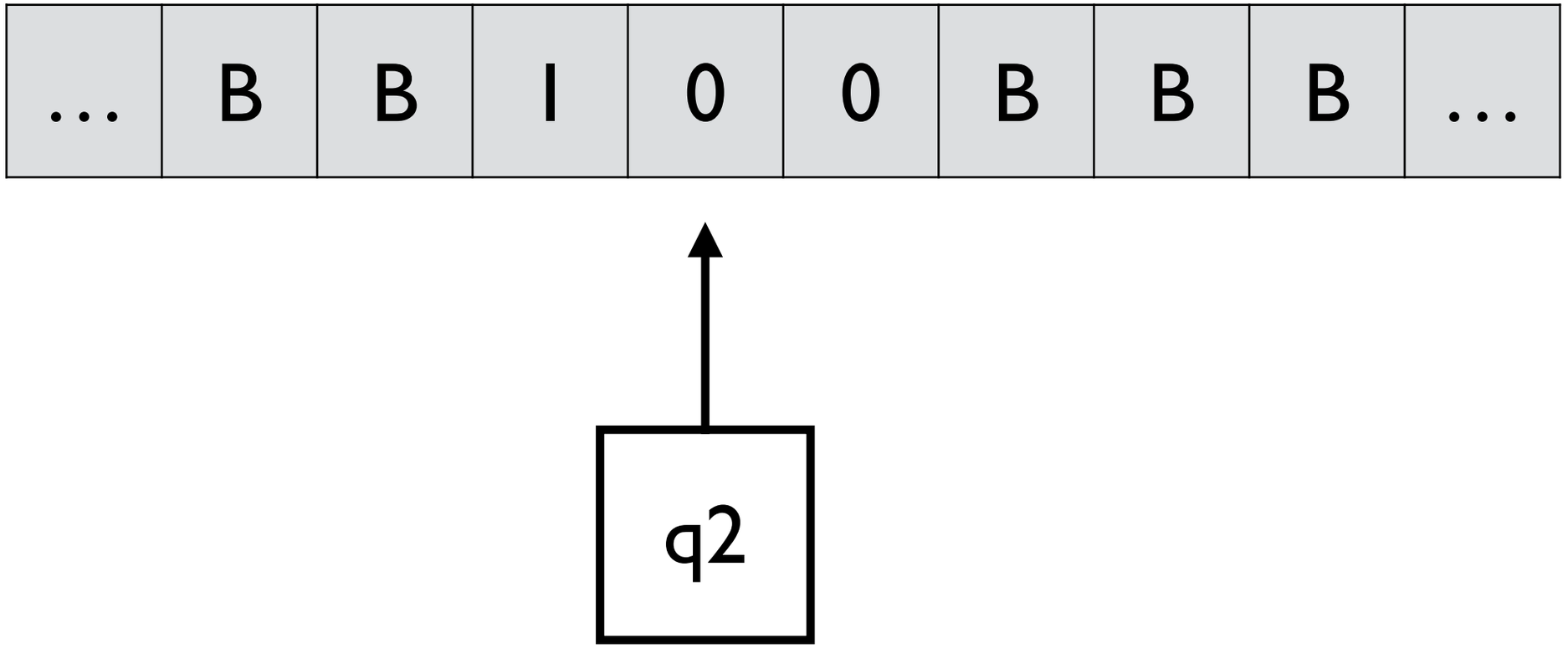
e.g., f(1,2)



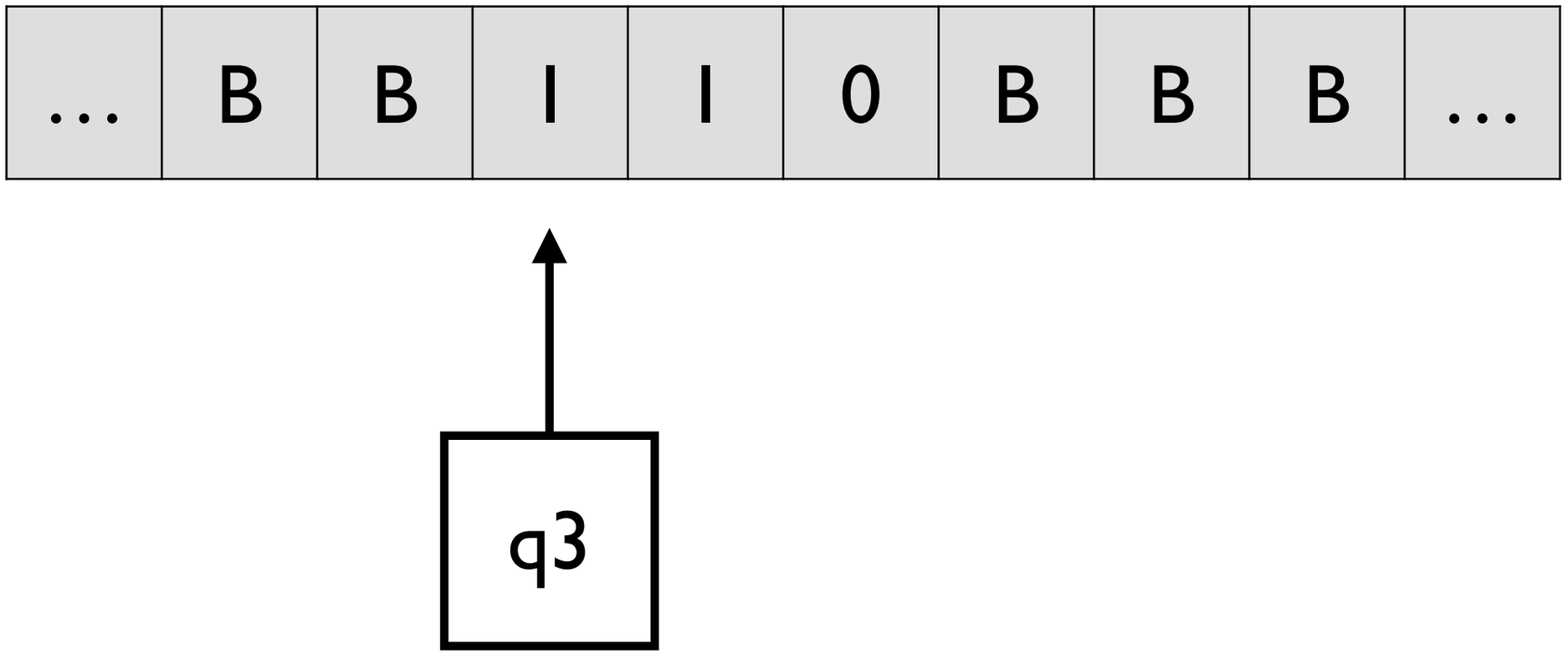
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



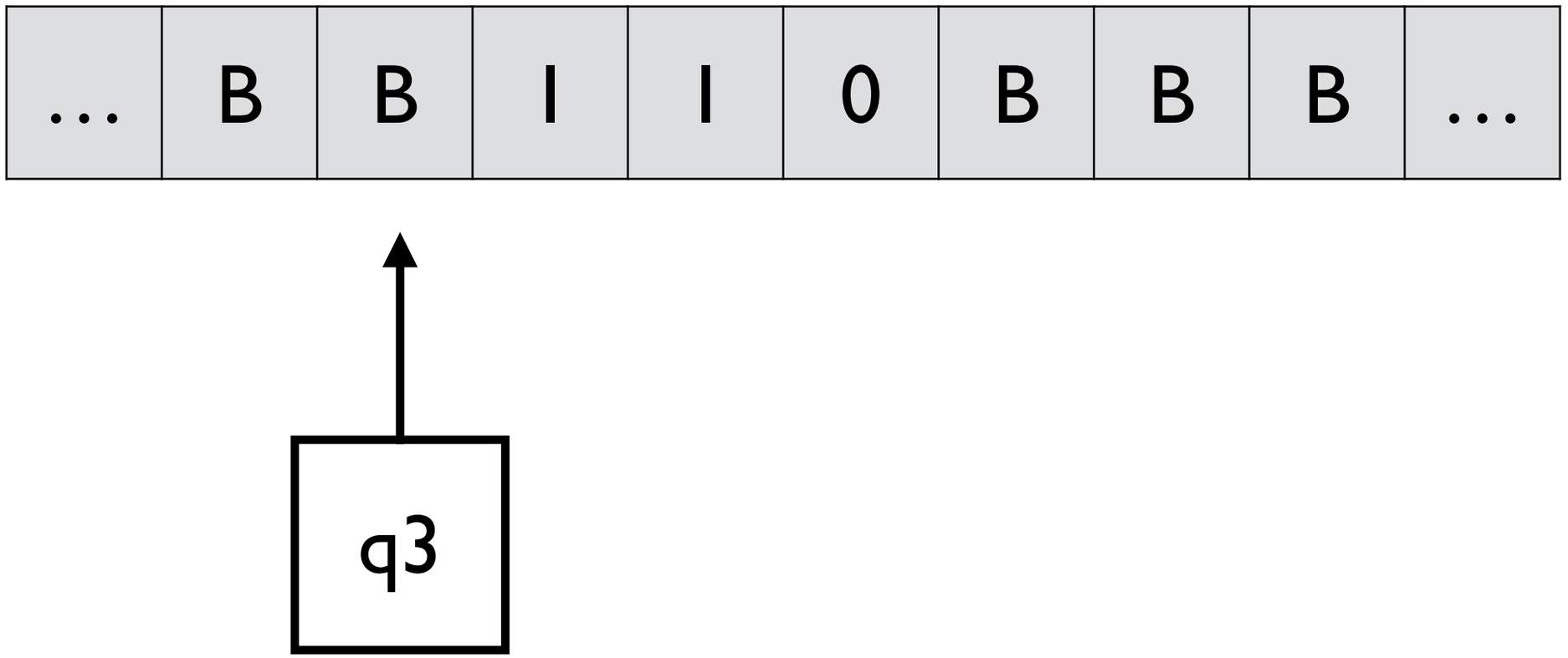
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



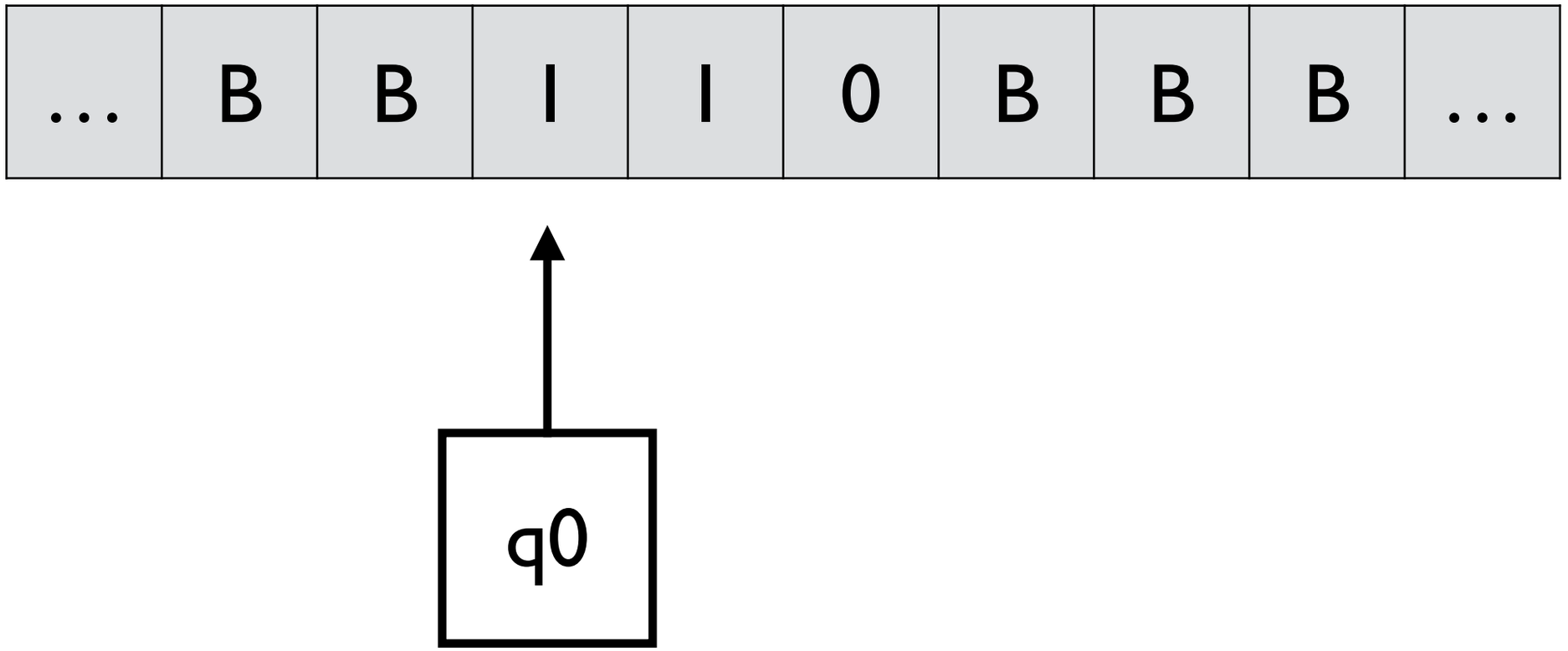
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



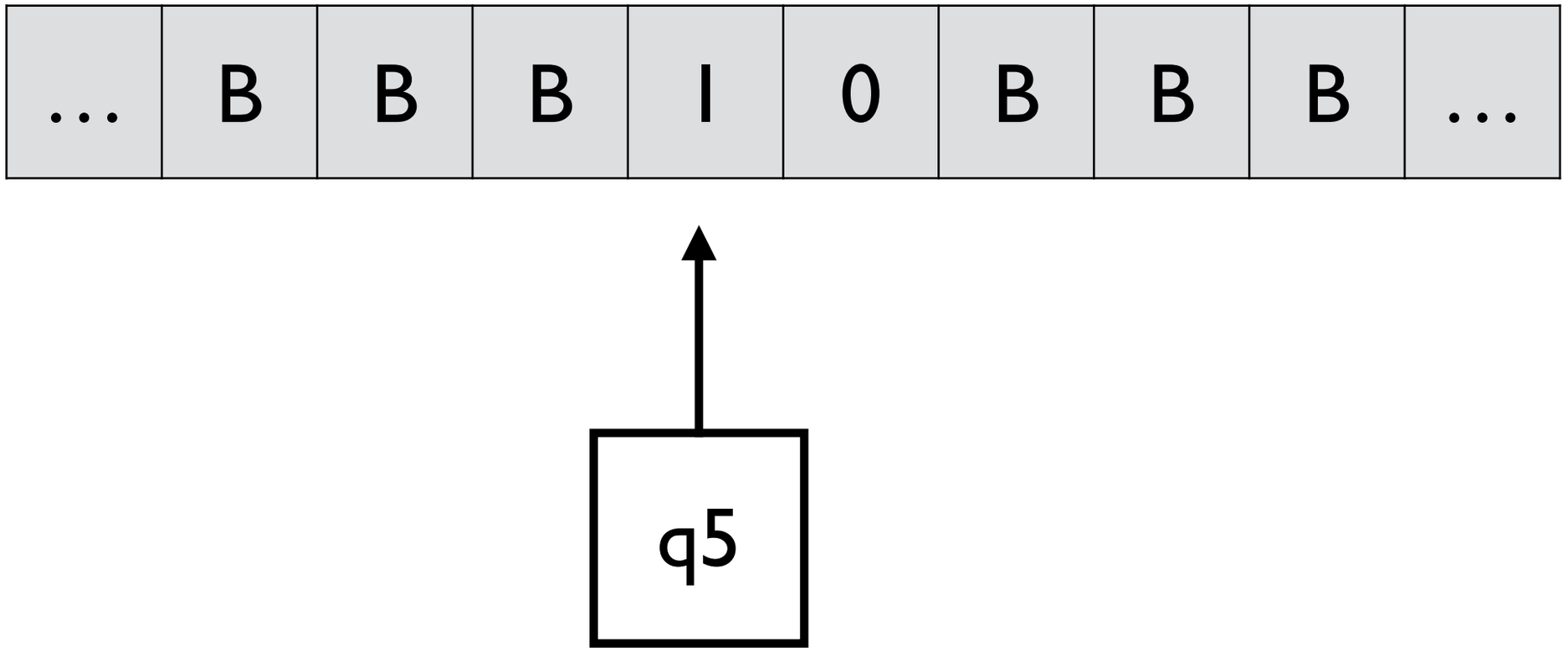
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



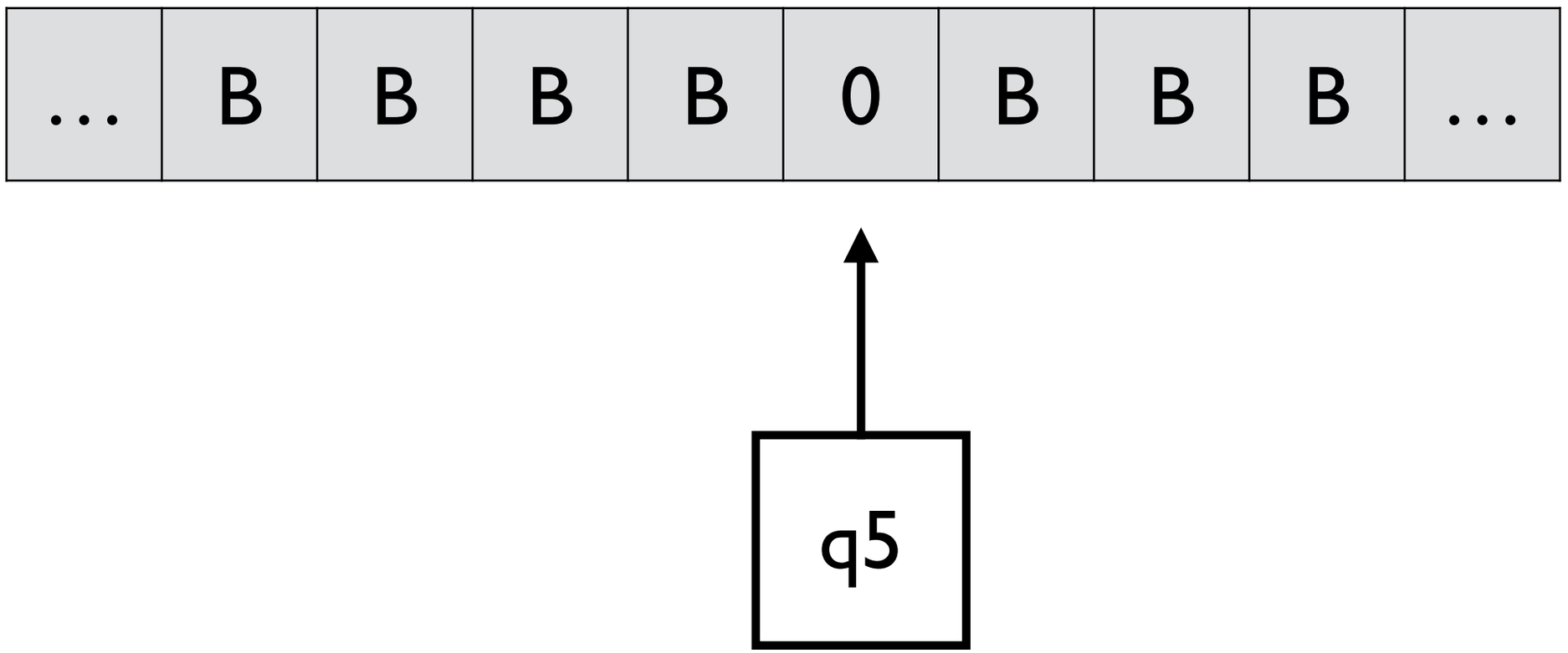
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



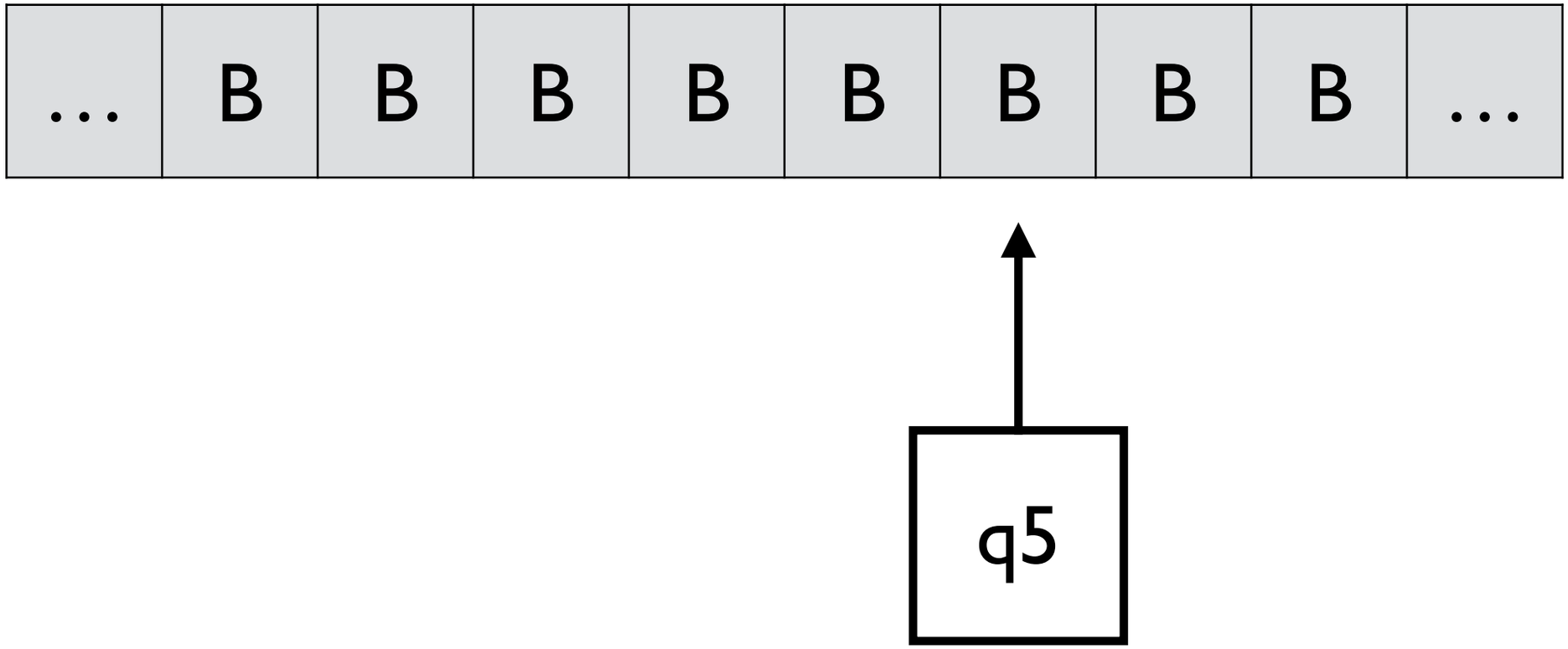
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



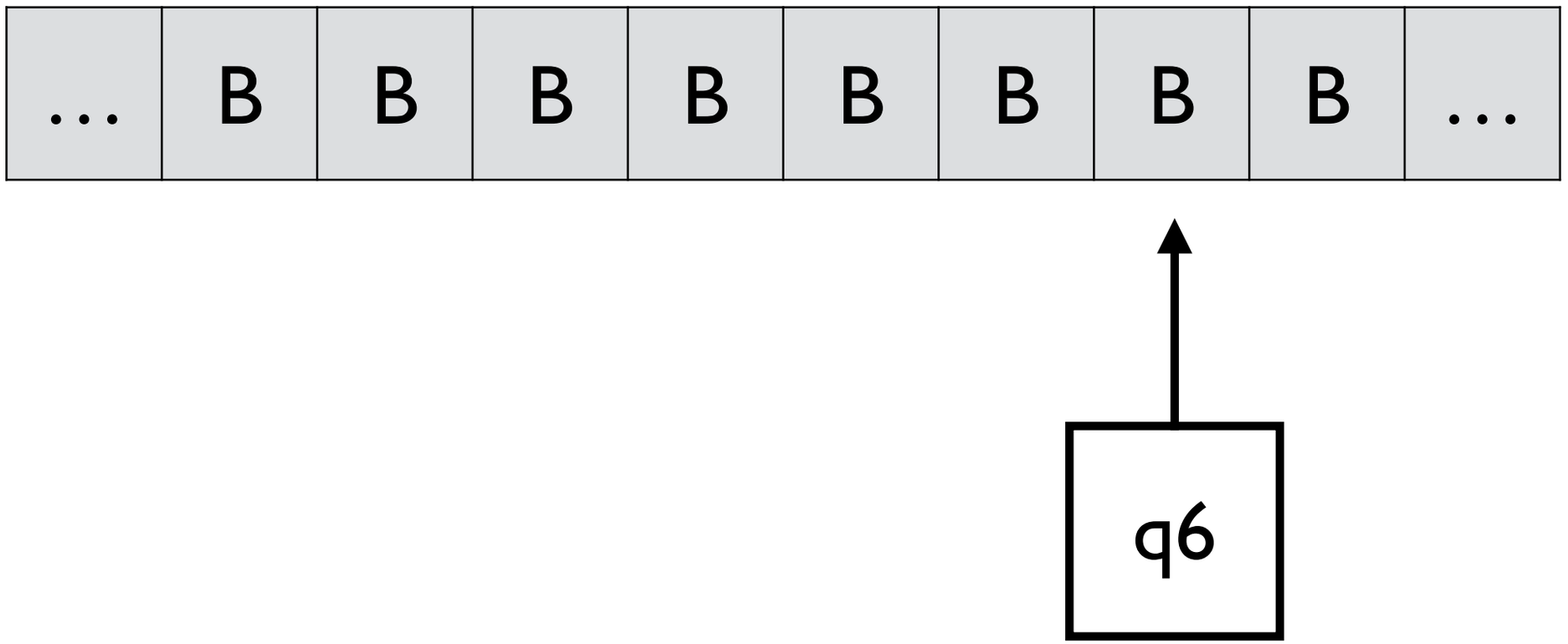
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



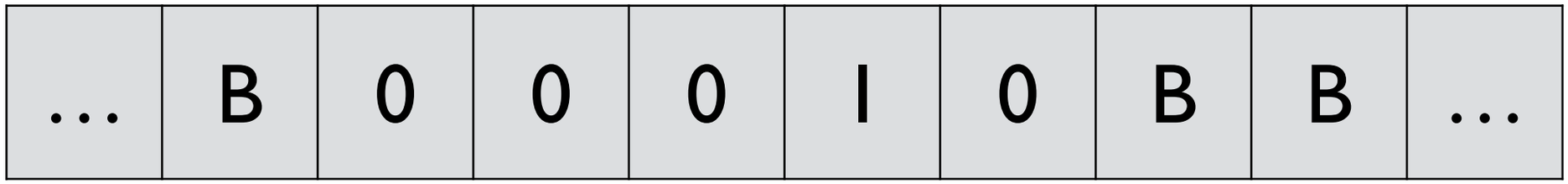
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

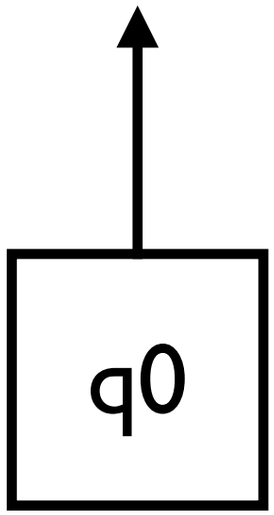


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

Example, revisited

e.g., f(3,2)

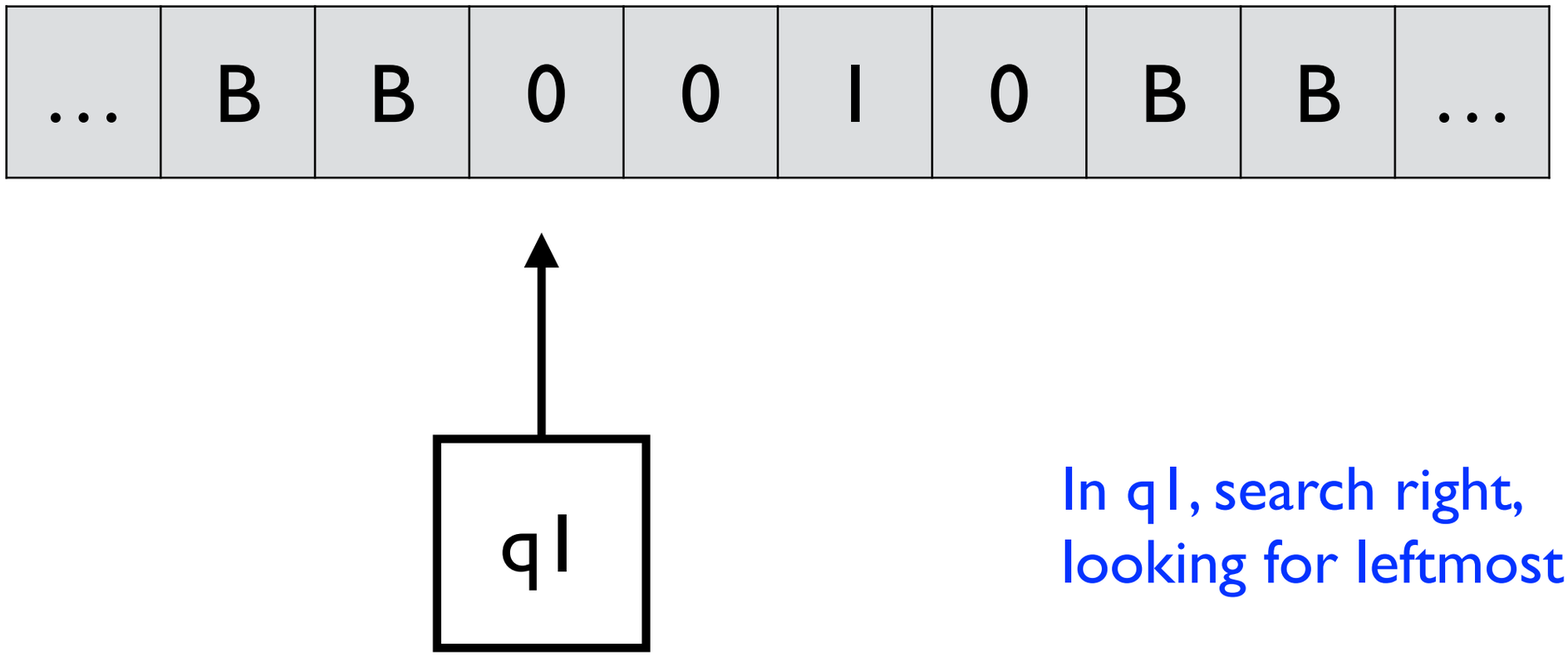




Scanned 0 in q0, the cycle must repeat:

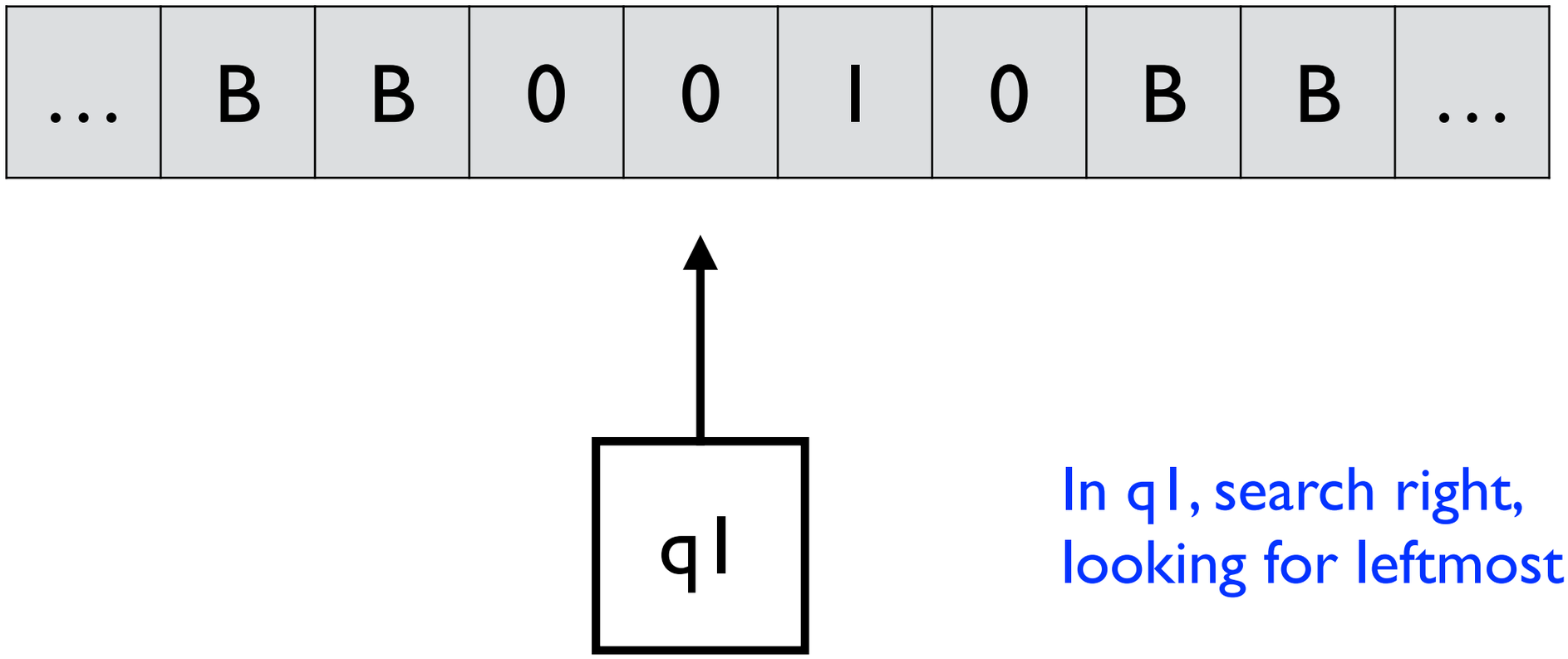
1. replace 0 by B
2. move right
3. enter q1

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



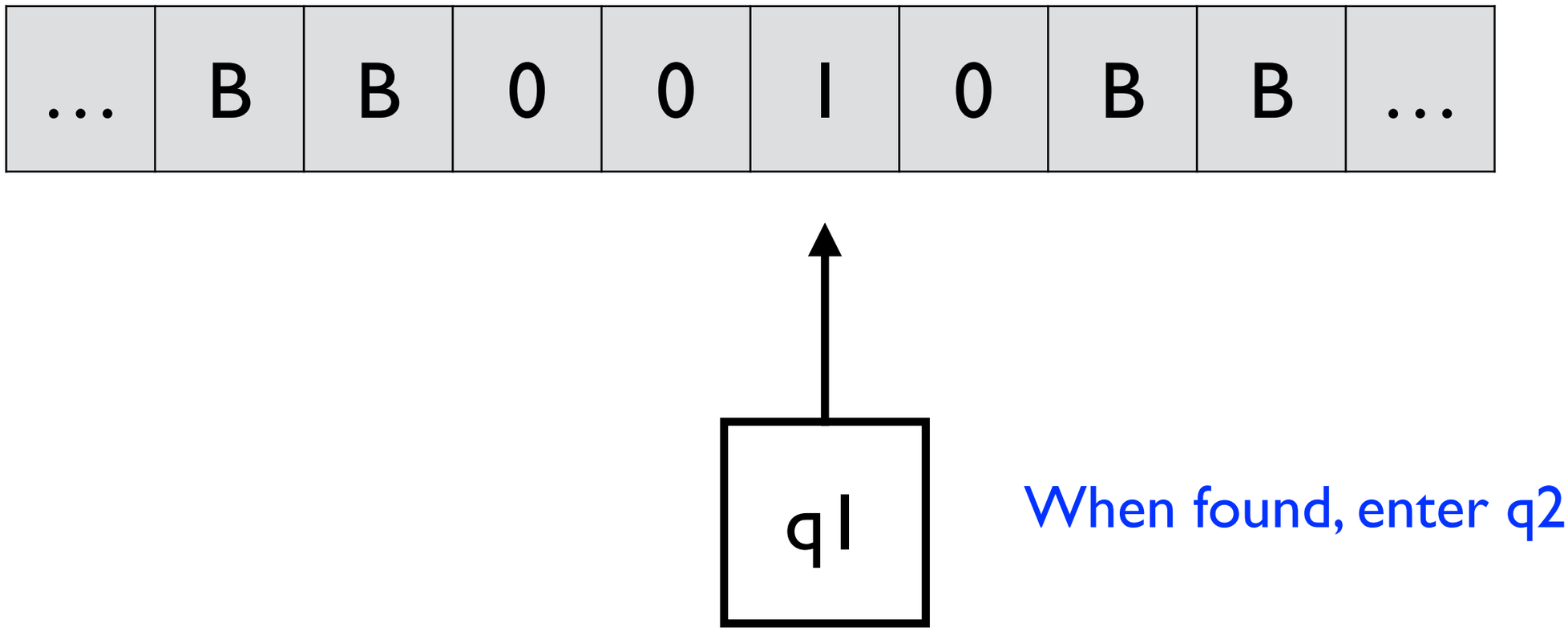
In q1, search right,
looking for leftmost 1

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

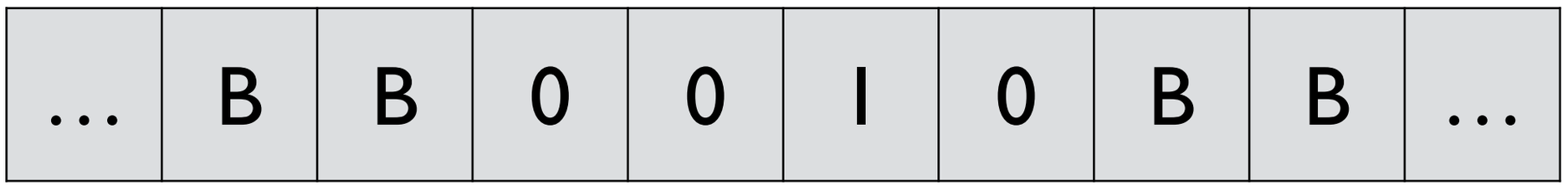


In q1, search right,
looking for leftmost 1

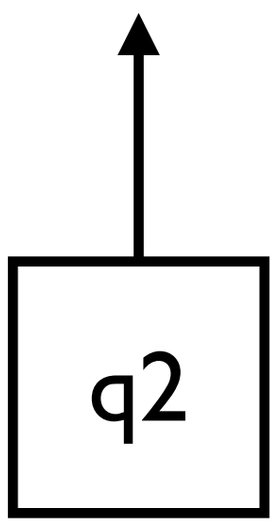
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



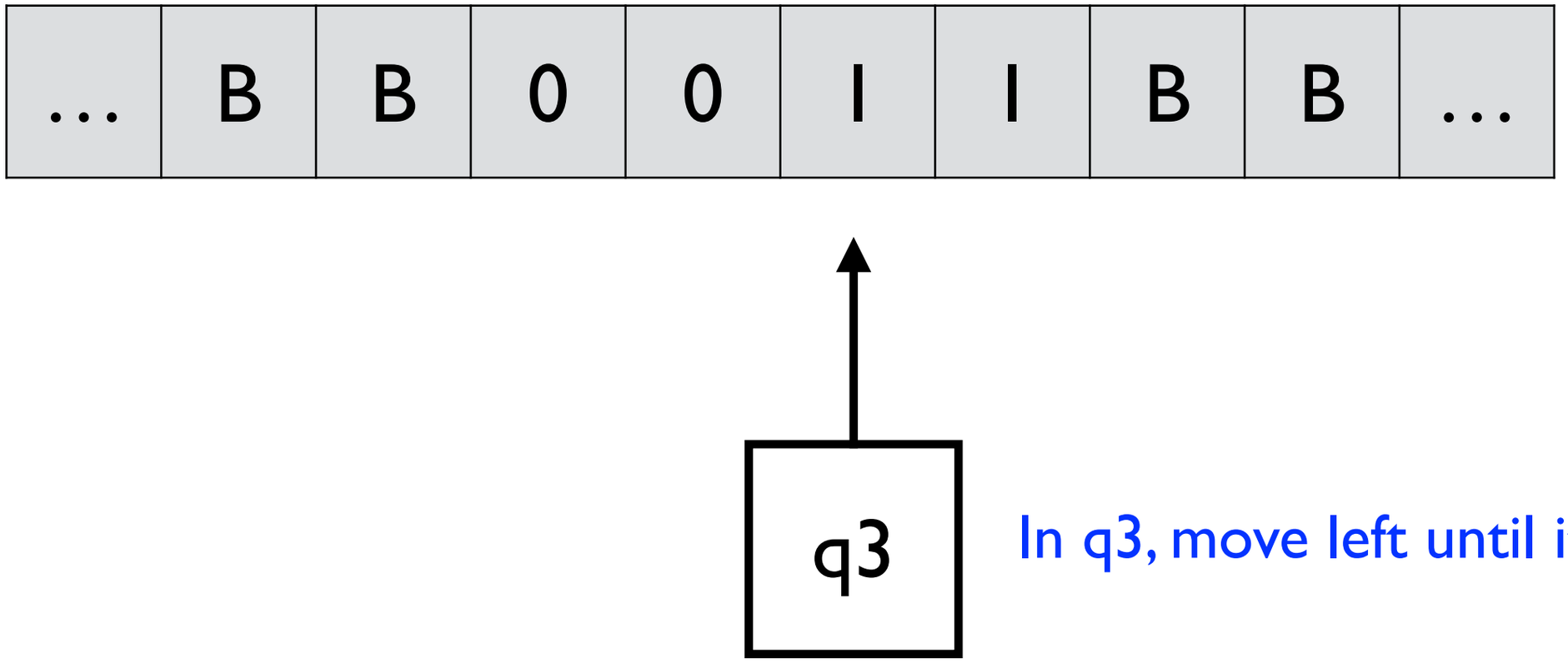
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



- In q2, move right until it finds 0
- When found, change it by 1
- enter q3

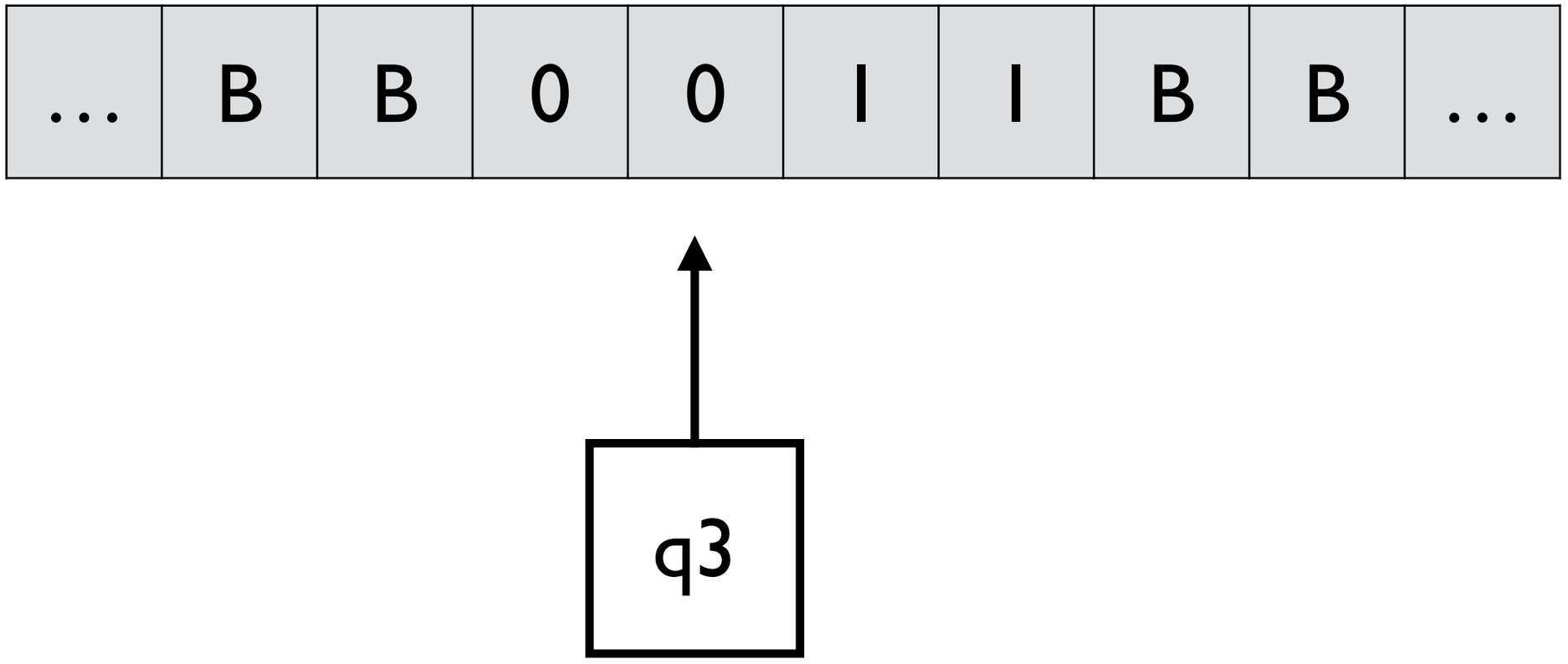


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

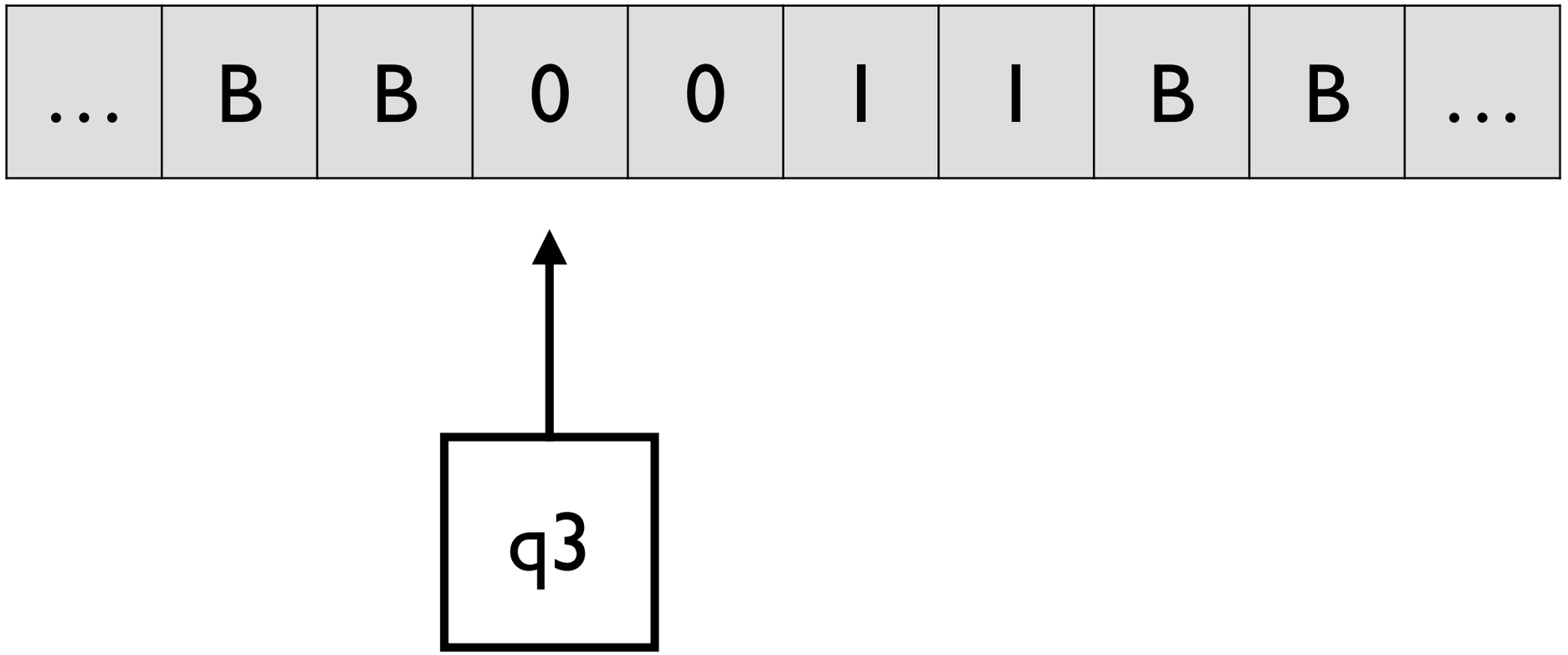


In q3, move left until it find B

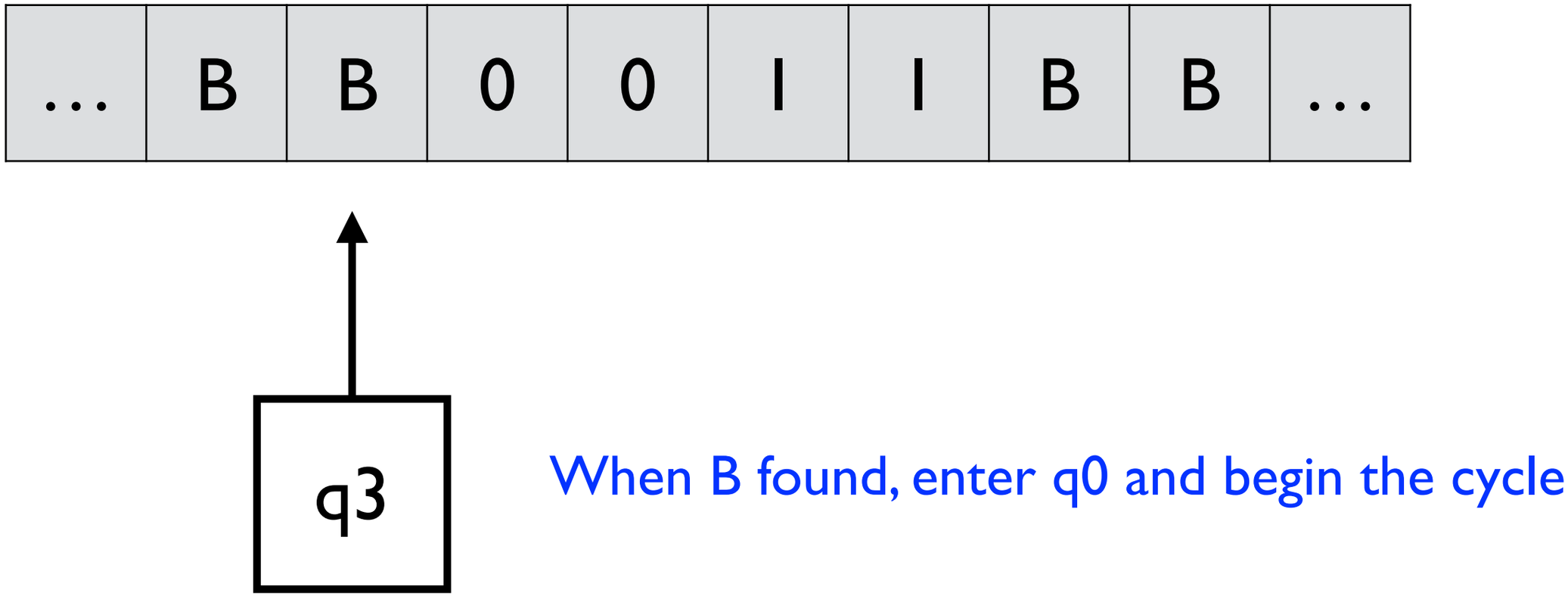
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

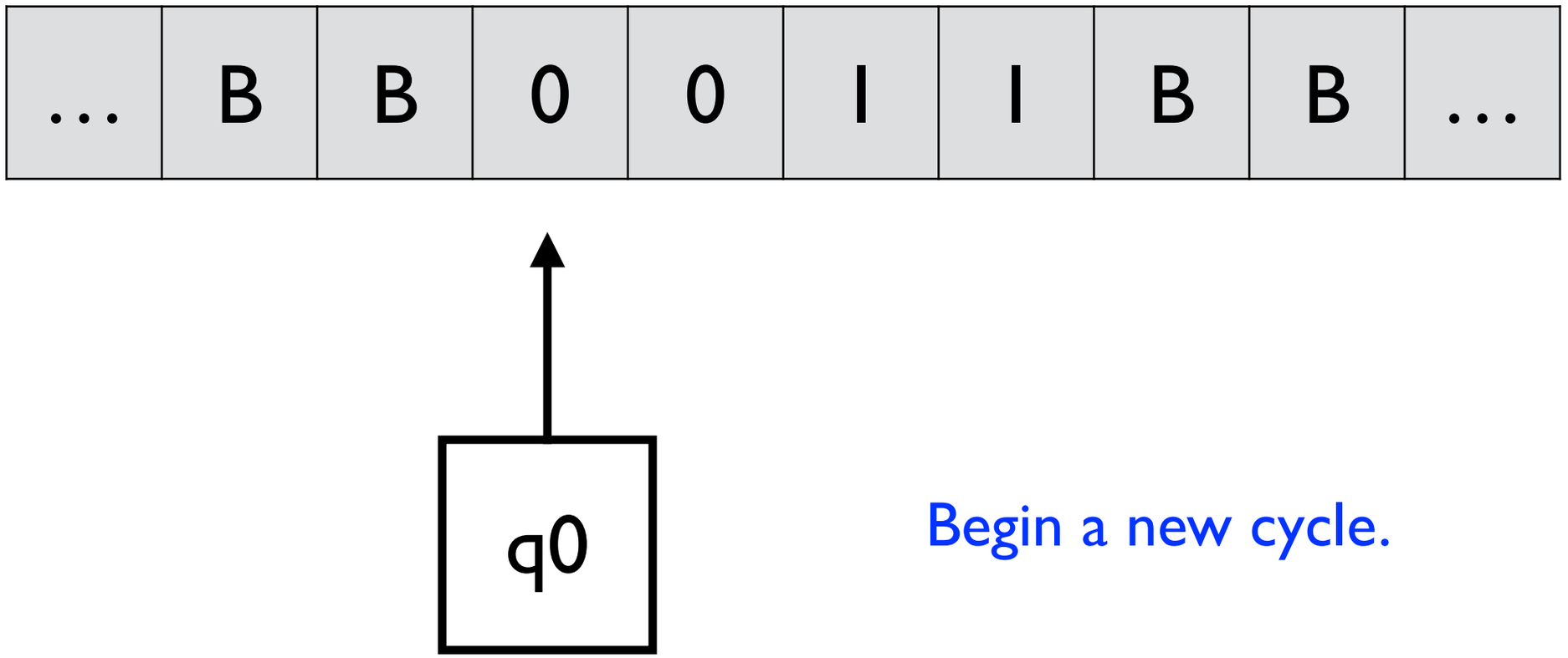


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



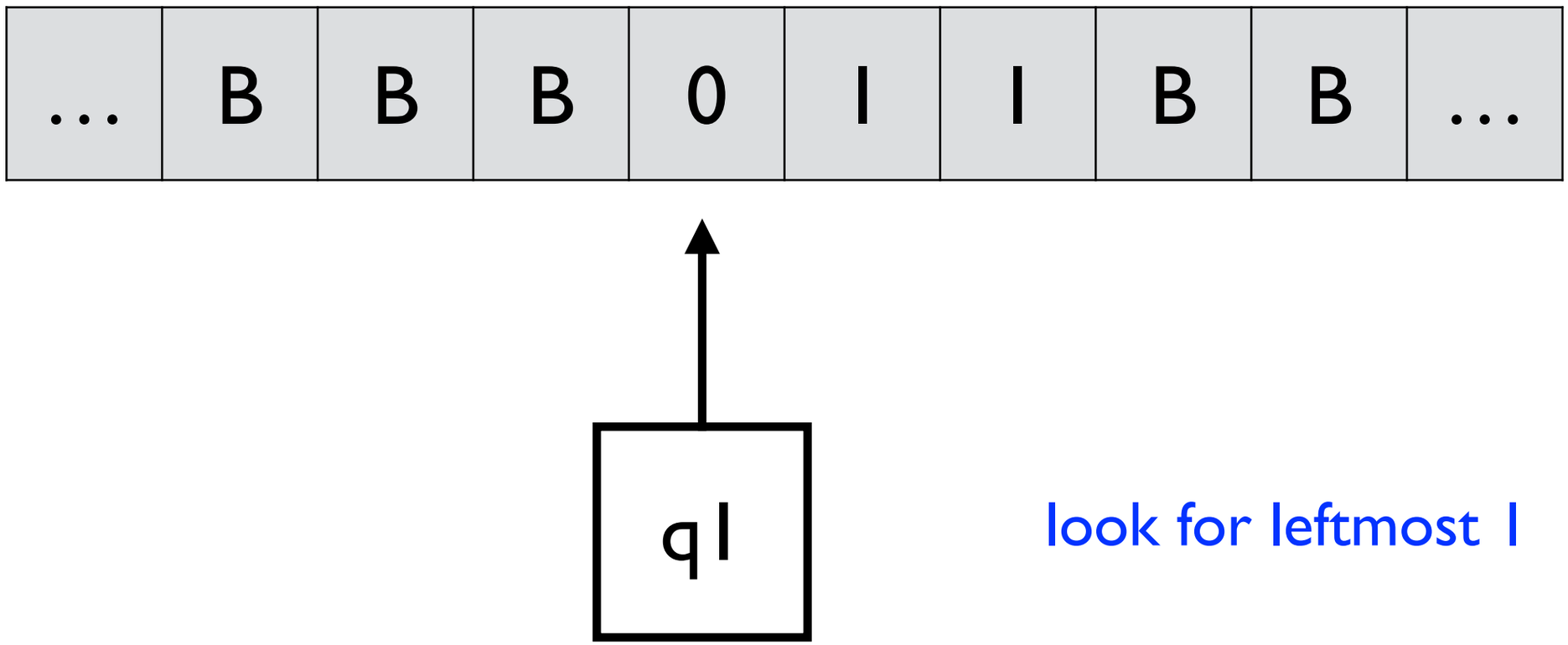
When B found, enter q0 and begin the cycle

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

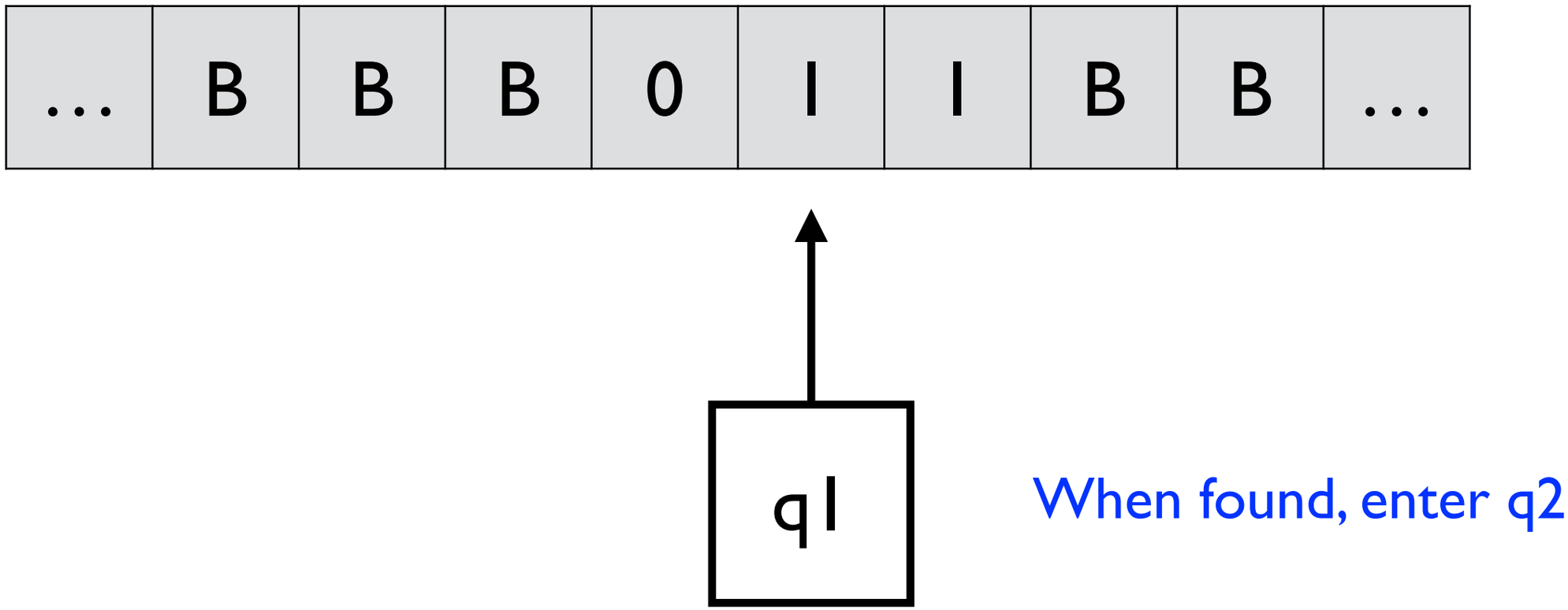


Begin a new cycle.

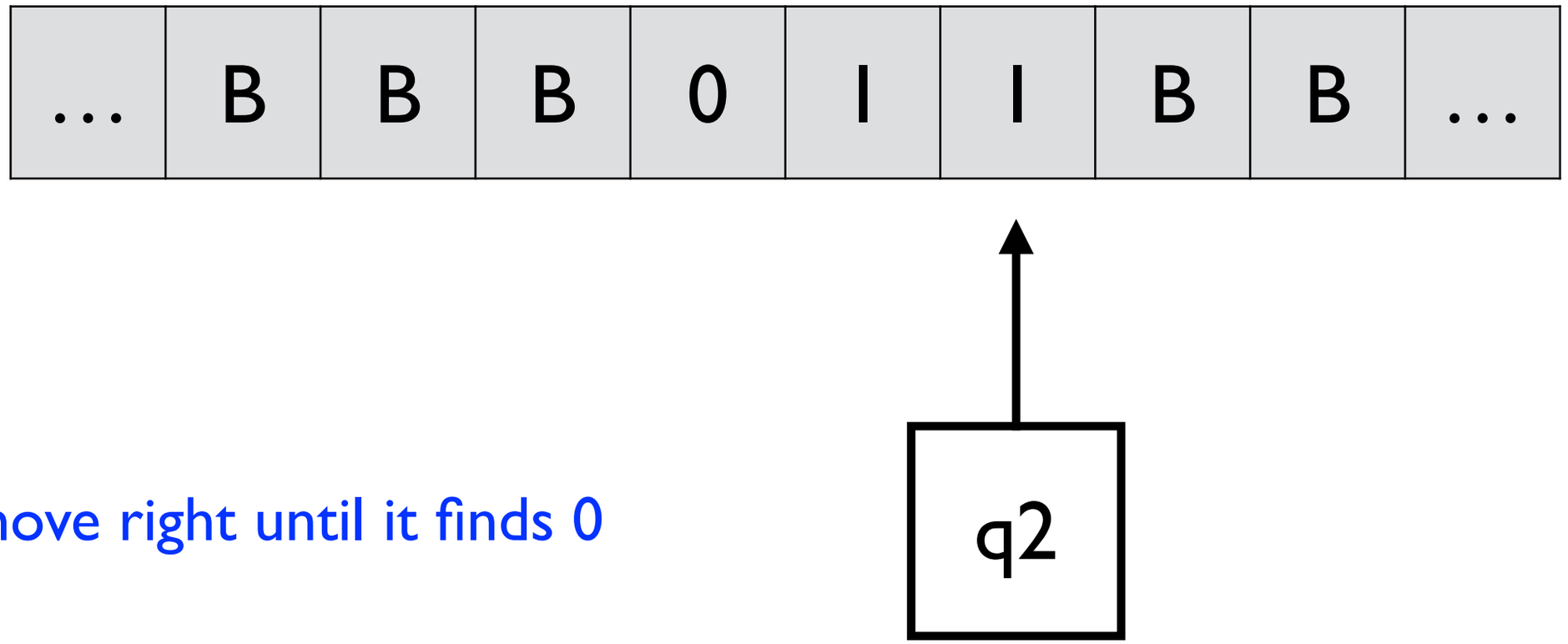
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

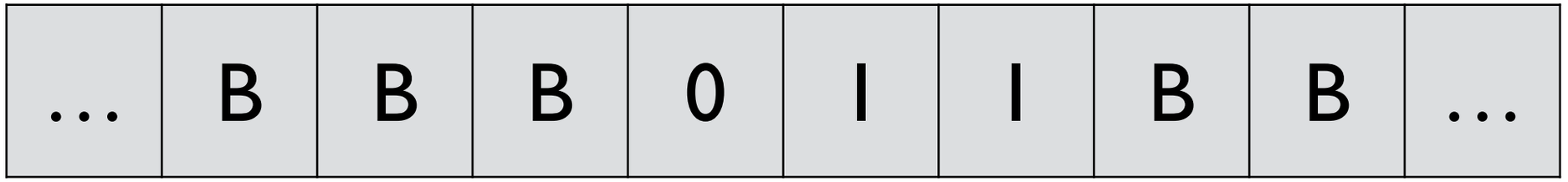


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

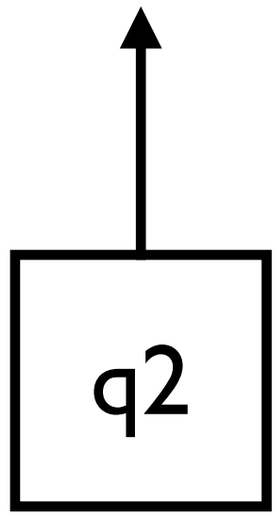


move right until it finds 0

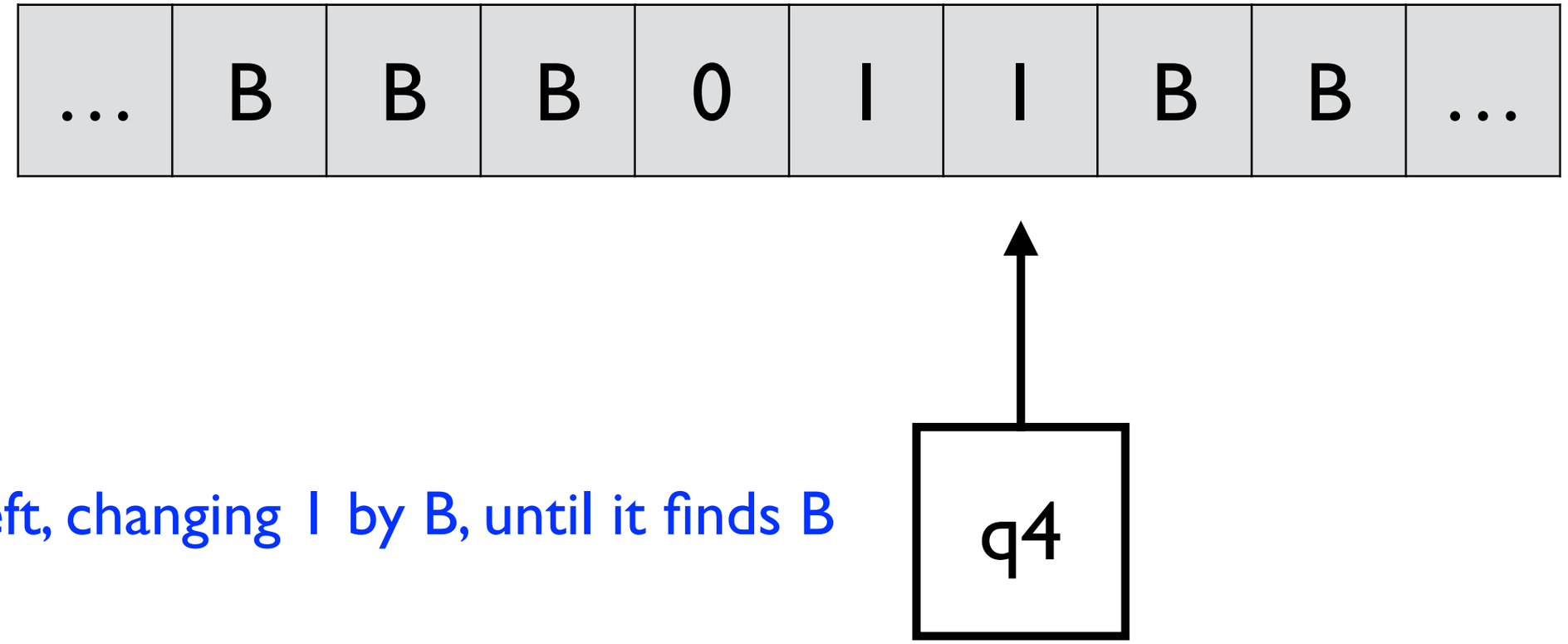
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



- No more 0's.
- All n 0's changed to 1
- n+1 0's changed to B
- m-(n+1) 0's on the tape
- replace all 1's by B and put one 0

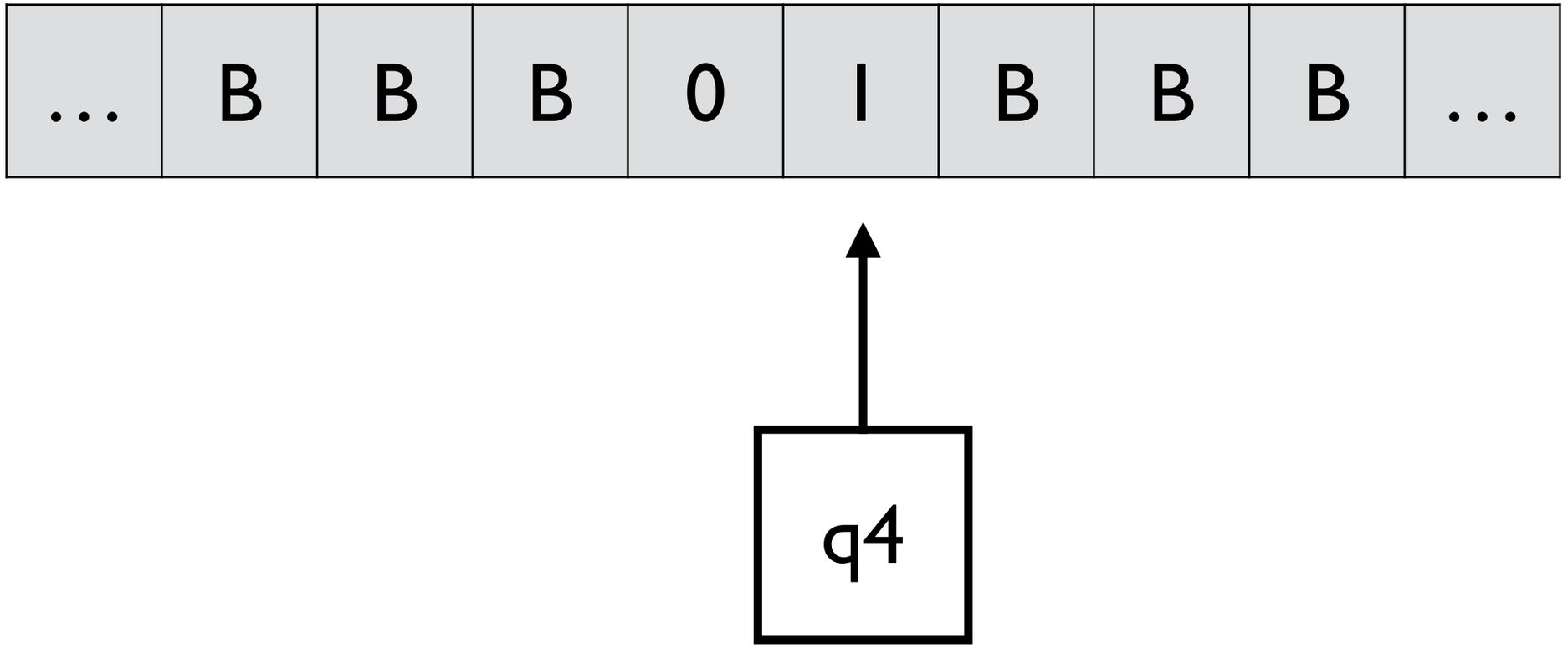


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

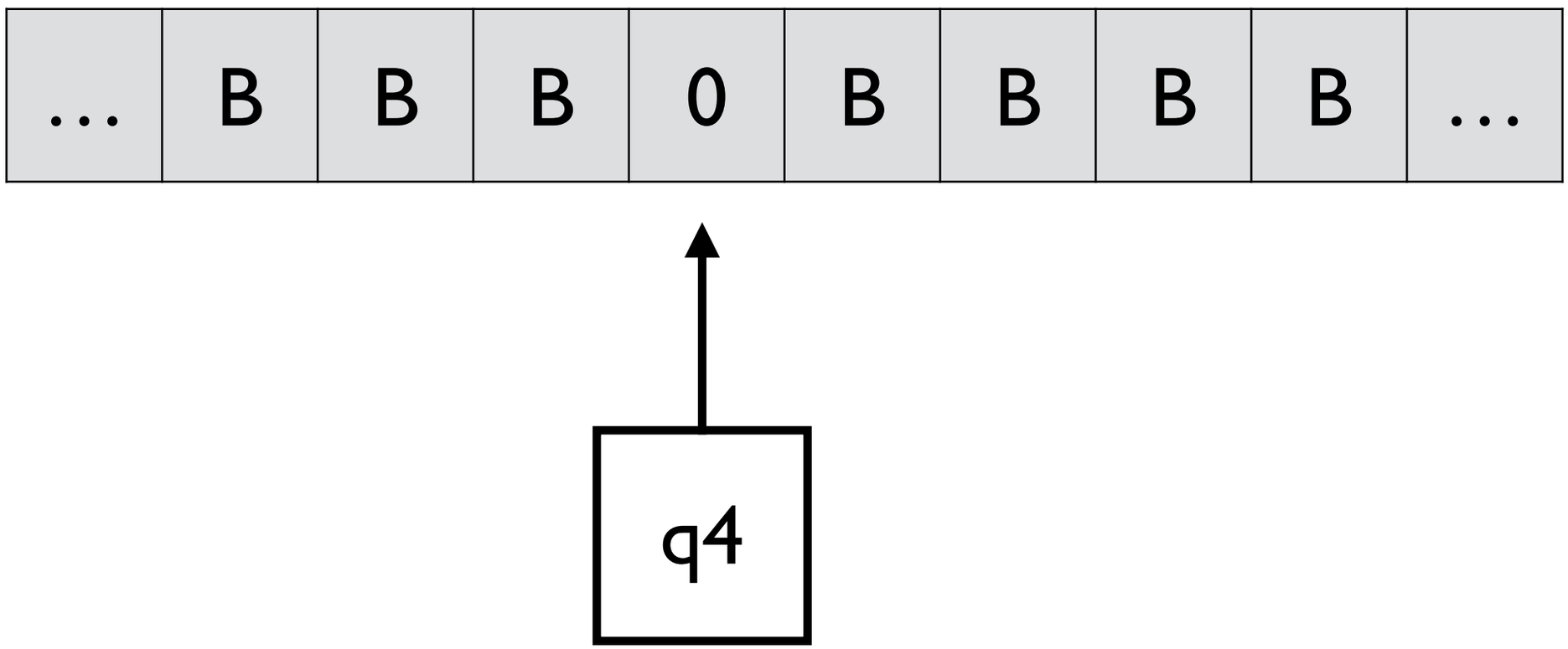


move left, changing I by B, until it finds B

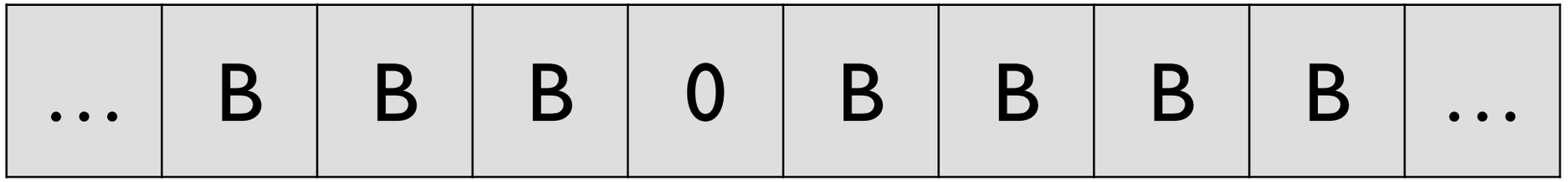
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

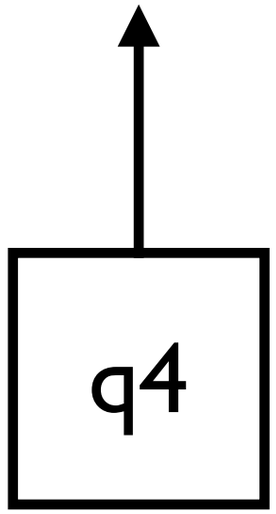


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



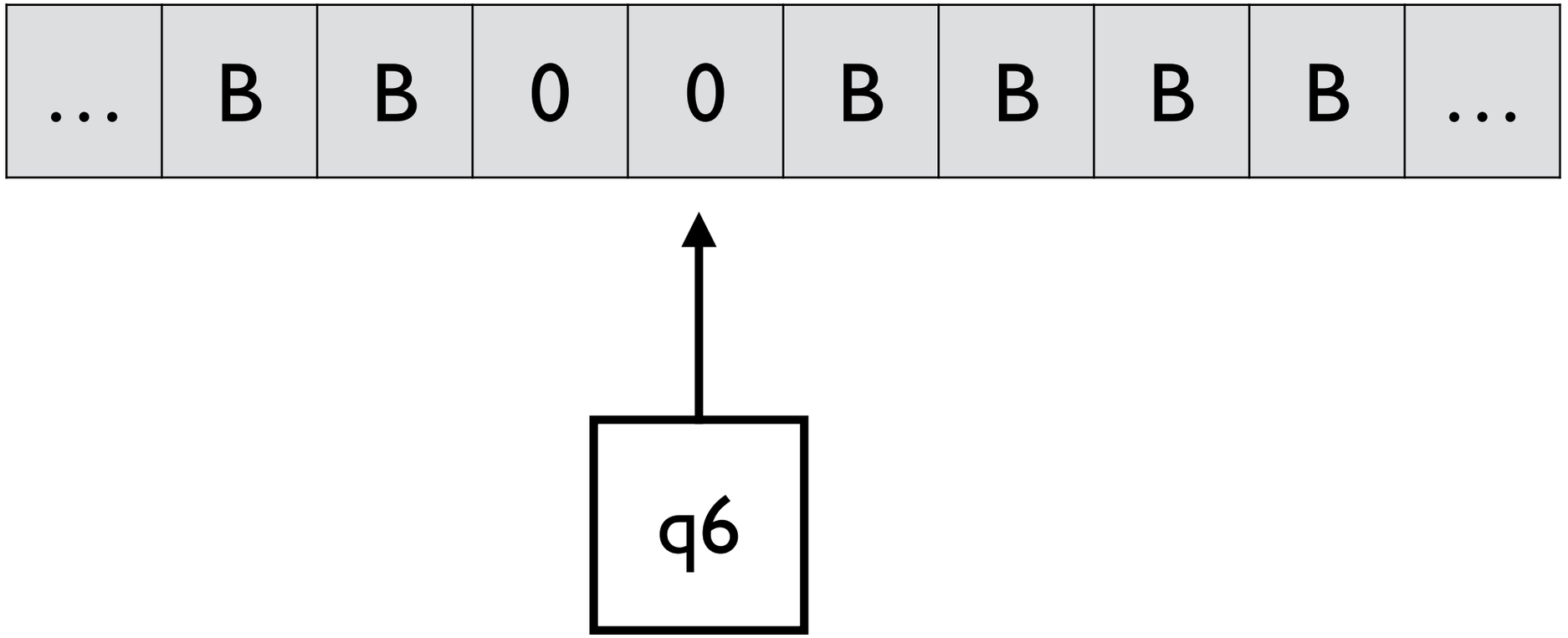
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			





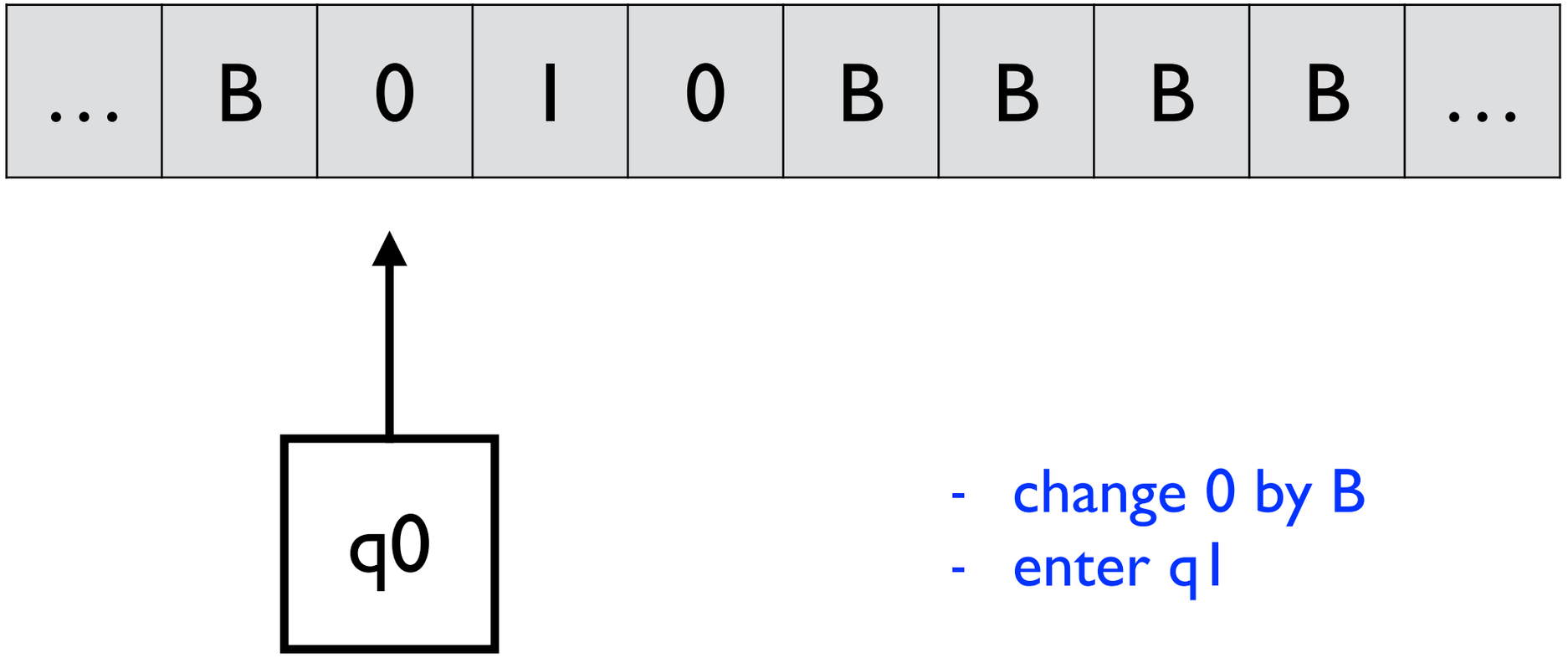
- change that B by 0
- enter the final state

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



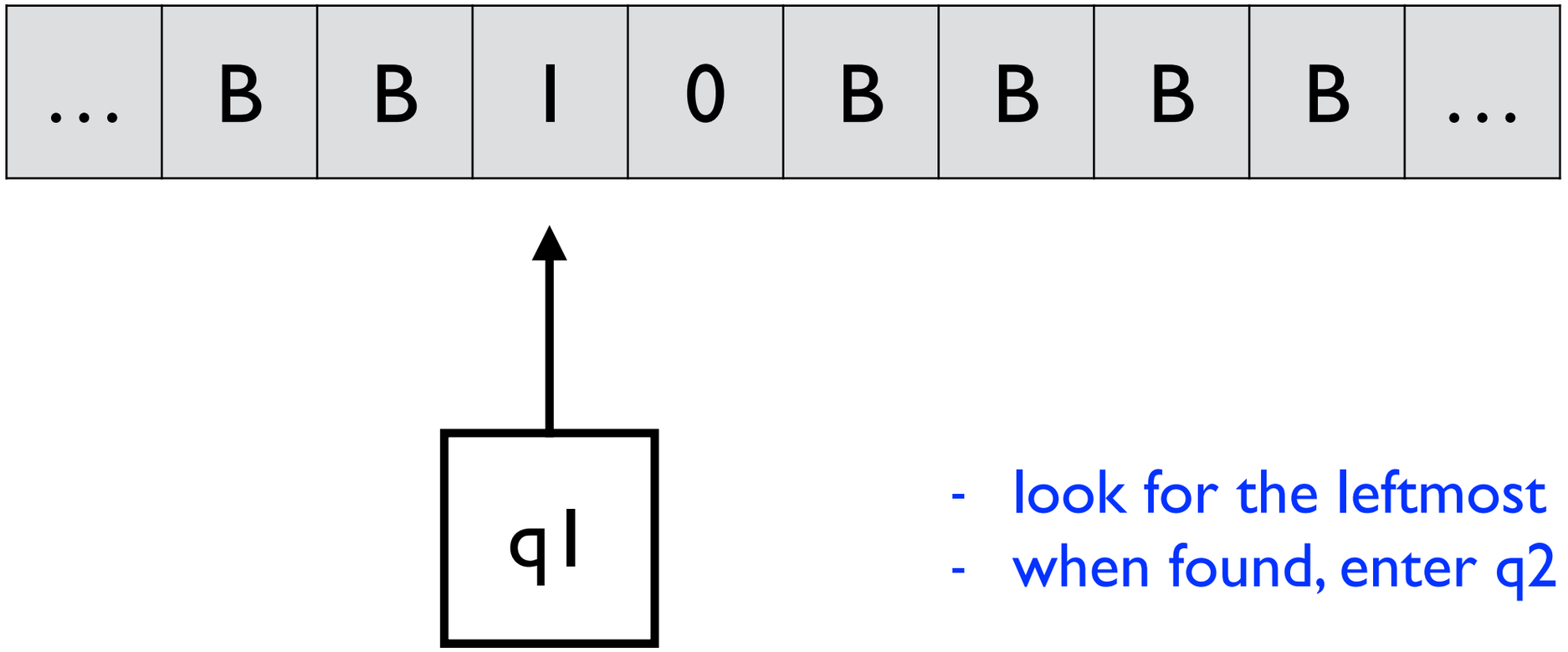
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

e.g., f(1,1)



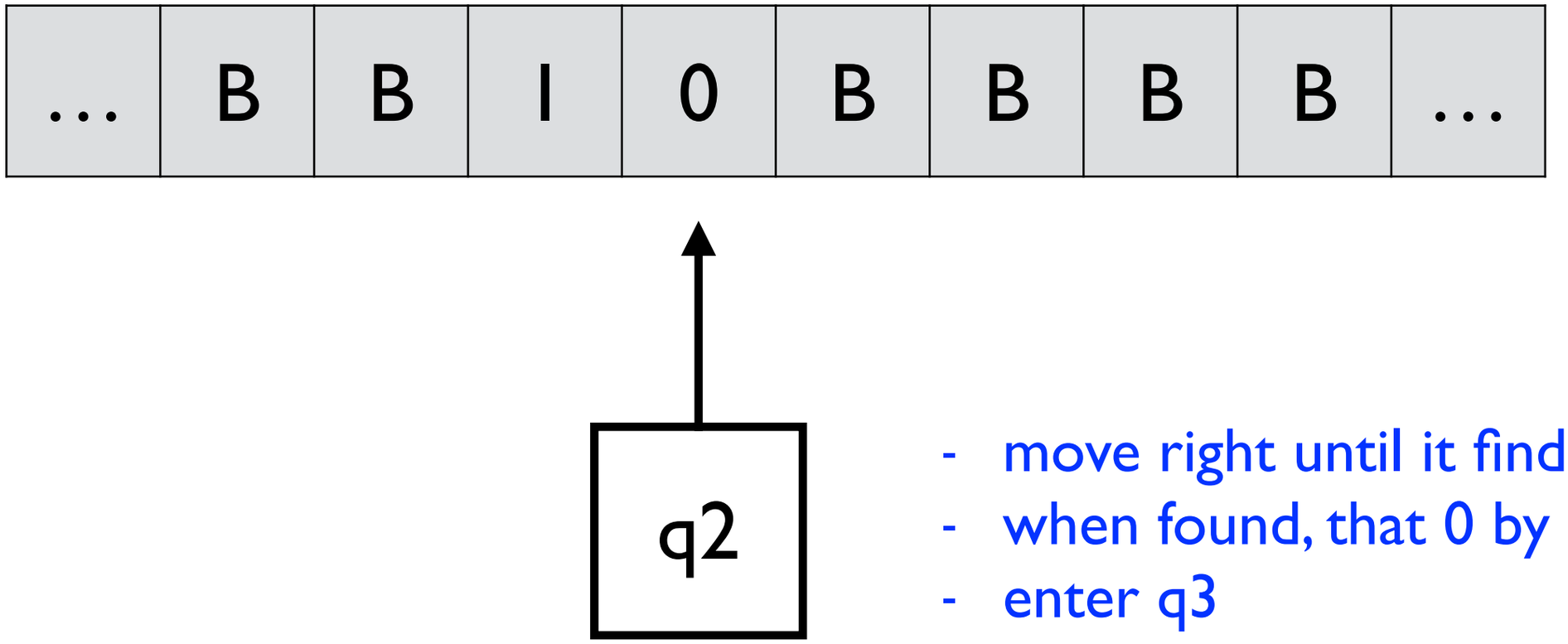
- change 0 by B
- enter q1

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



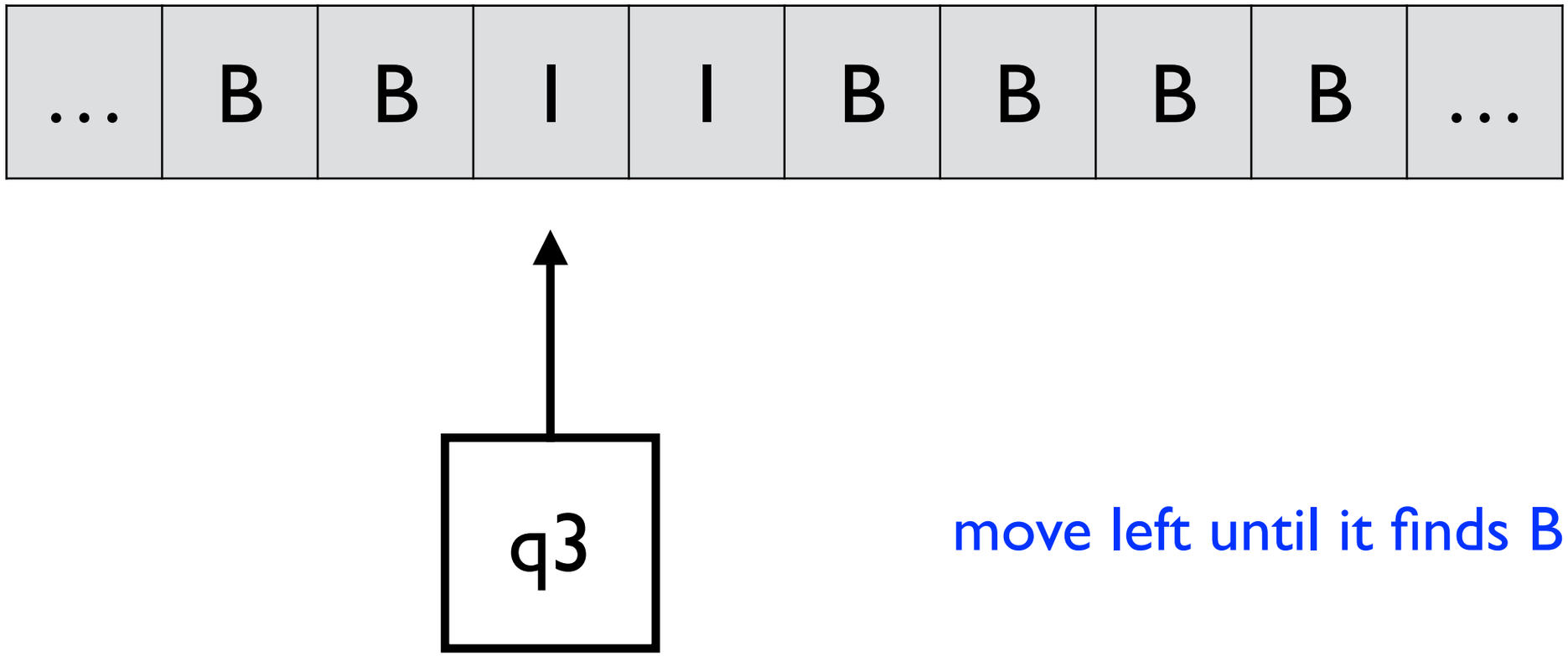
- look for the leftmost 1
- when found, enter q2

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



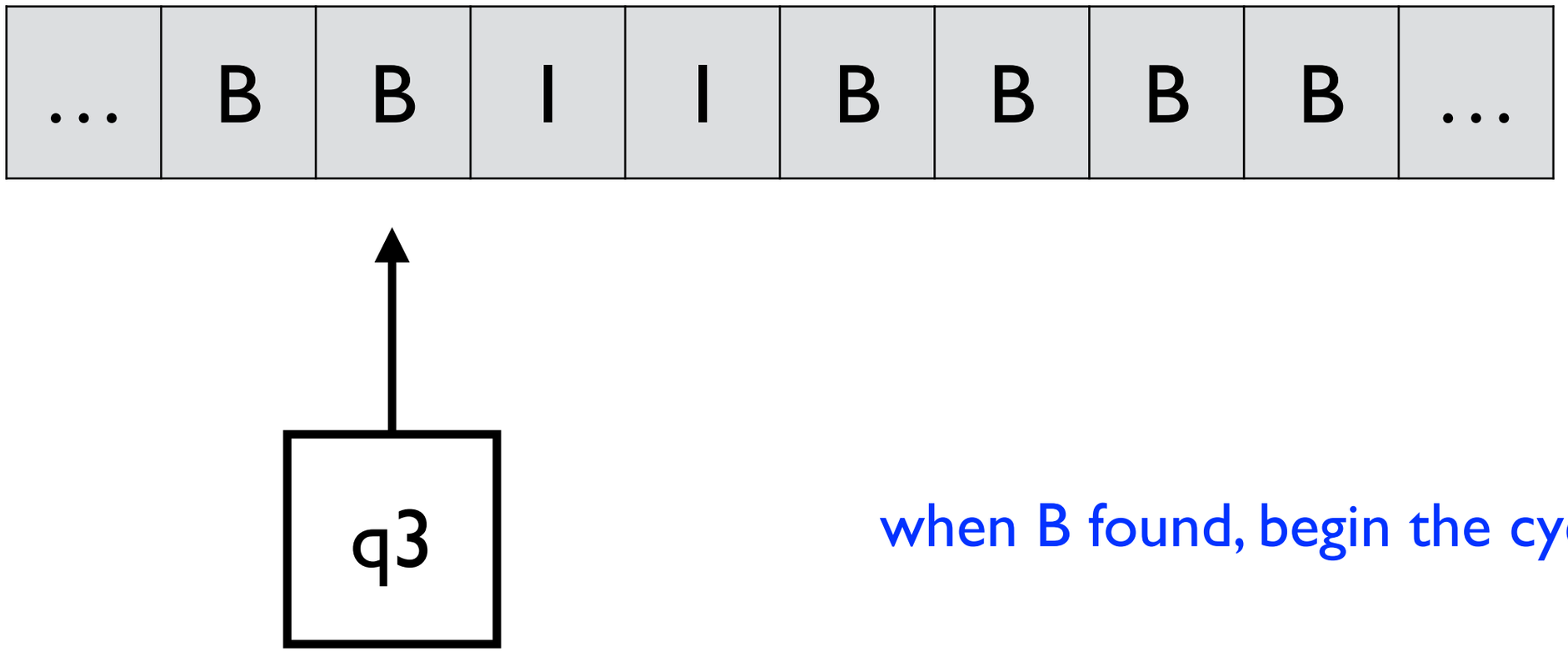
- move right until it finds 0
- when found, that 0 by 1
- enter q3

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



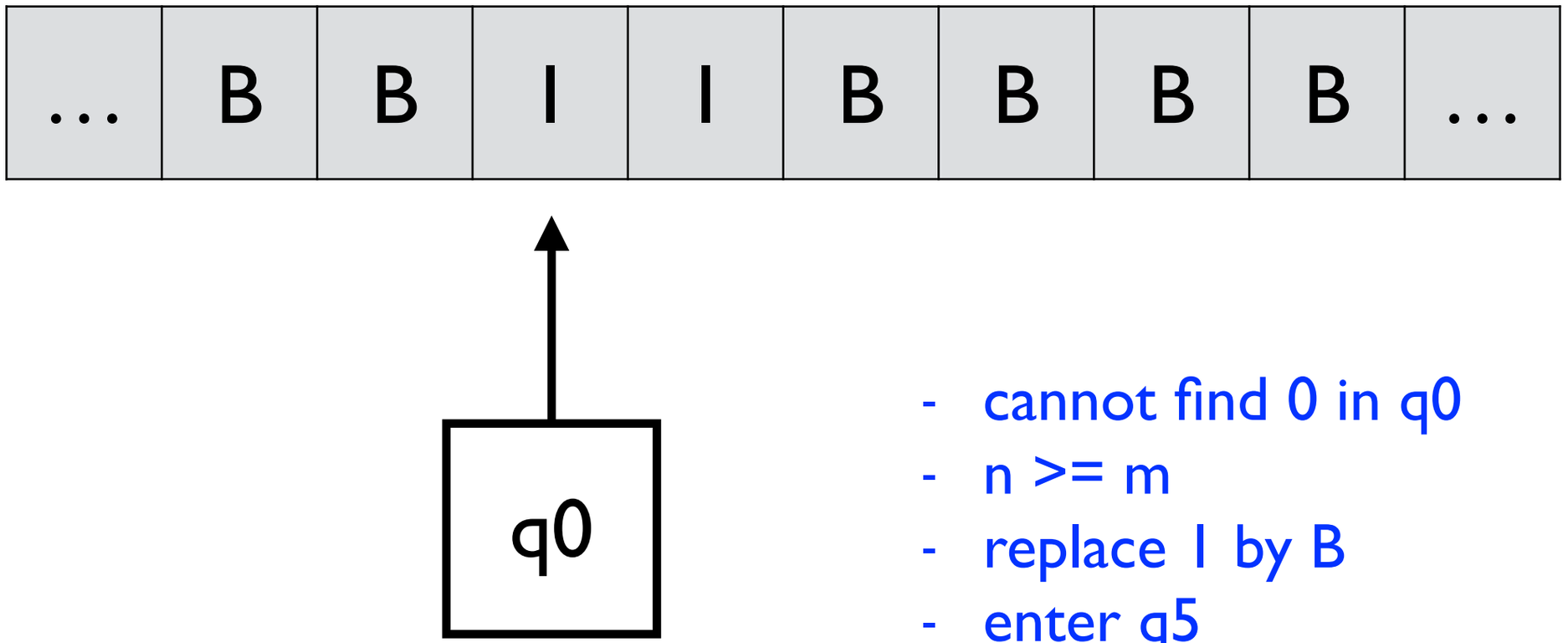
move left until it finds B

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



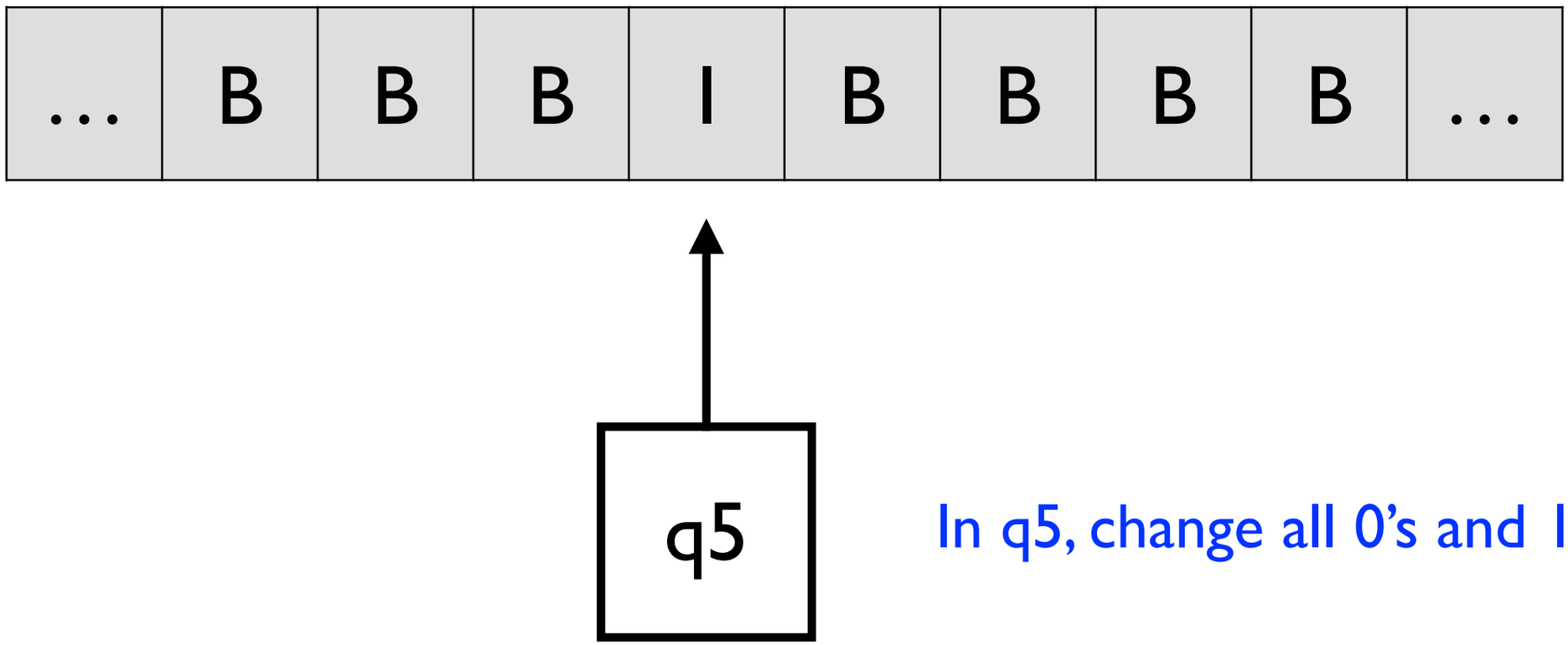
when B found, begin the cycle

	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

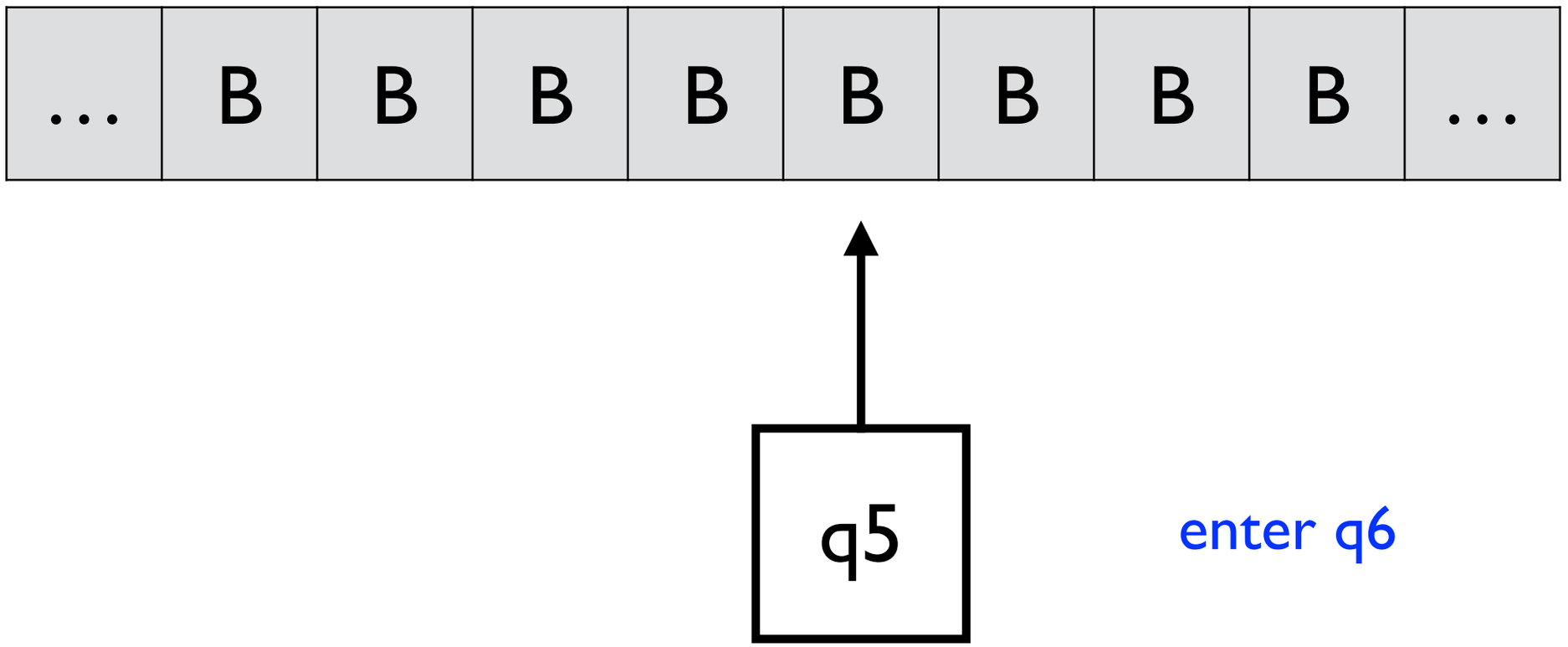


- cannot find 0 in q0
- n >= m
- replace 1 by B
- enter q5

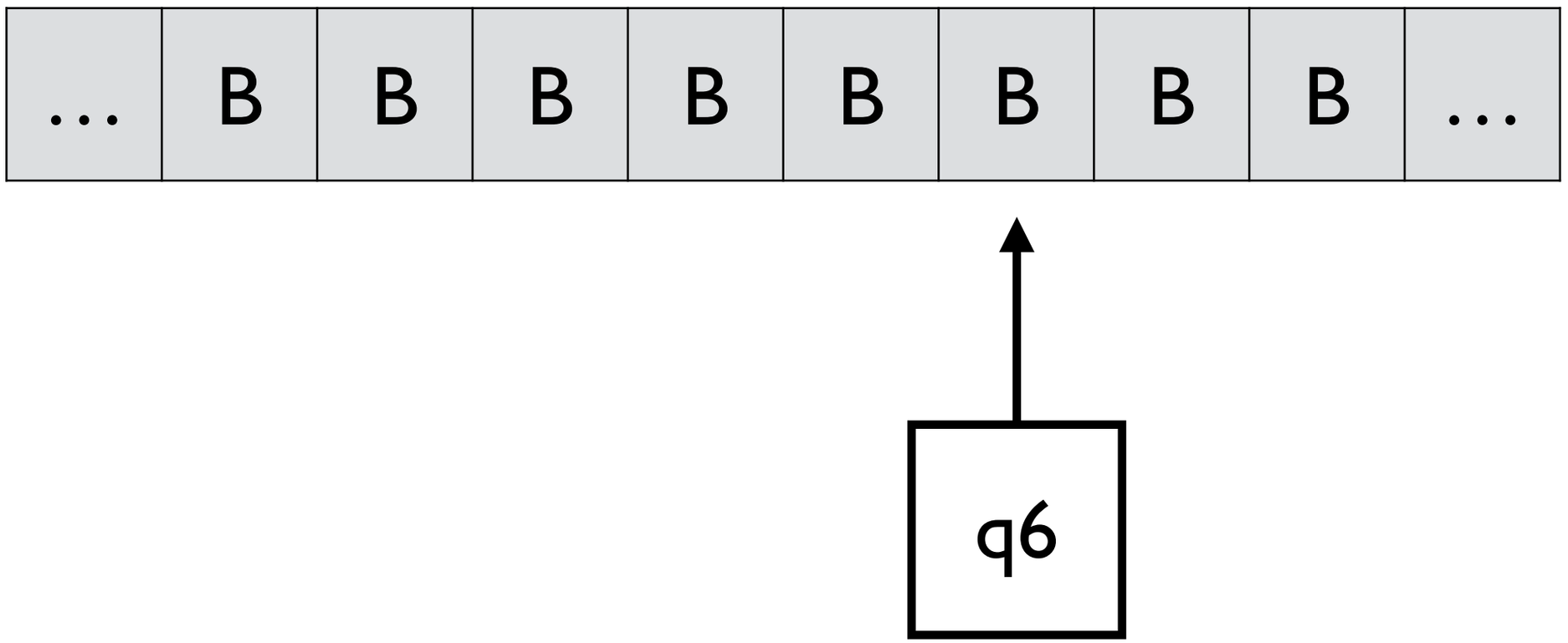
	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			



	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

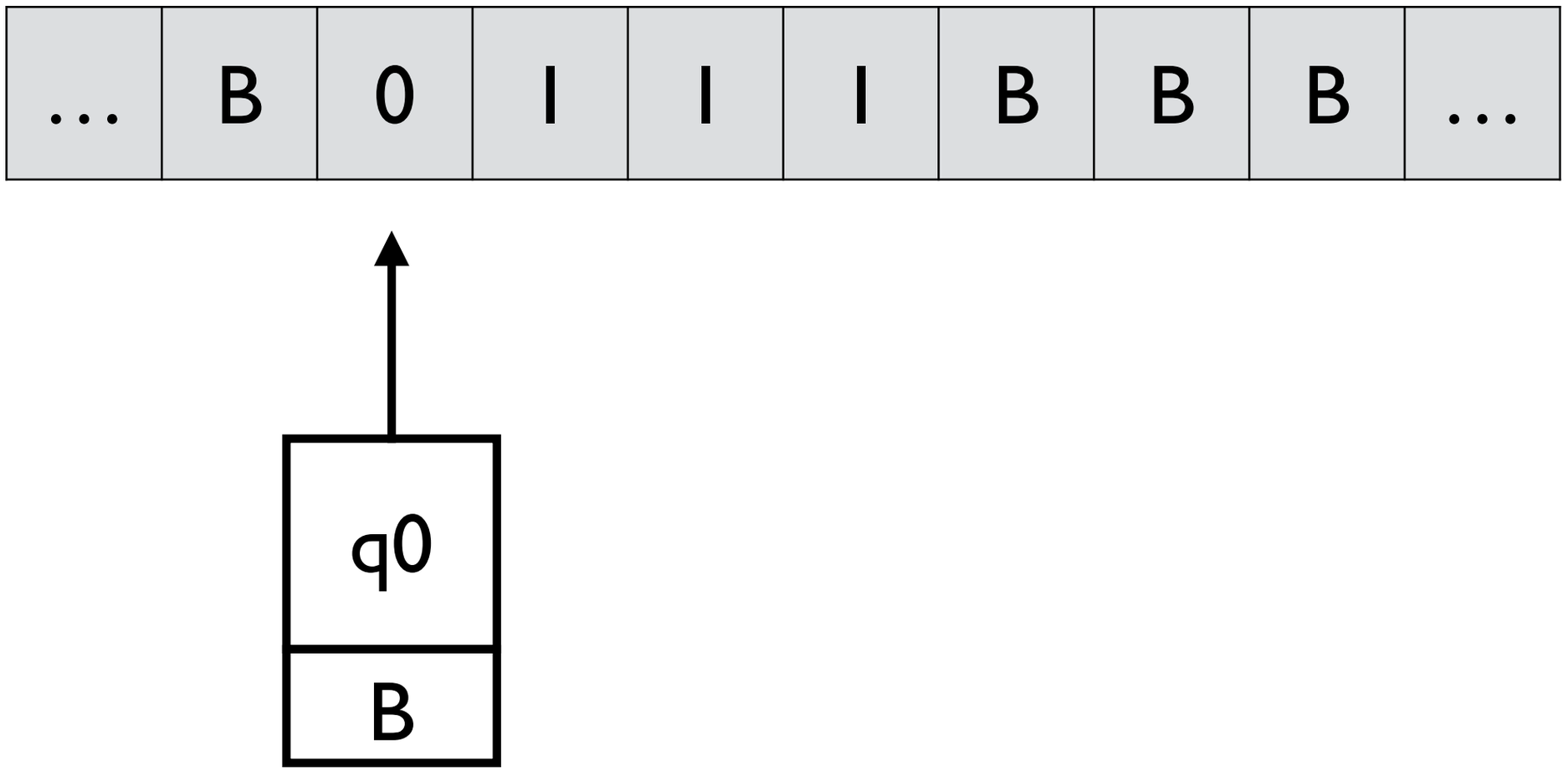


	0	1	B
q_0	(q_1, B, R)	(q_5, B, R)	
q_1	$(q_1, 0, R)$	$(q_2, 1, R)$	
q_2	$(q_3, 1, L)$	$(q_2, 1, R)$	(q_4, B, L)
q_3	$(q_3, 0, L)$	$(q_3, 1, L)$	(q_0, B, R)
q_4	$(q_4, 0, L)$	(q_4, B, L)	$(q_6, 0, R)$
q_5	(q_5, B, R)	(q_5, B, R)	(q_6, B, R)
q_6			

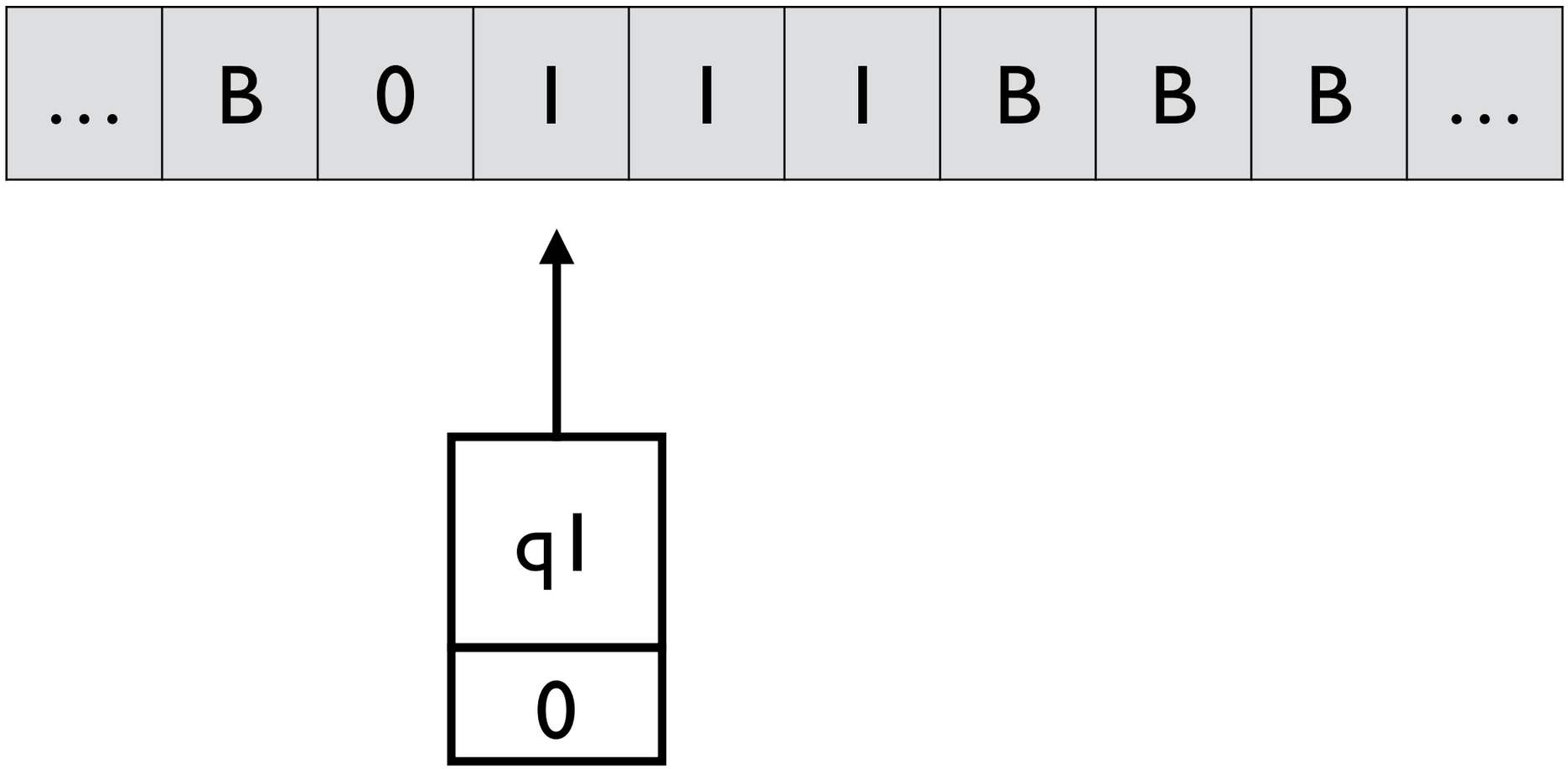
Example 5. Design a Turing machine that accepts $01^* + 10^*$.

$$M = (\{q_0, q_1\} \times \{0, 1, B\}, \{0, 1\}, \{0, 1, B\}, \delta, (q_0, B), B, \{(q_1, B)\})$$

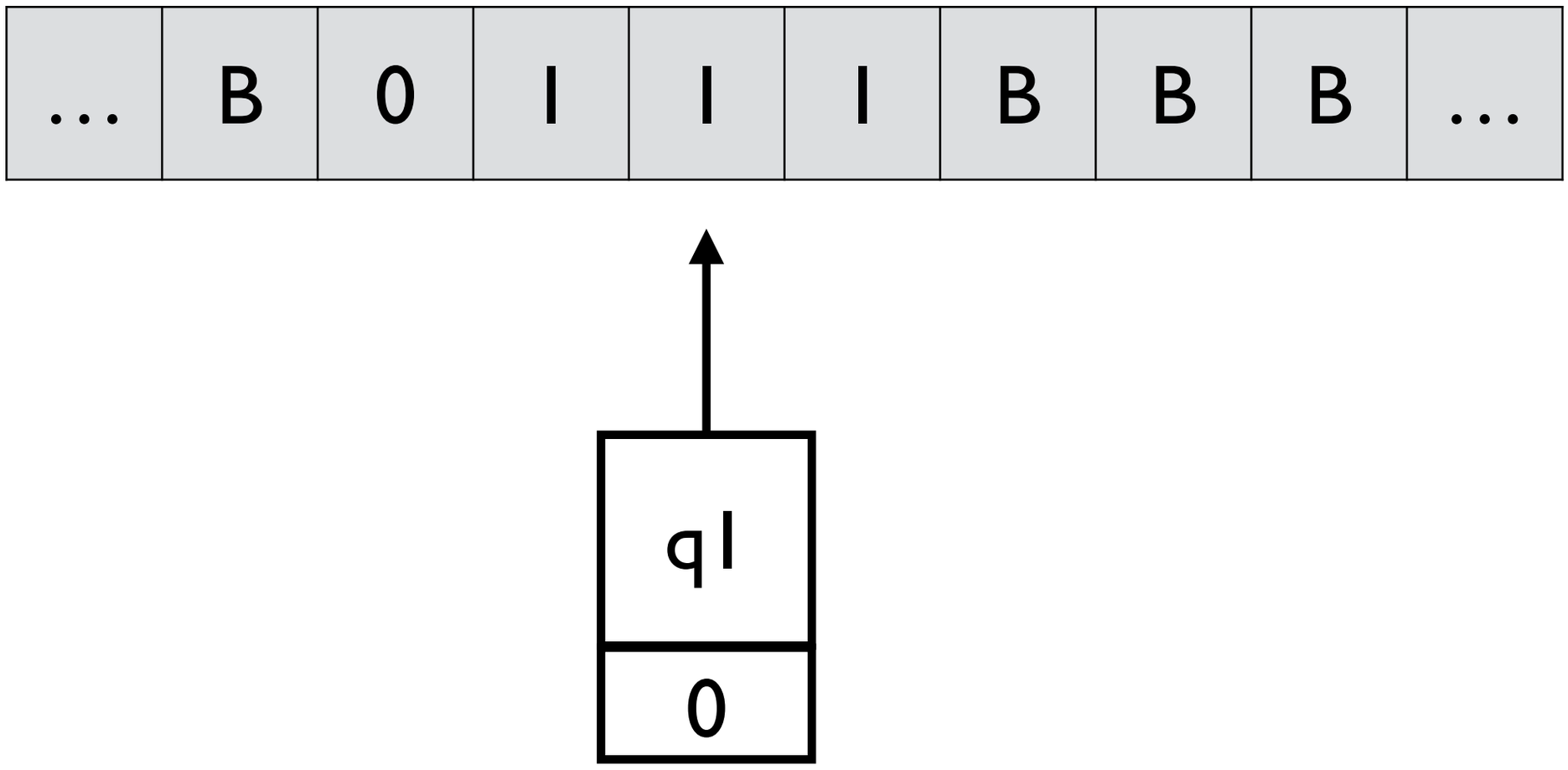
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



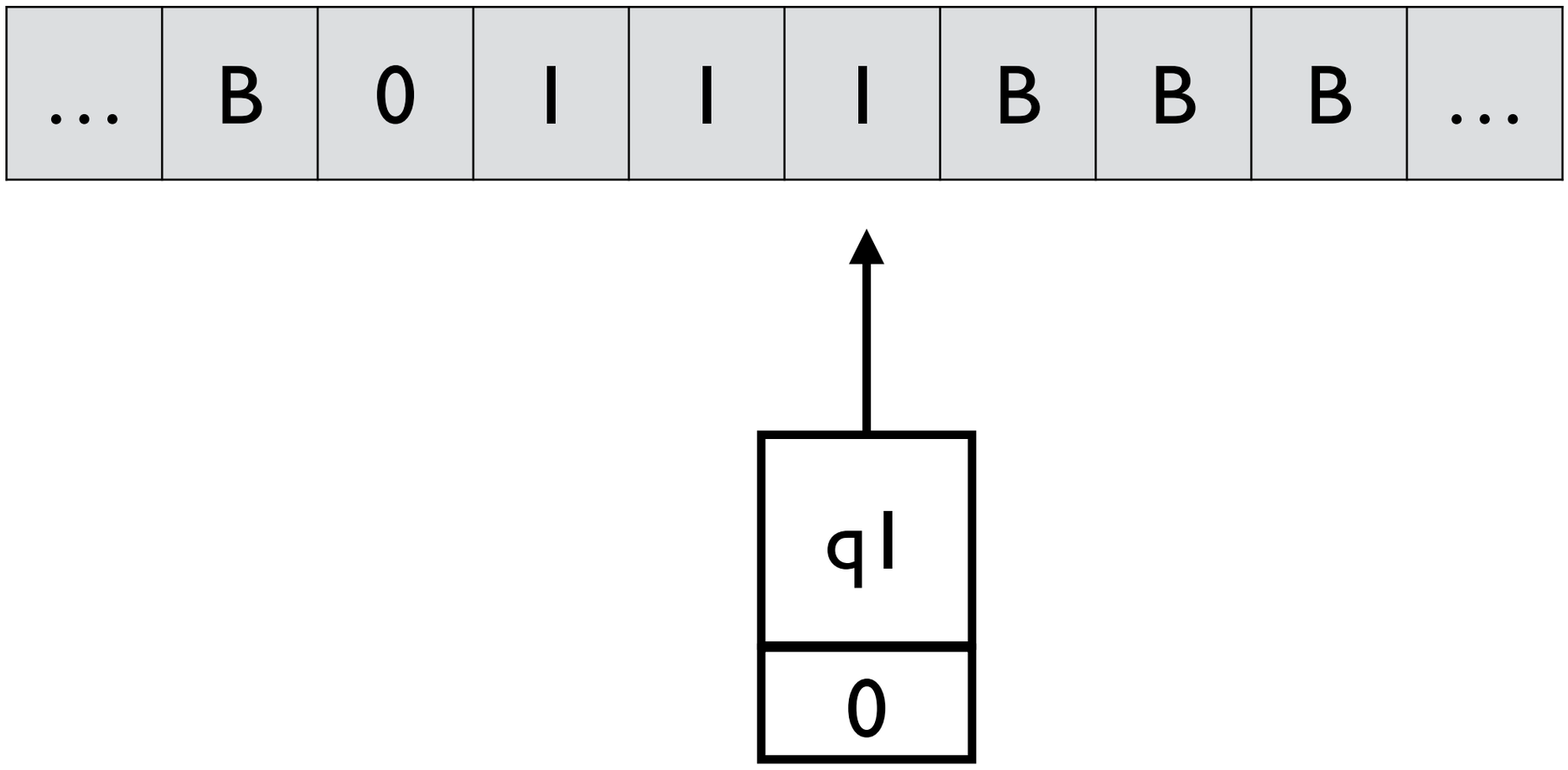
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



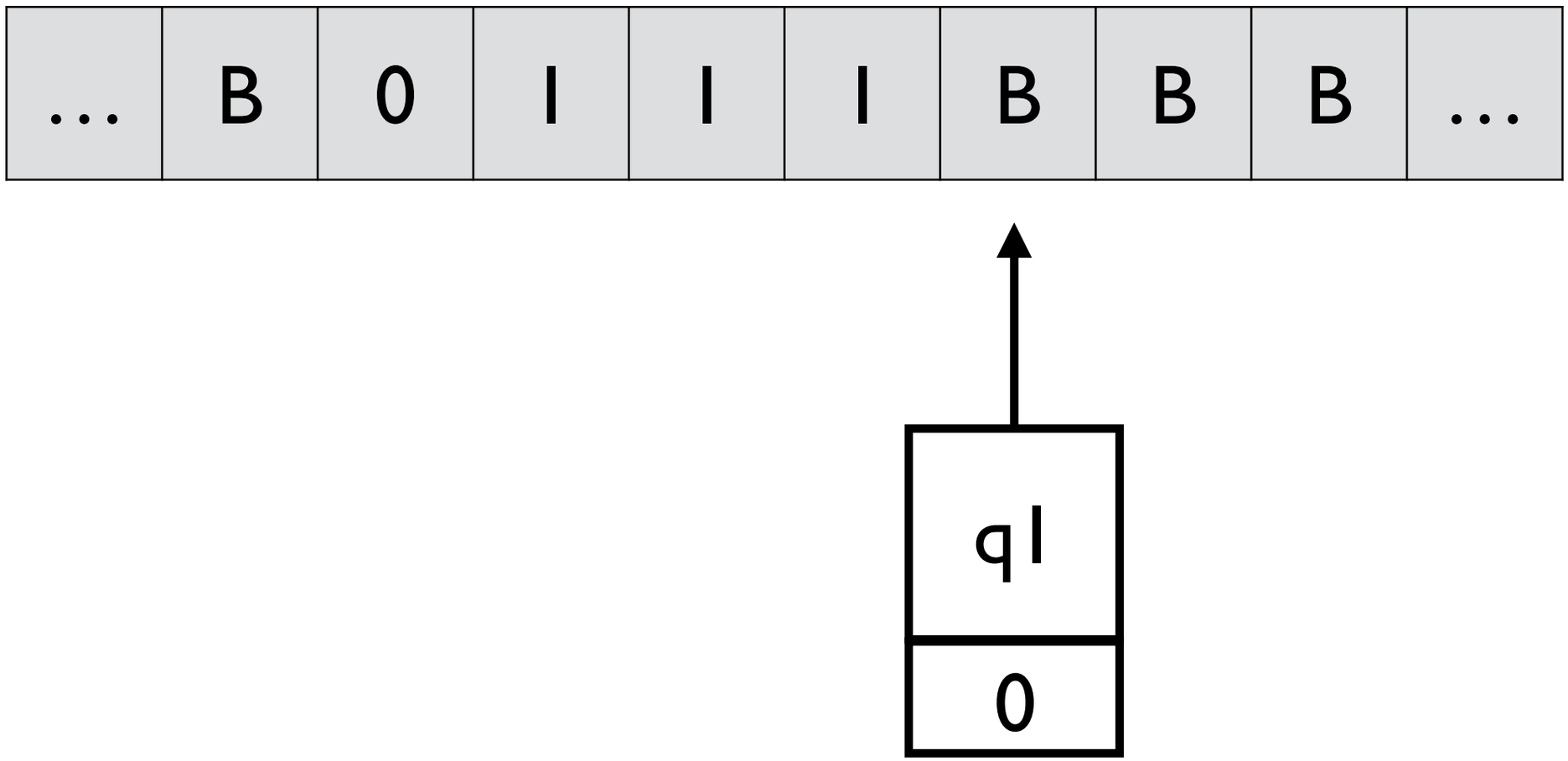
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



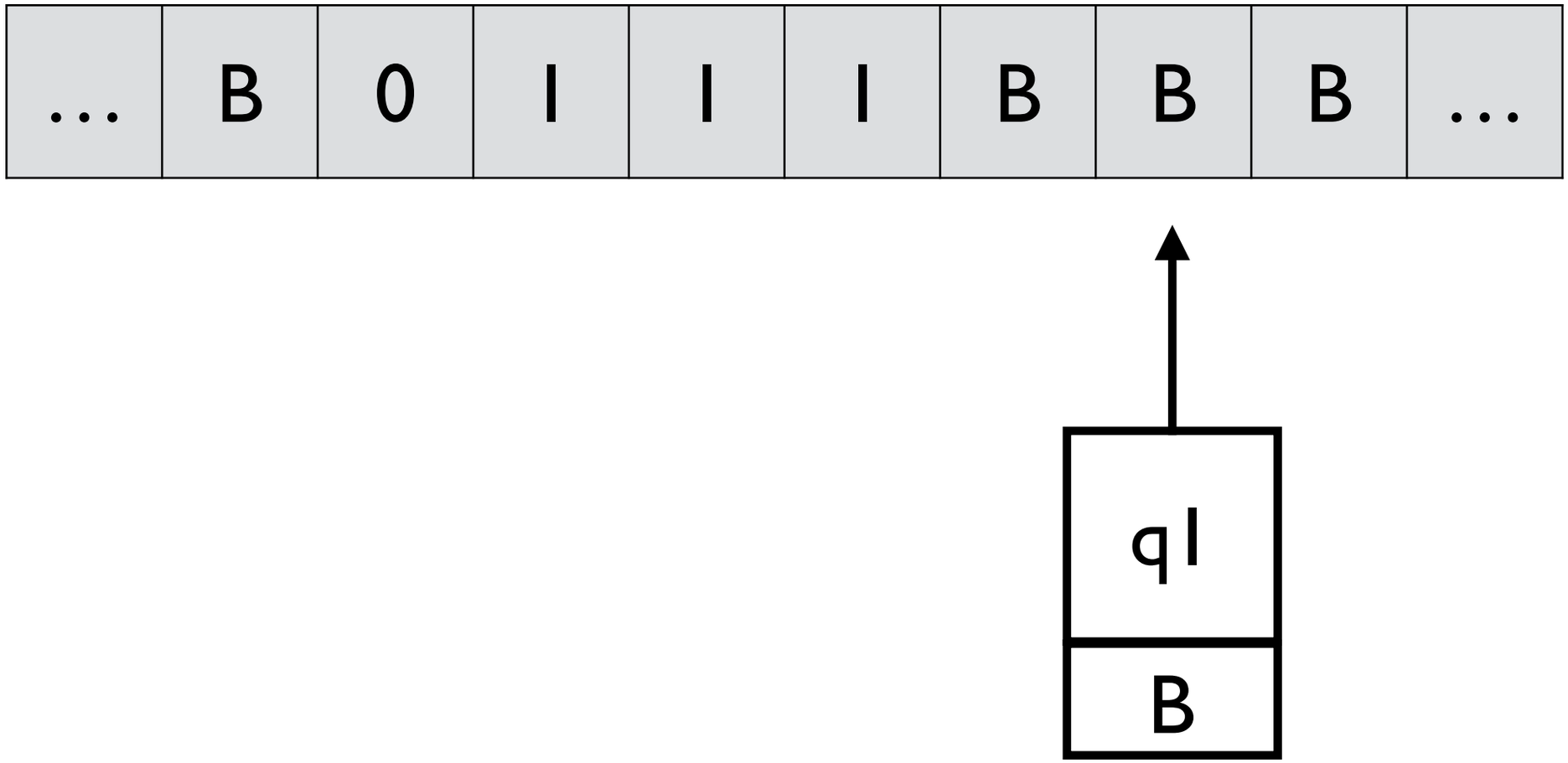
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



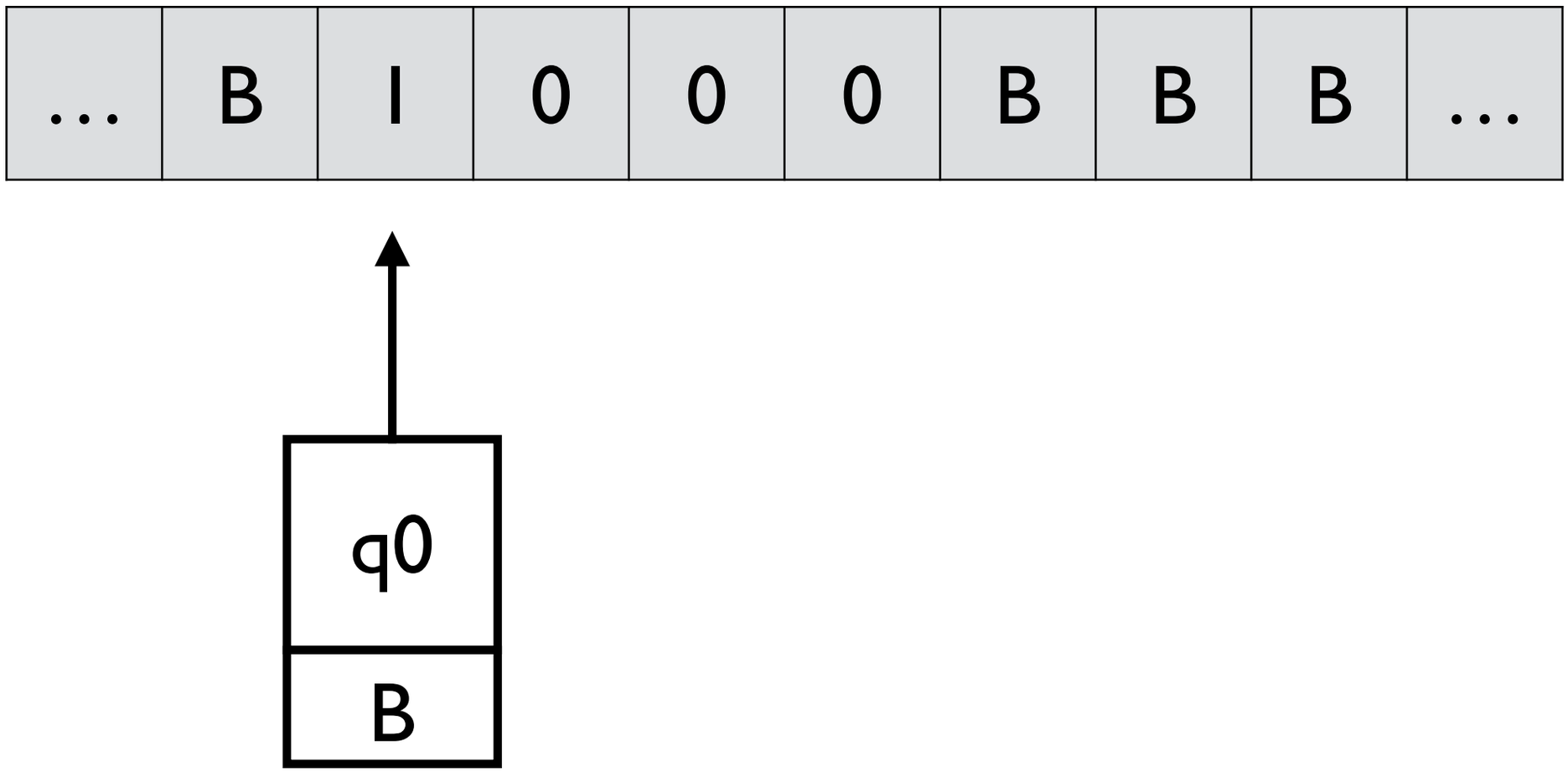
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



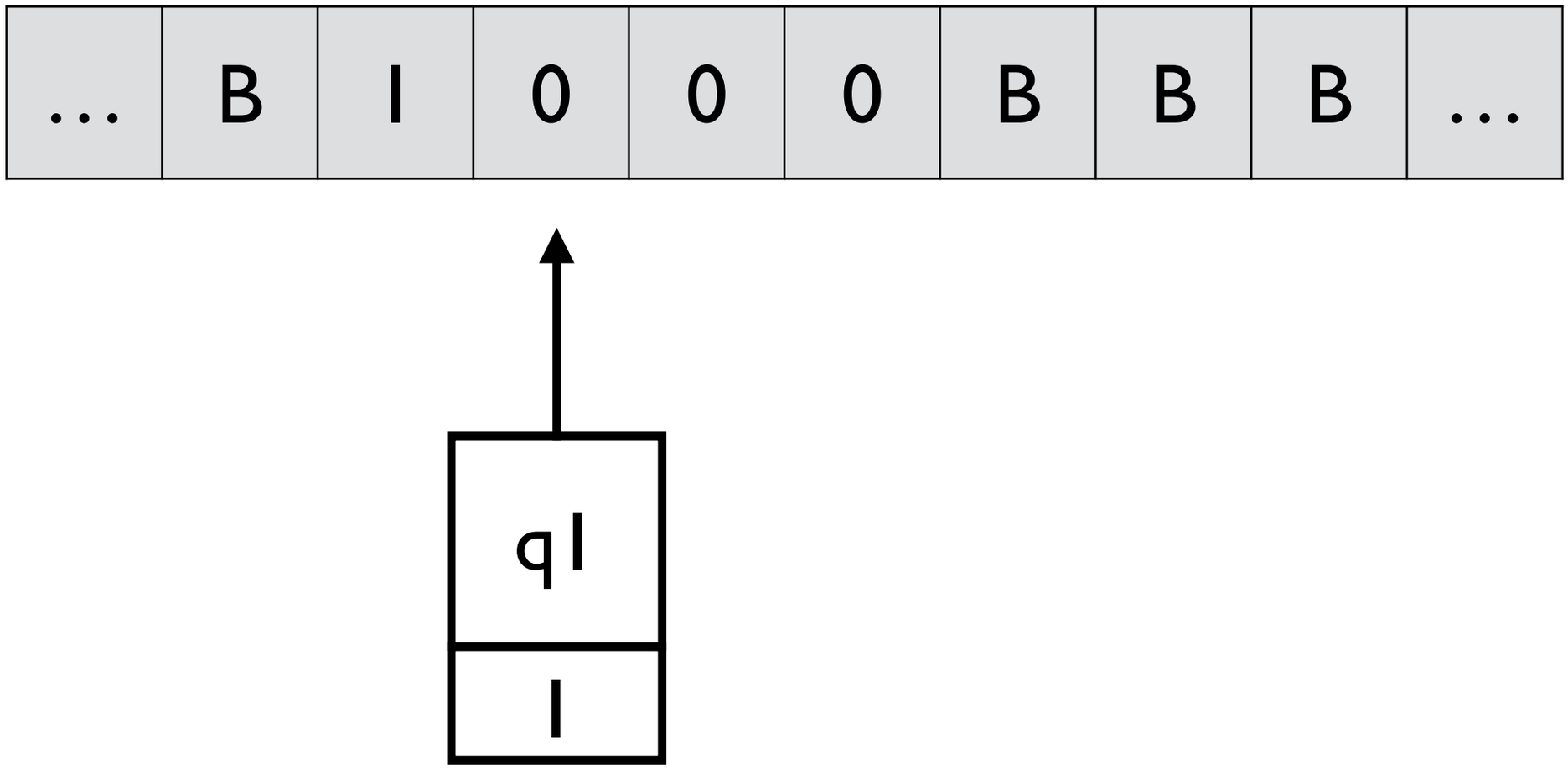
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



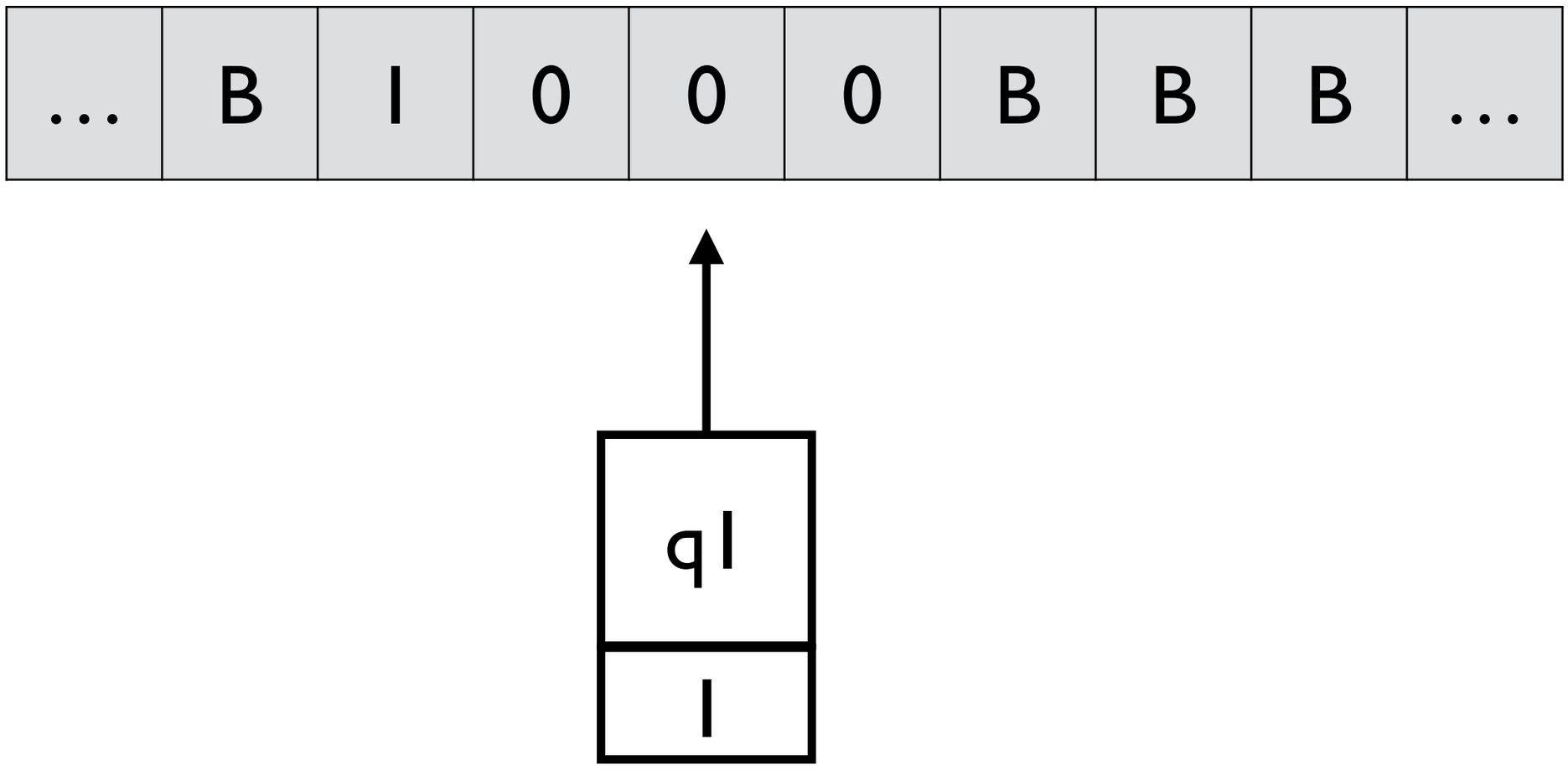
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



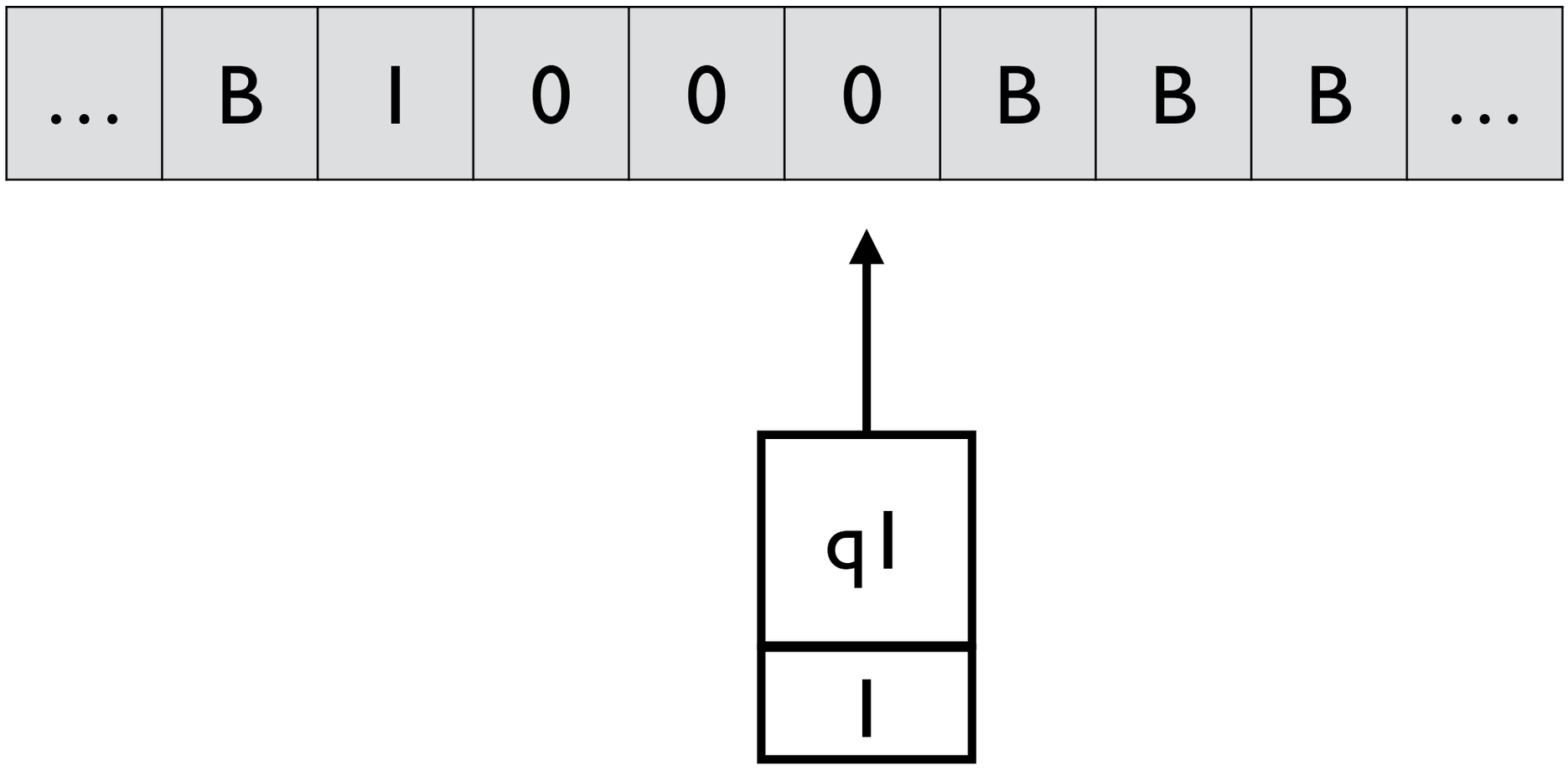
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



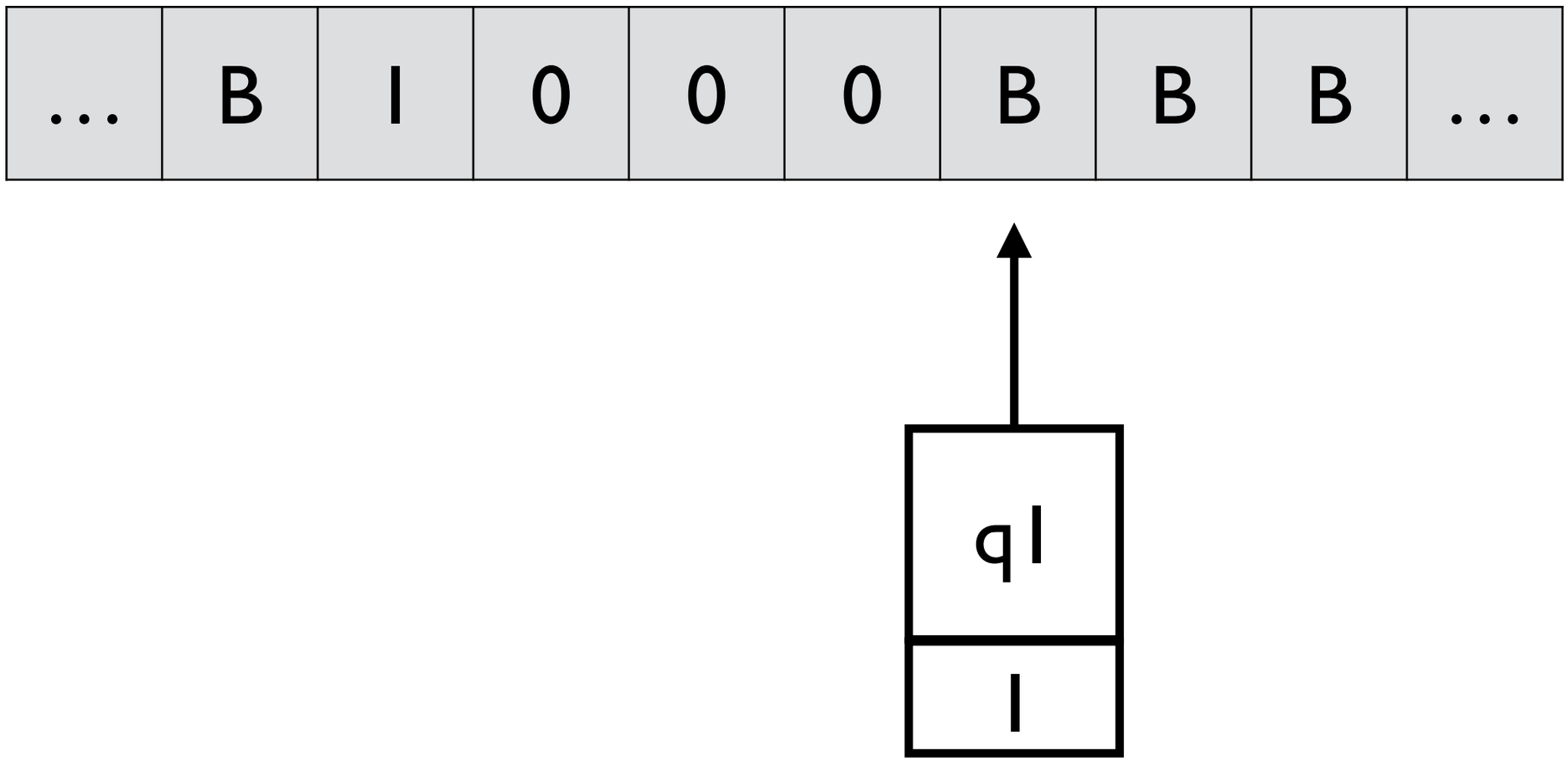
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



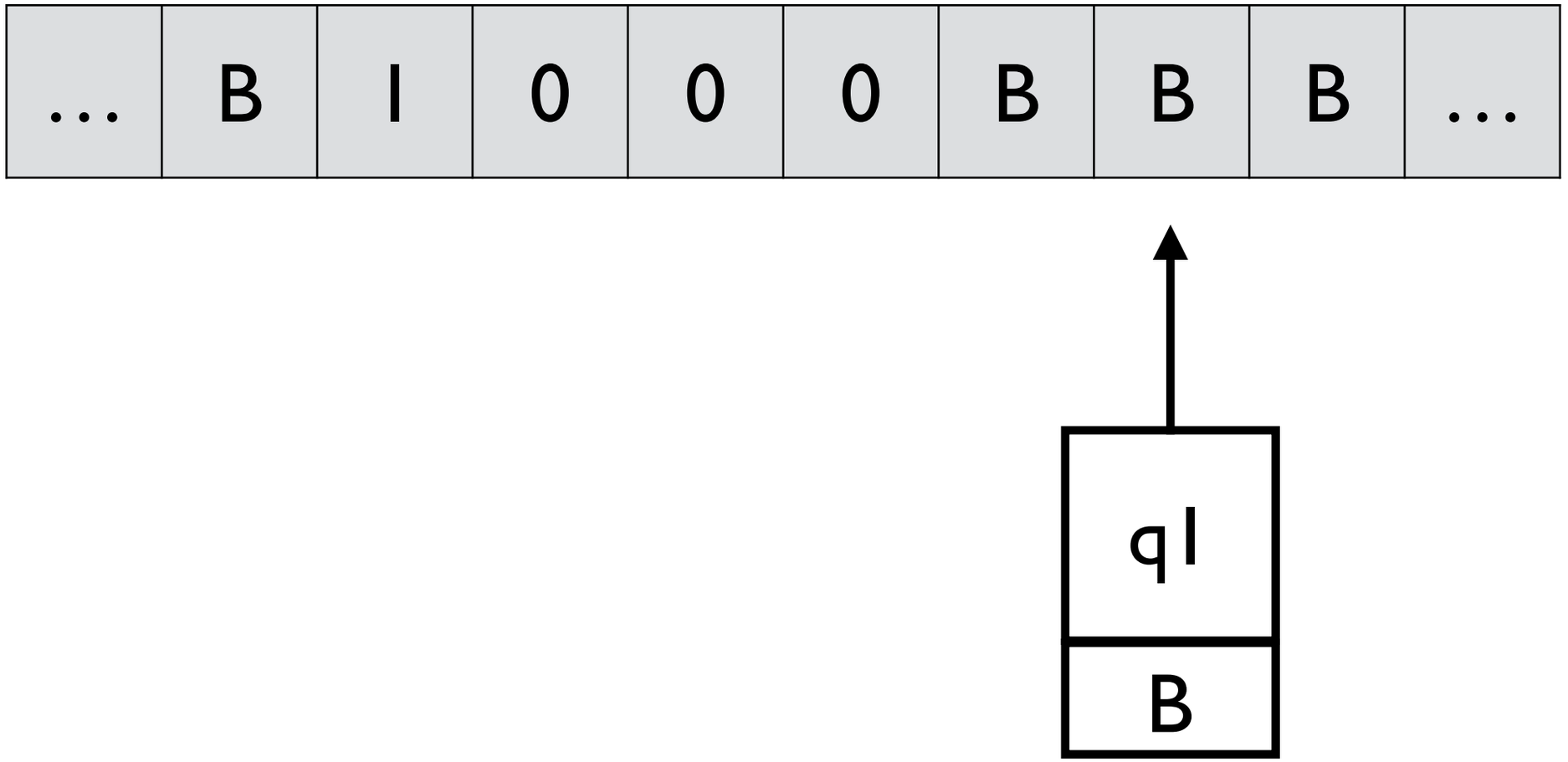
1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$



1. $\delta((q_0, B), a) = ((q_1, a), a, R)$ for $a = 0$ or $a = 1$
2. $\delta((q_1, a), \bar{a}) = ((q_1, a), \bar{a}, R)$
3. $\delta((q_1, a), B) = ((q_1, B), B, R)$

Example 6. Design a Turing machine that accepts $L = \{wcw \mid w \in \{0,1\}^+\}$.

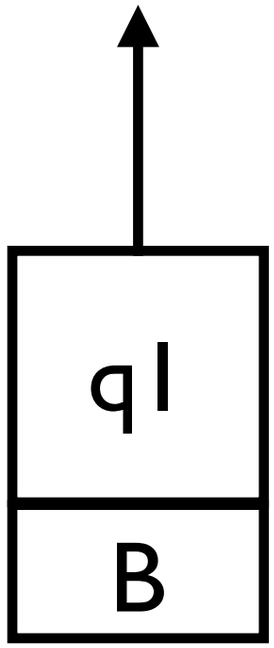
$$M = (Q, \Sigma, \Gamma, \delta, (q_1, B), (B, B), \{q_9, B\})$$

- $\{q_1, q_2, \ldots, q_9\} \times \{0, 1, B\}$
- $\Gamma = \{B, *\} \times \{0, 1, c, B\}$
- $\Sigma = \{(B, 0), (B, 1), (B, c)\}$

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

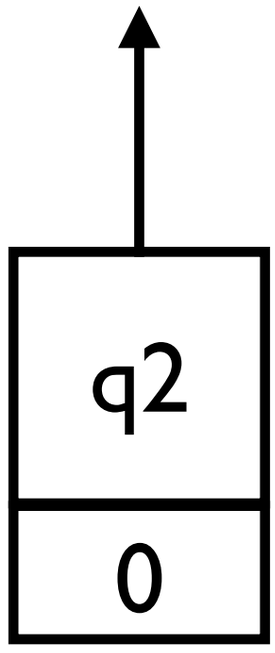
…	B	B	B	B	B	B	B	B	…
…	B	0	I	c	0	I	B	B	…



$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

...	B	*	B	B	B	B	B	B	...
...	B	0	I	c	0	I	B	B	...

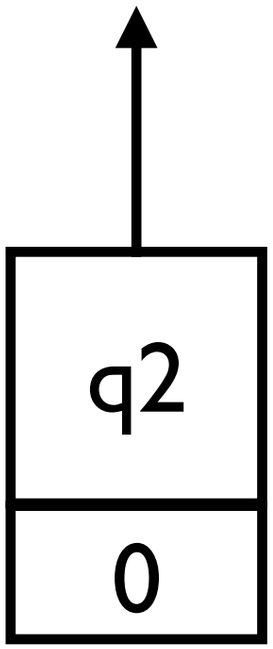


In q2, moves right, looking for c

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

…	B	*	B	B	B	B	B	B	…
…	B	0	I	c	0	I	B	B	…

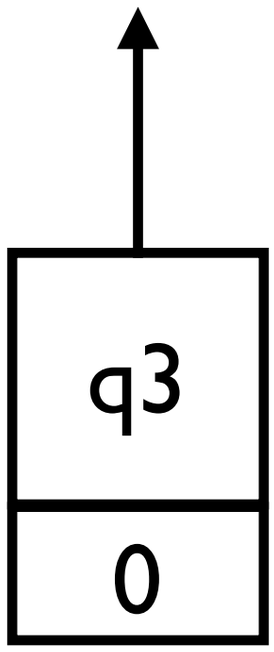


When found,
- enter q3
- continue right

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

…	B	*	B	B	B	B	B	B	…
…	B	0	1	c	0	1	B	B	…

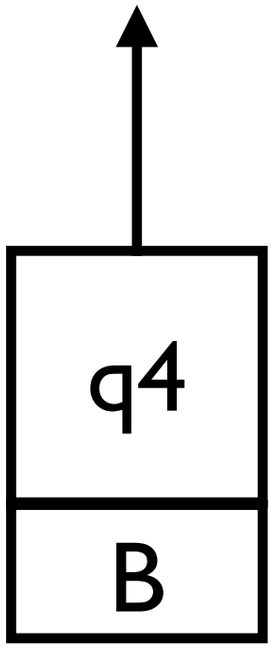


In q3,
look for the first
unchecked symbol

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

…	B	*	B	B	*	B	B	B	…
…	B	0	I	c	0	I	B	B	…

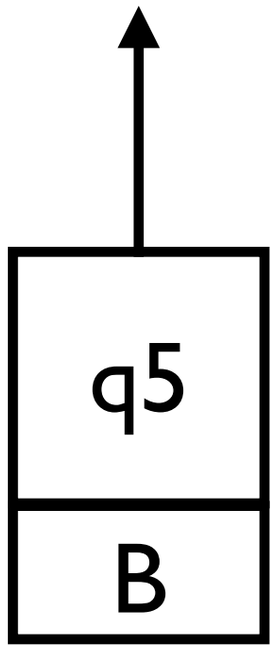


- In q4, move left until it finds c
- When found, enter q5

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

…	B	*	B	B	*	B	B	B	…
…	B	0	I	c	0	I	B	B	…

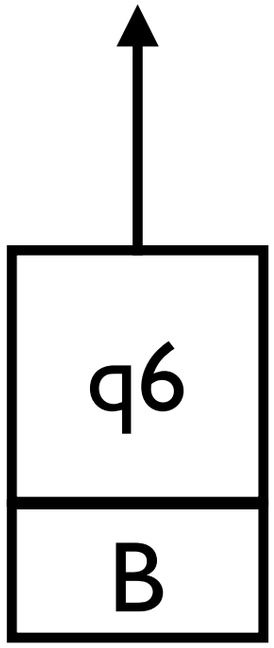


- If there is some unchecked symbol, enter q6

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

…	B	*	B	B	*	B	B	B	…
…	B	0	I	c	0	I	B	B	…

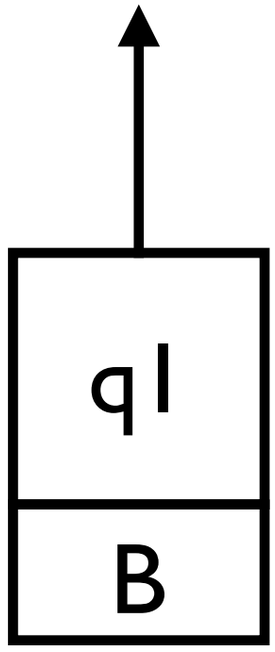


- In q6, move left and look for the first unchecked symbol

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

…	B	*	B	B	*	B	B	B	…
…	B	0	I	c	0	I	B	B	…

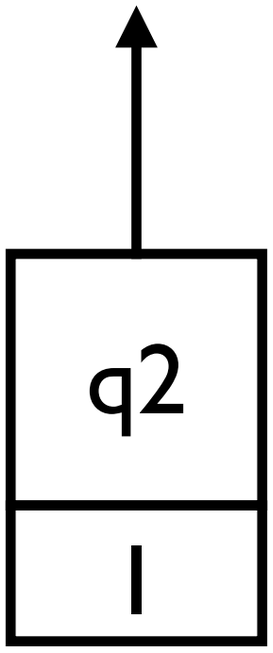


- Repeat the cycle

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

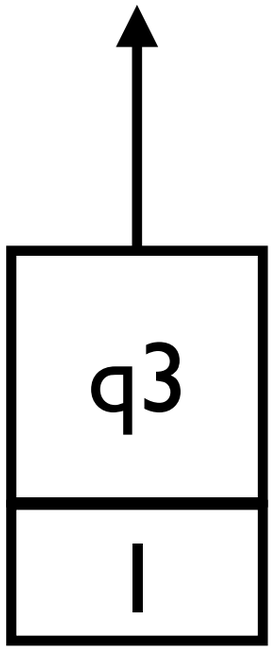
...	B	*	*	B	*	B	B	B	...
...	B	0	I	c	0	I	B	B	...



$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

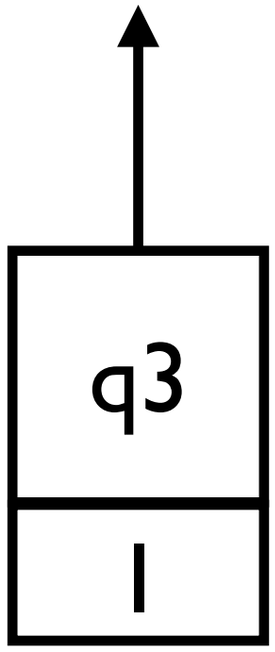
...	B	*	*	B	*	B	B	B	...
...	B	0	I	c	0	I	B	B	...



$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

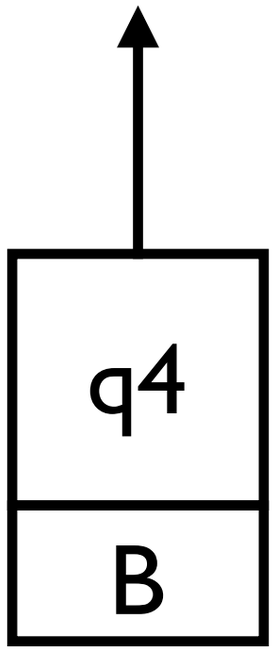
...	B	*	*	B	*	B	B	B	...
...	B	0	I	c	0	I	B	B	...



$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

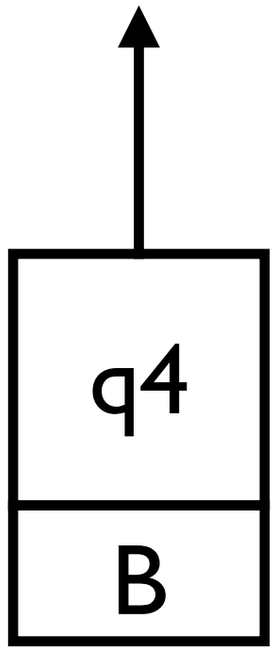
…	B	*	*	B	*	*	B	B	…
…	B	0	I	c	0	I	B	B	…



$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

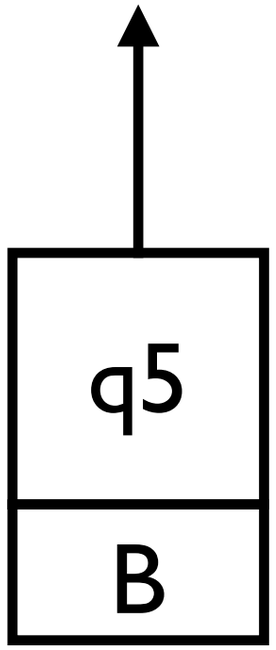
...	B	*	*	B	*	*	B	B	...
...	B	0	I	c	0	I	B	B	...



$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

…	B	*	*	B	*	*	B	B	…
…	B	0	I	c	0	I	B	B	…

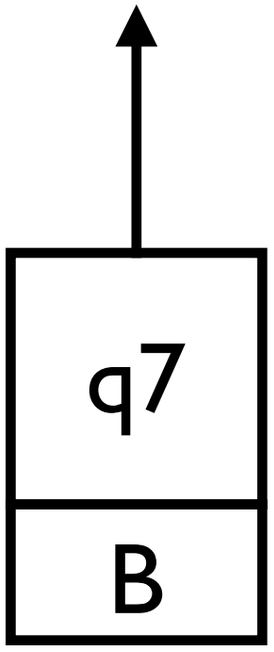


- If every symbols are checked, move right and enter q7

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

…	B	*	*	B	*	*	B	B	…
…	B	0	I	c	0	I	B	B	…

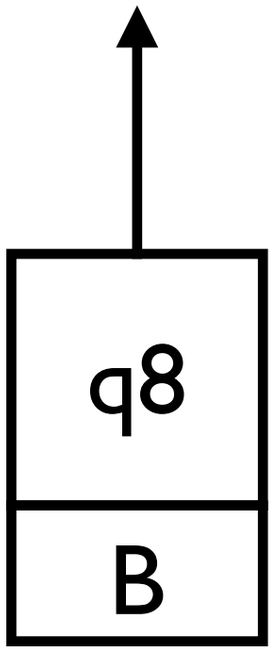


- If c is found, enter q8

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

…	B	*	*	B	*	*	B	B	…
…	B	0	I	c	0	I	B	B	…

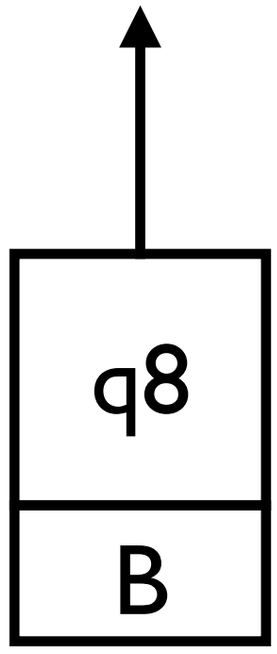


- move right until it finds B

$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

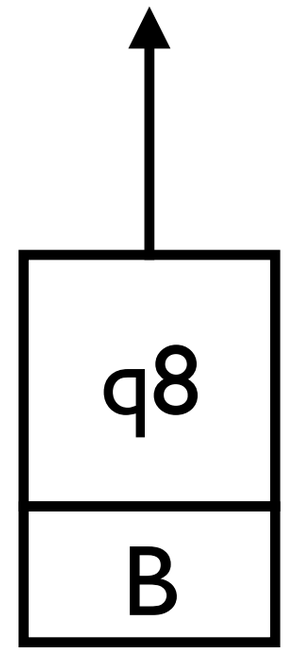
...	B	*	*	B	*	*	B	B	...
...	B	0	I	c	0	I	B	B	...



$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

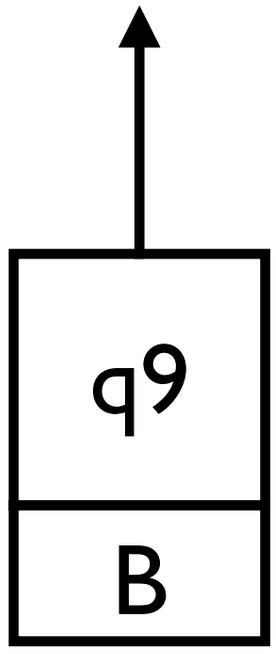
...	B	*	*	B	*	*	B	B	...
...	B	0	I	c	0	I	B	B	...



$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$

...	B	*	*	B	*	*	B	B	...
...	B	0	I	c	0	I	B	B	...



$\delta((q_1, B), (B, a)) = ((q_2, a), (*, a), R)$
$\delta((q_2, a), (B, b)) = ((q_2, a), (B, b), R)$
$\delta((q_2, a), (B, c)) = ((q_3, a), (B, c), R)$
$\delta((q_3, a), (*, b)) = ((q_3, a), (*, b), R)$
$\delta((q_3, a), (B, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (*, a)) = ((q_4, B), (*, a), L)$
$\delta((q_4, B), (B, c)) = ((q_5, B), (B, c), L)$

$\delta((q_5, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (B, a)) = ((q_6, B), (B, a), L)$
$\delta((q_6, B), (*, a)) = ((q_1, B), (*, a), R)$
$\delta((q_5, B), (*, a)) = ((q_7, B), (*, a), R)$
$\delta((q_7, B), (B, c)) = ((q_8, B), (B, c), R)$
$\delta((q_8, B), (*, a)) = ((q_8, B), (*, a), R)$
$\delta((q_8, B), (B, B)) = ((q_9, B), (B, B), R)$