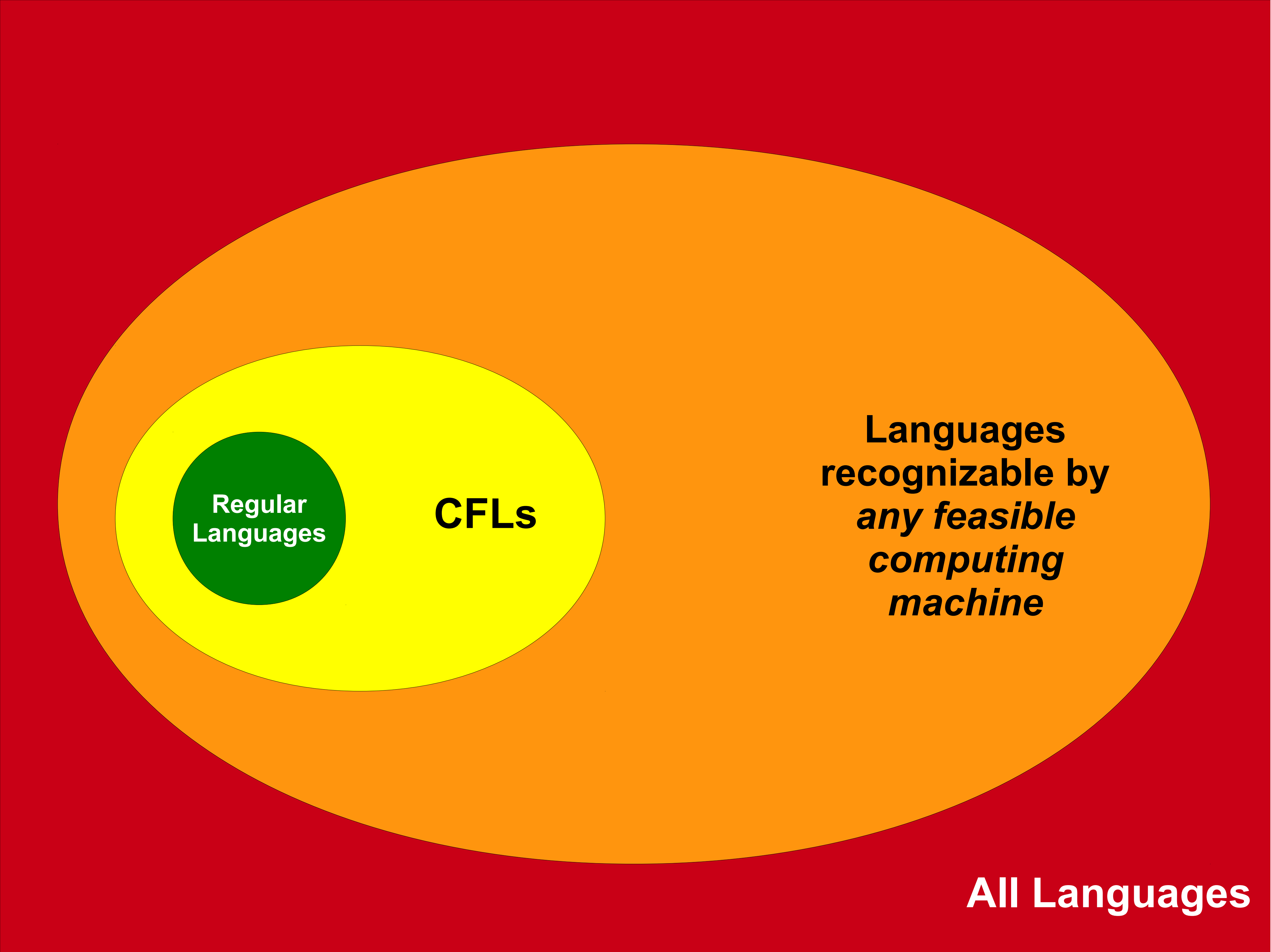
Turing Machines

Part One

Are some problems inherently harder than others?



Regular Languages

CFLs

Languages recognizable by *any feasible computing machine*

All Languages

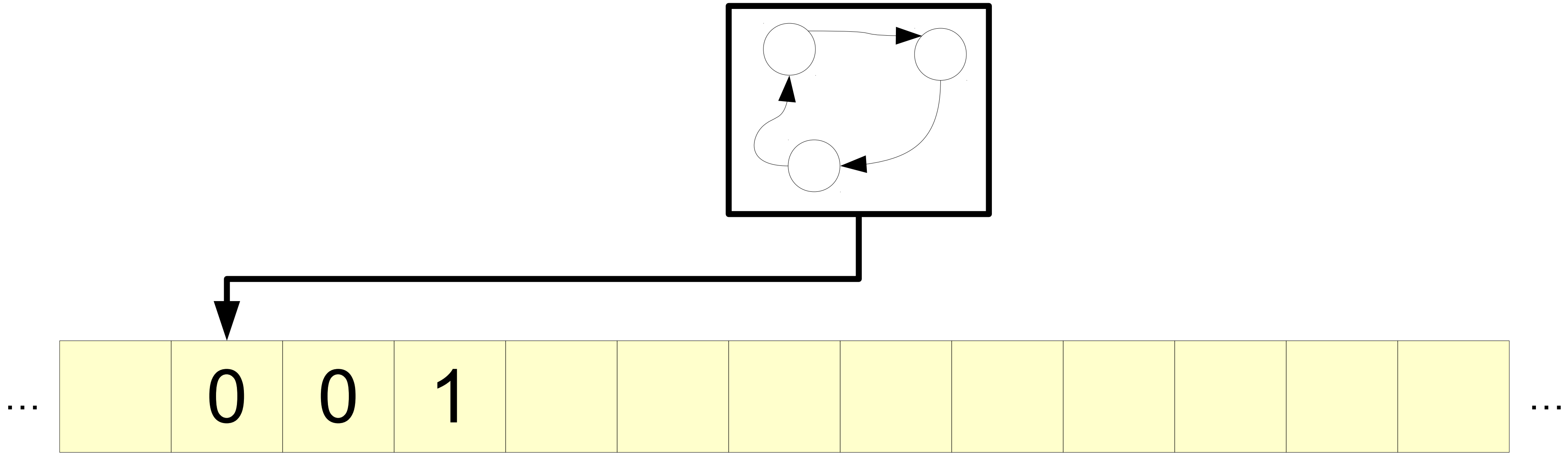
That same drawing, to scale.

The Problem

- Finite automata accept precisely the regular languages.
- We may need unbounded memory to recognize context-free languages.
  - e.g. { $\mathtt{a}^n\mathtt{b}^n$ | $n \in \mathbb{N}$ } requires unbounded counting.
- How do we build an automaton with finitely many states but unbounded memory?

A Better Memory Device

- A ***Turing machine*** is a finite automaton equipped with an ***infinite tape*** as its memory.
- The input is written on the tape when the computation begins, surrounded by infinitely many blank cells.
- Each transition depends on the current symbol under the tape head.



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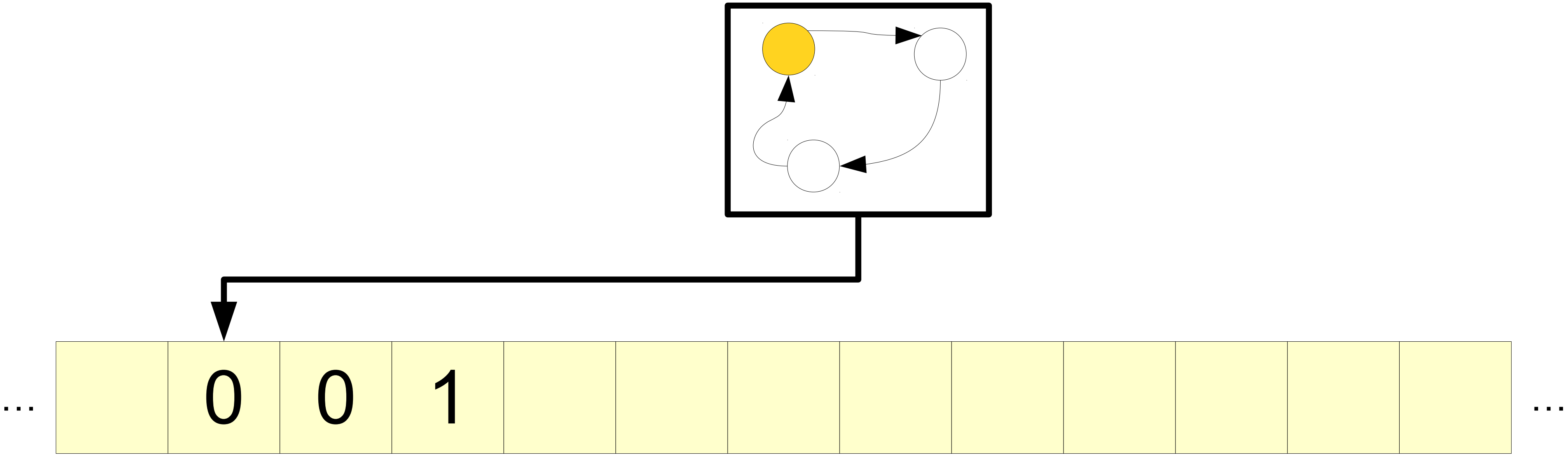

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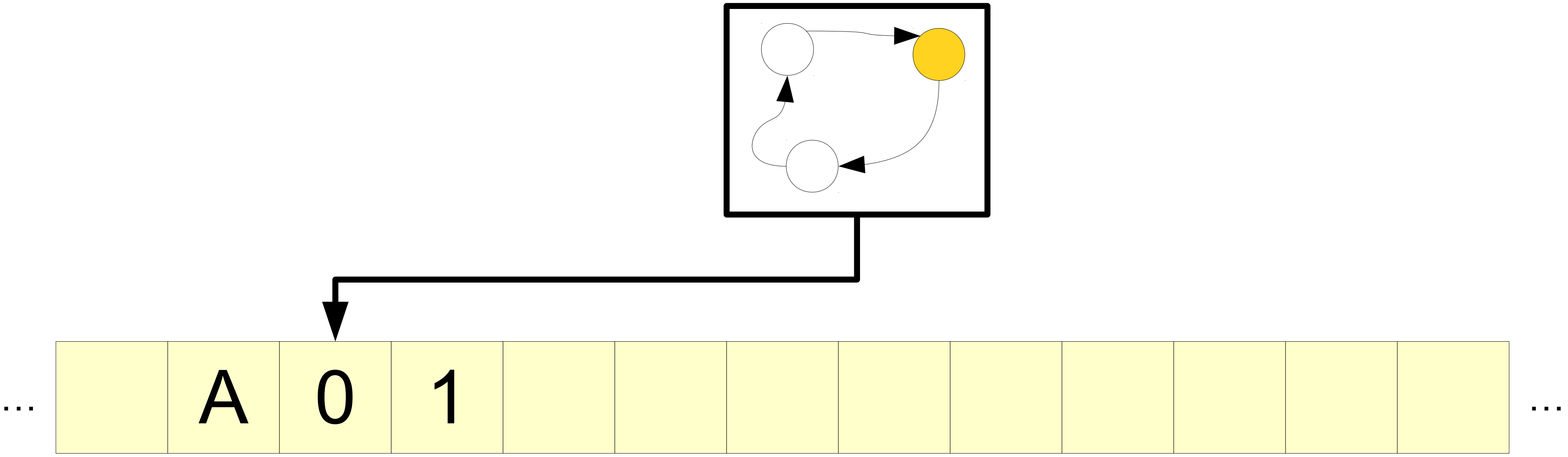

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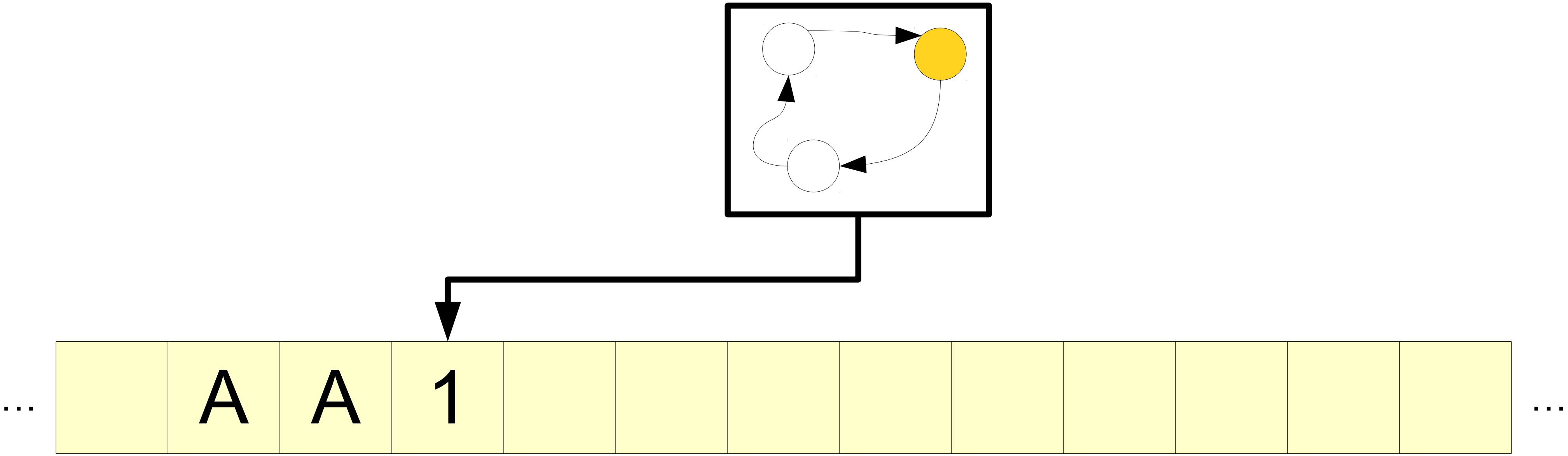

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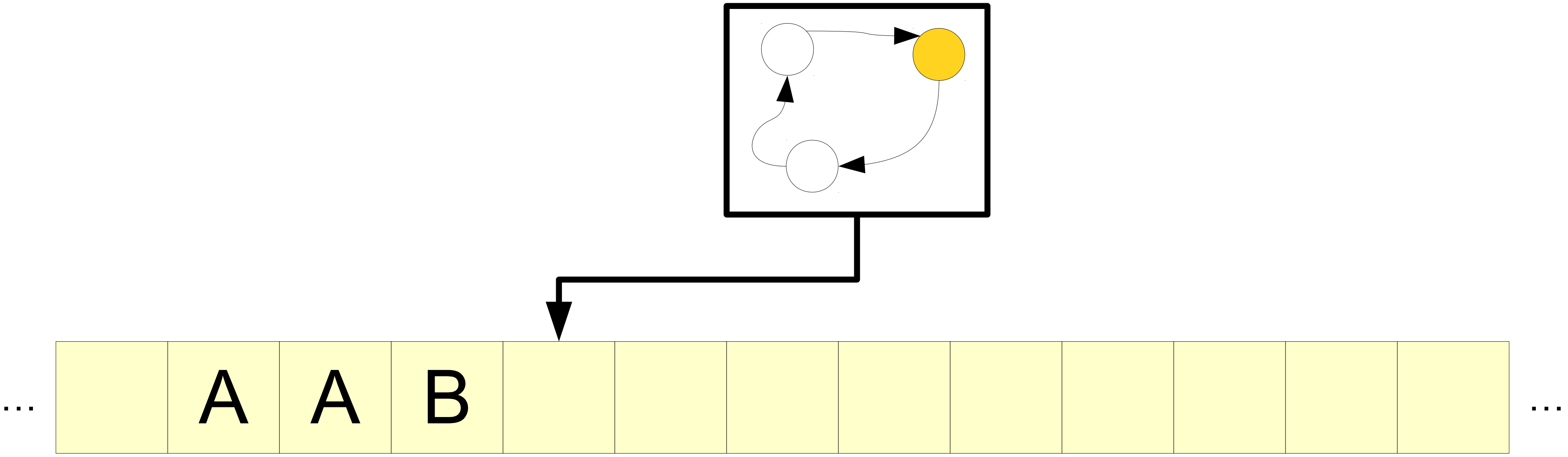

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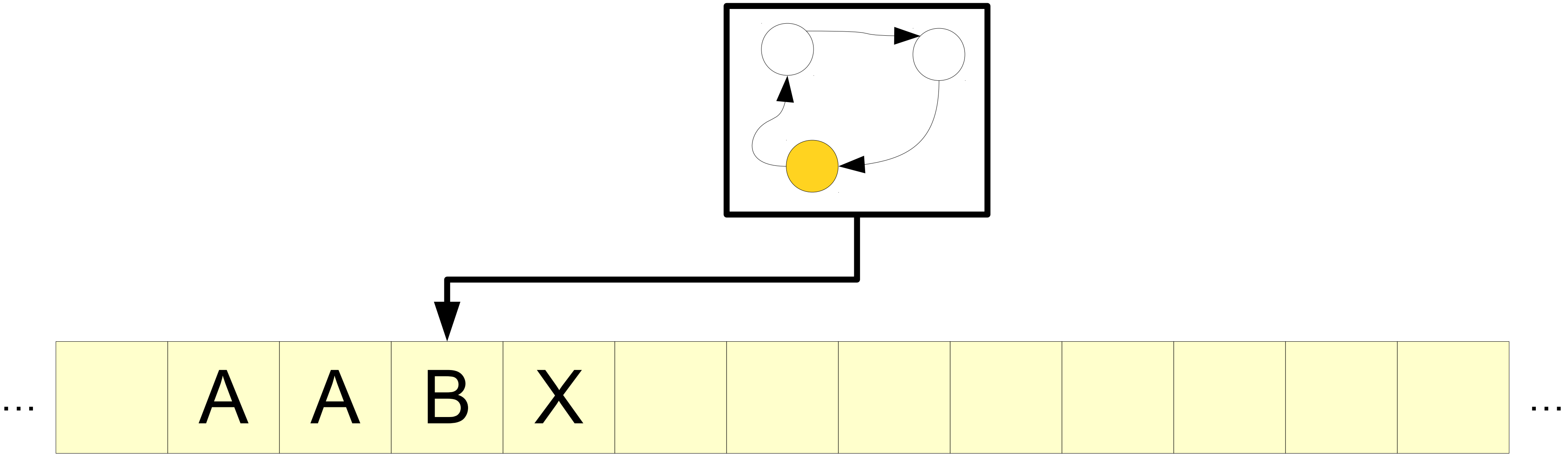

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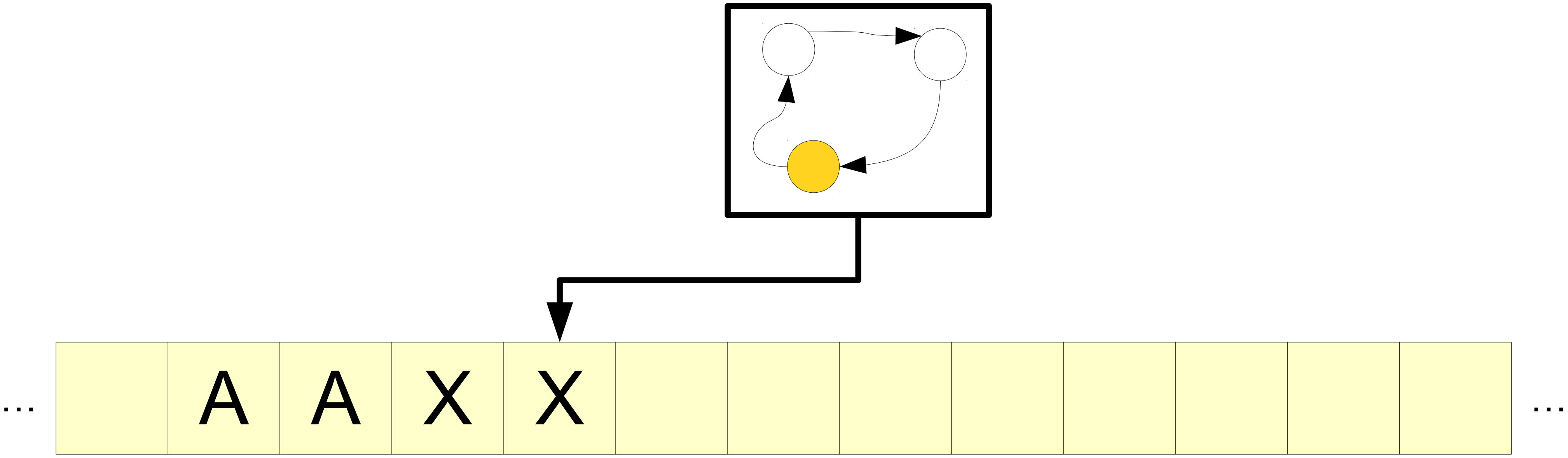

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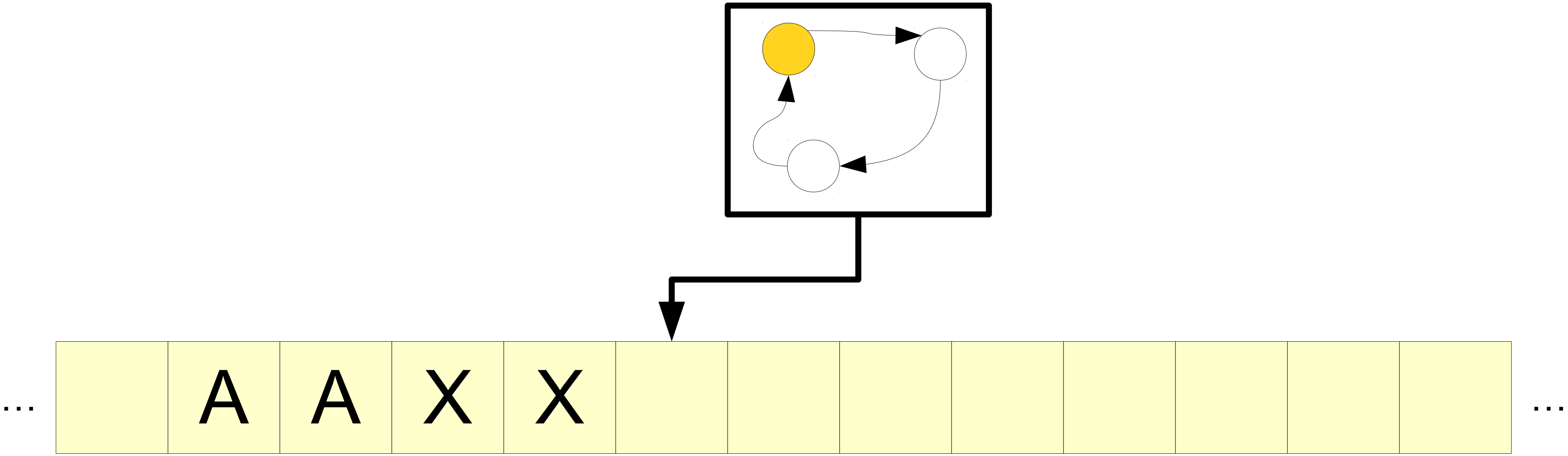

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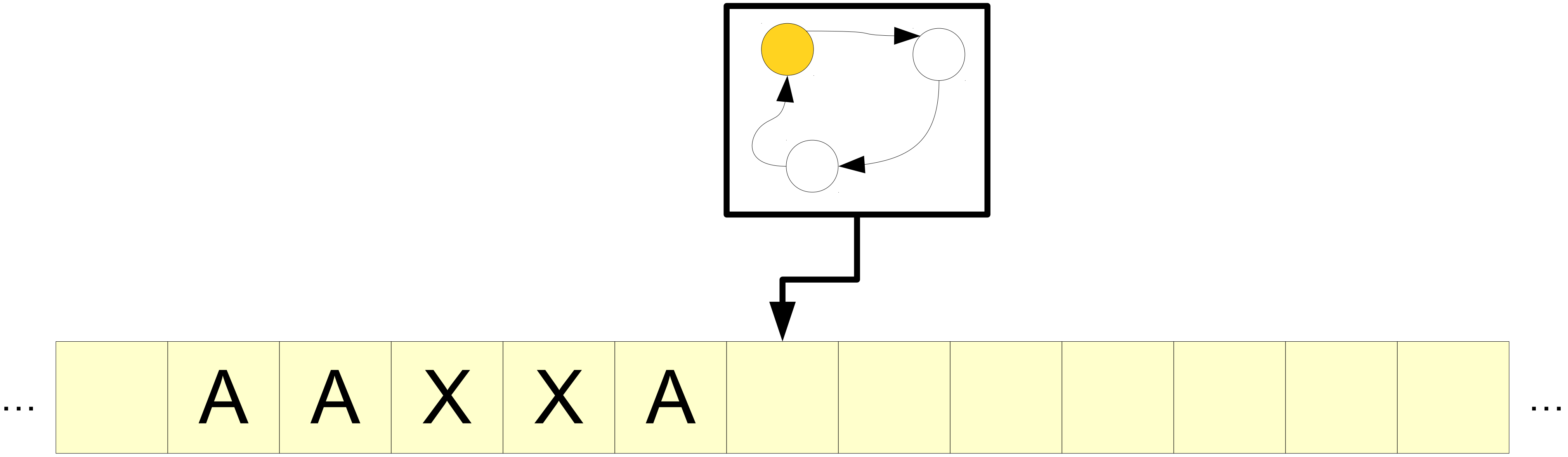

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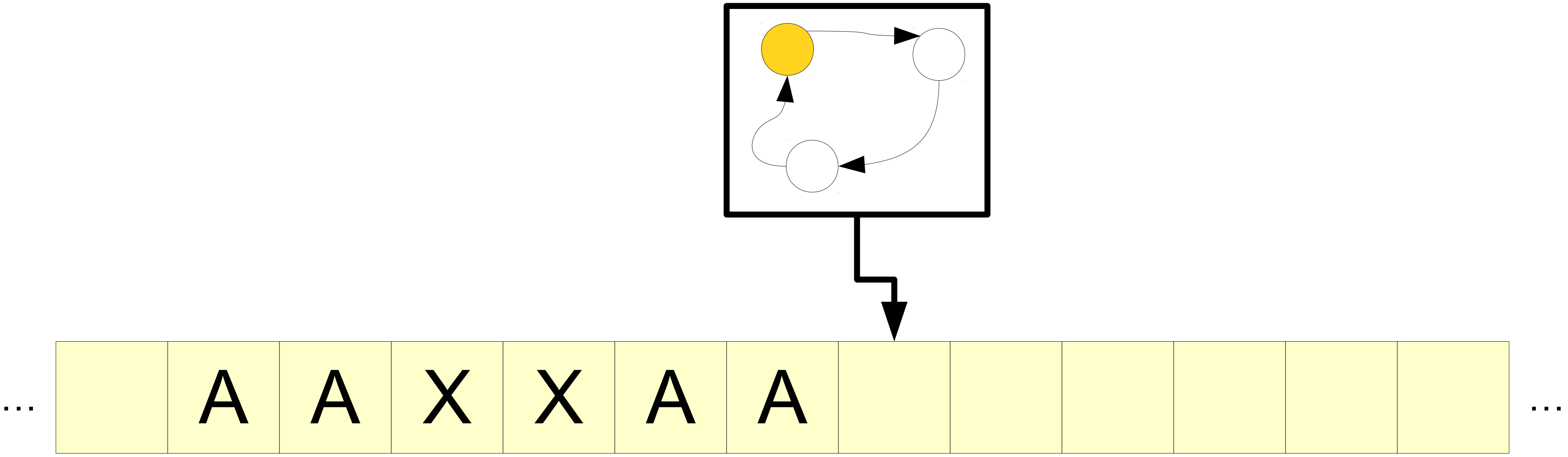

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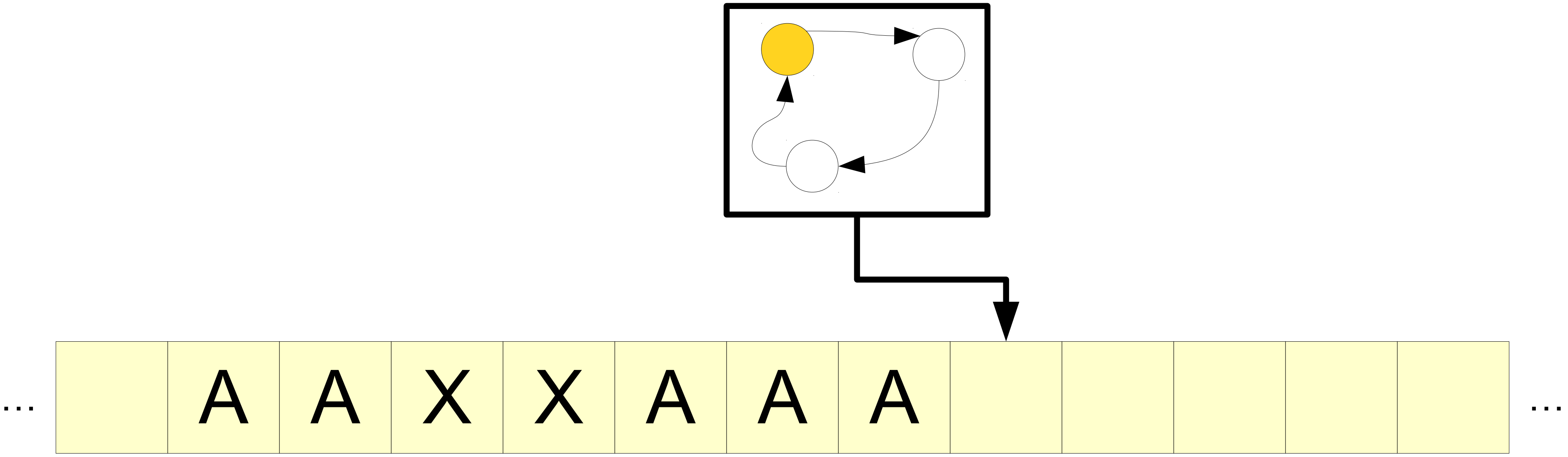


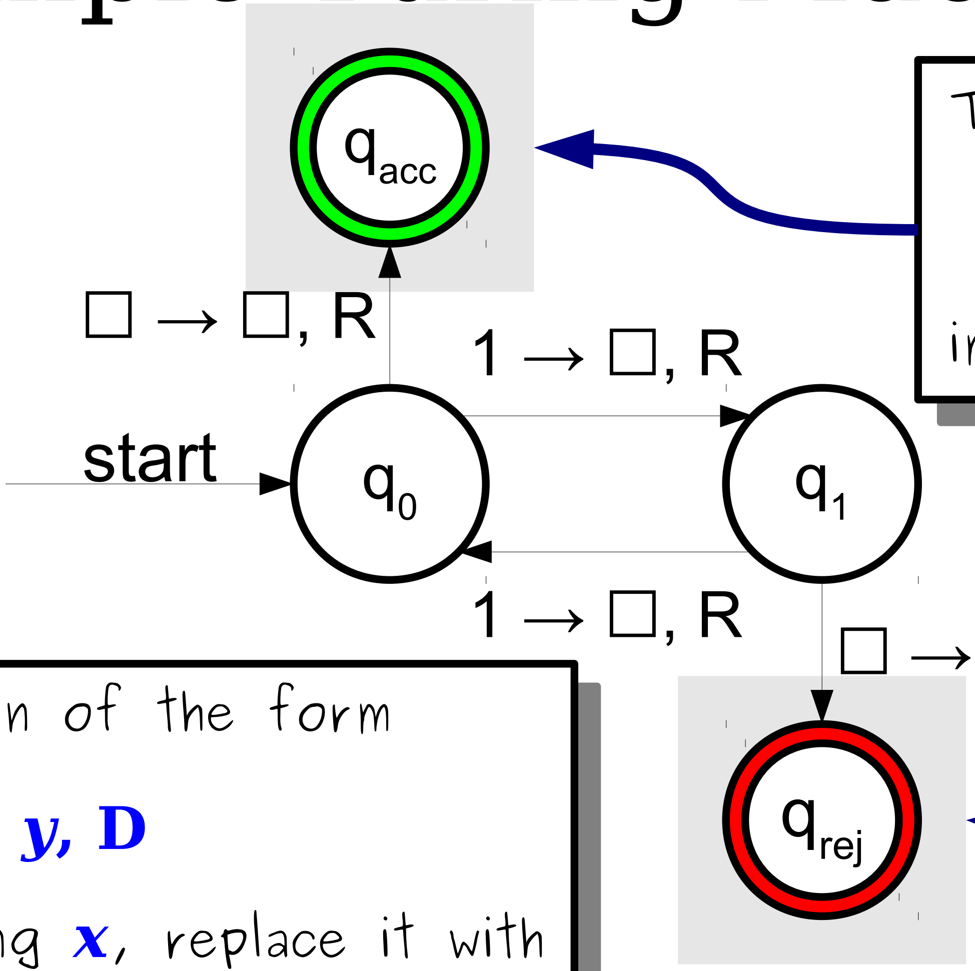
The Turing Machine

- A Turing machine consists of three parts:
  - A ***finite-state control*** that issues commands,
  - an ***infinite tape*** for input and scratch space, and
  - a ***tape head*** that can read and write a single tape cell.
- At each step, the Turing machine
  - writes a symbol to the tape cell under the tape head,
  - changes state, and
  - moves the tape head to the left or to the right.

Input and Tape Alphabets

- A Turing machine has two alphabets:
  - An ***input alphabet*** Σ. All input strings are written in the input alphabet.
  - A ***tape alphabet*** Γ, where Σ ⊆ Γ. The tape alphabet contains all symbols that can be written onto the tape.
- The tape alphabet Γ can contain any number of symbols, but always contains at least one ***blank symbol***, denoted ☐. You are guaranteed ☐ ∉ Σ.
- At startup, the Turing machine begins with an infinite tape of ☐ symbols with the input written at some location. The tape head is positioned at the start of the input.

A Simple Turing Machine



This special accept state causes the machine to immediately accept.

This special reject state causes the machine to immediately reject.

Each transition of the form

x → y, D

means “upon reading **x**, replace it with symbol **y** and move the tape head in direction **D** (which is either **L** or **R**). The symbol □ represents the blank symbol.

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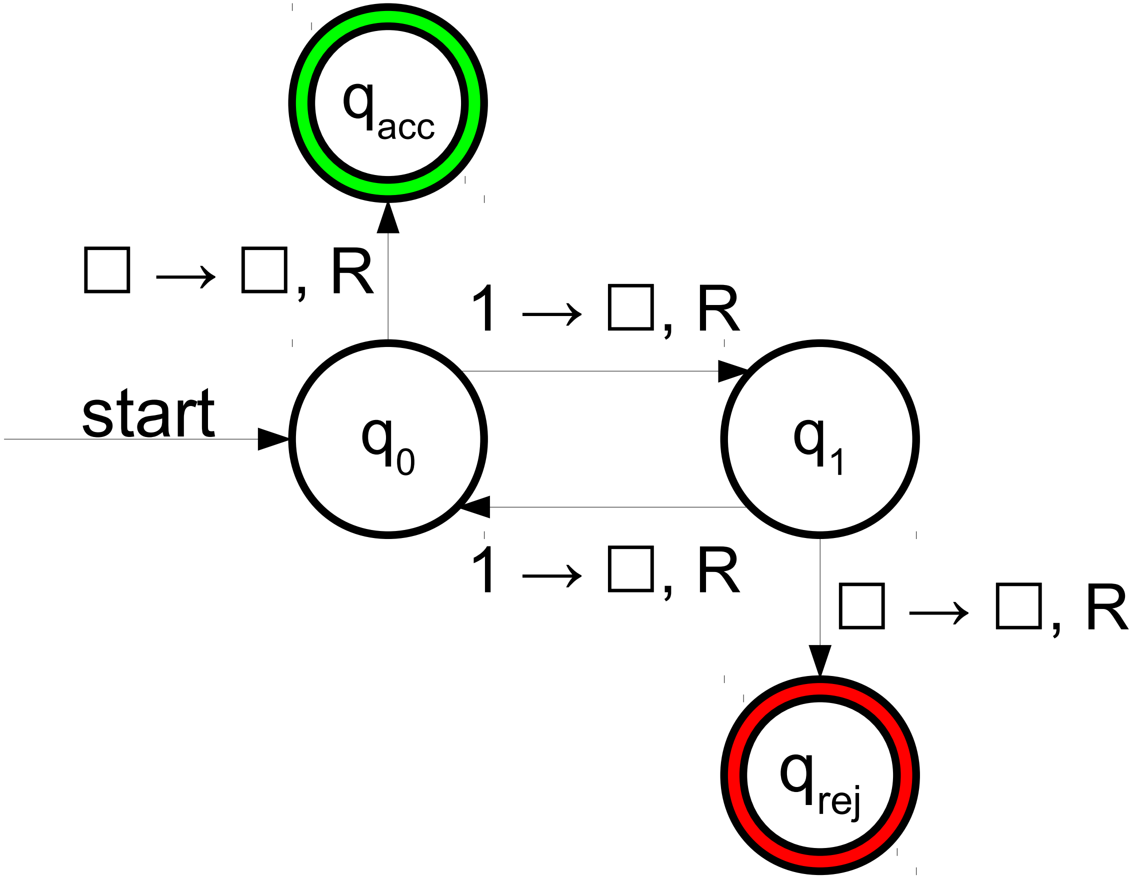

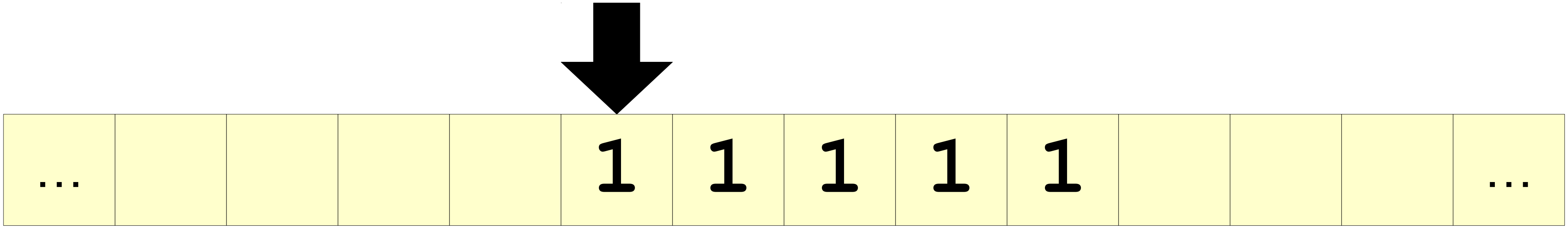

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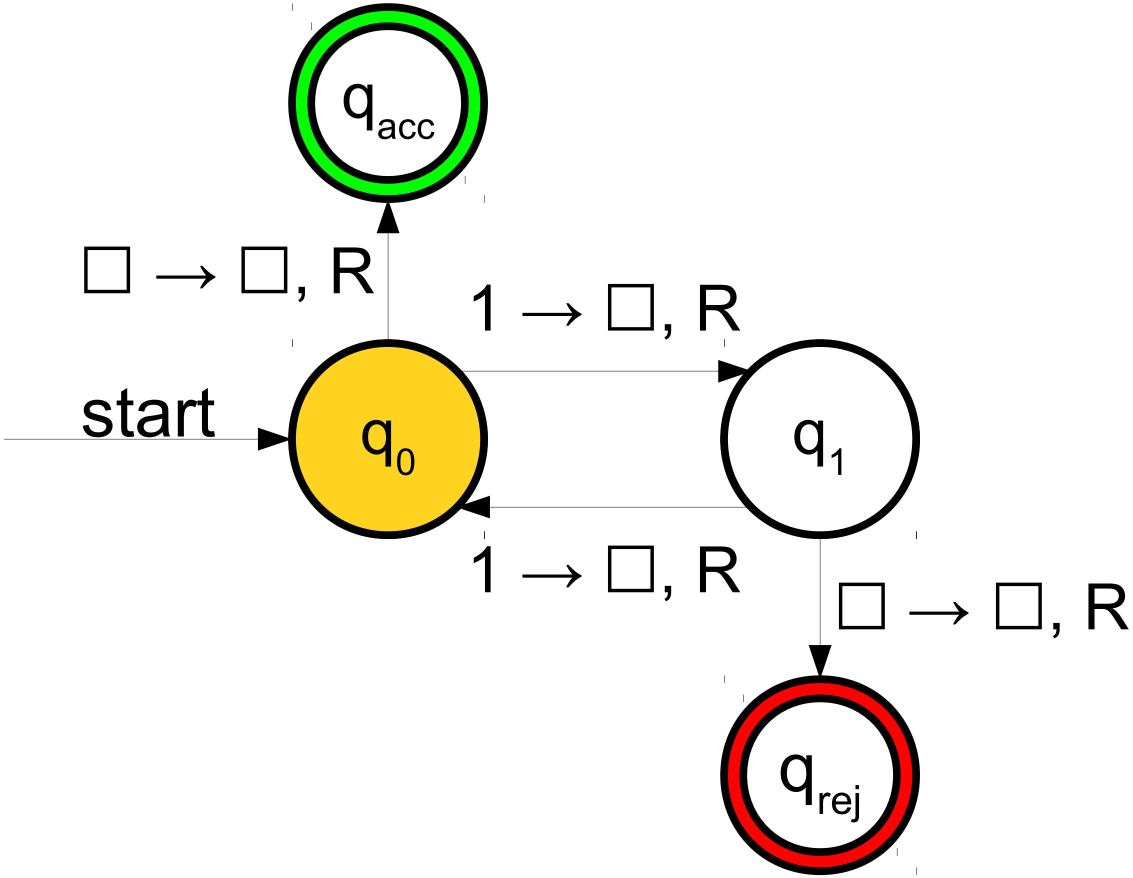

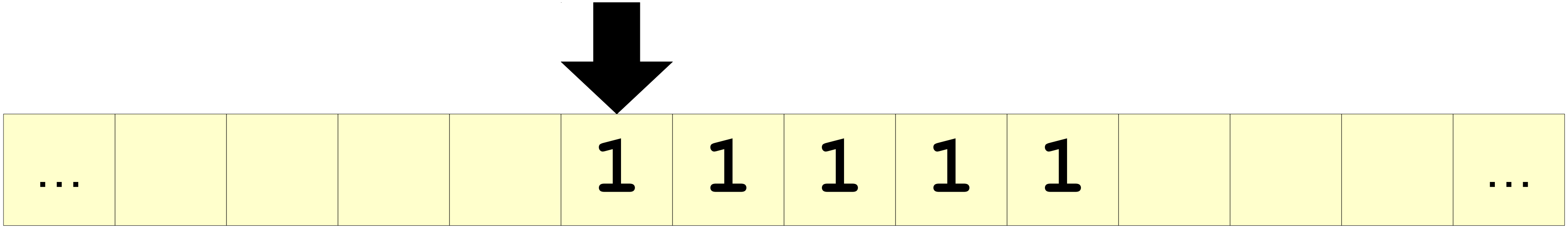

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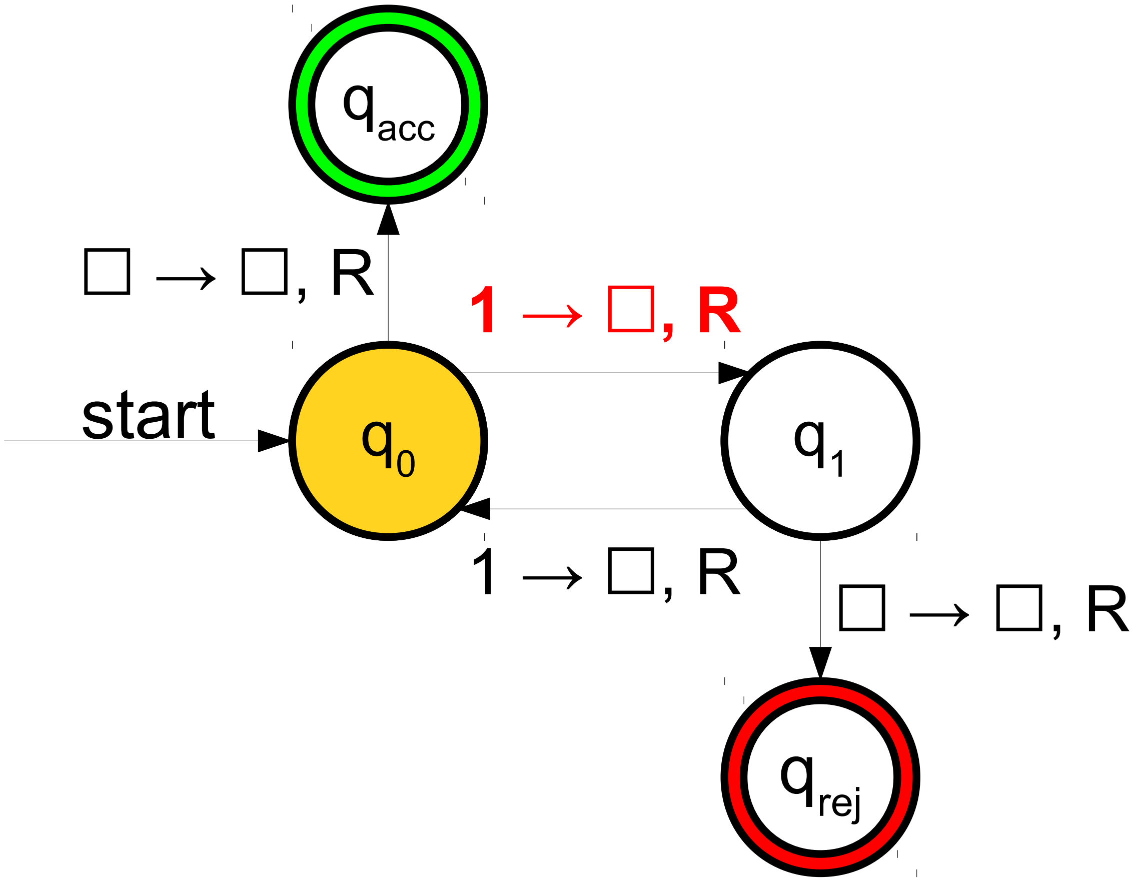

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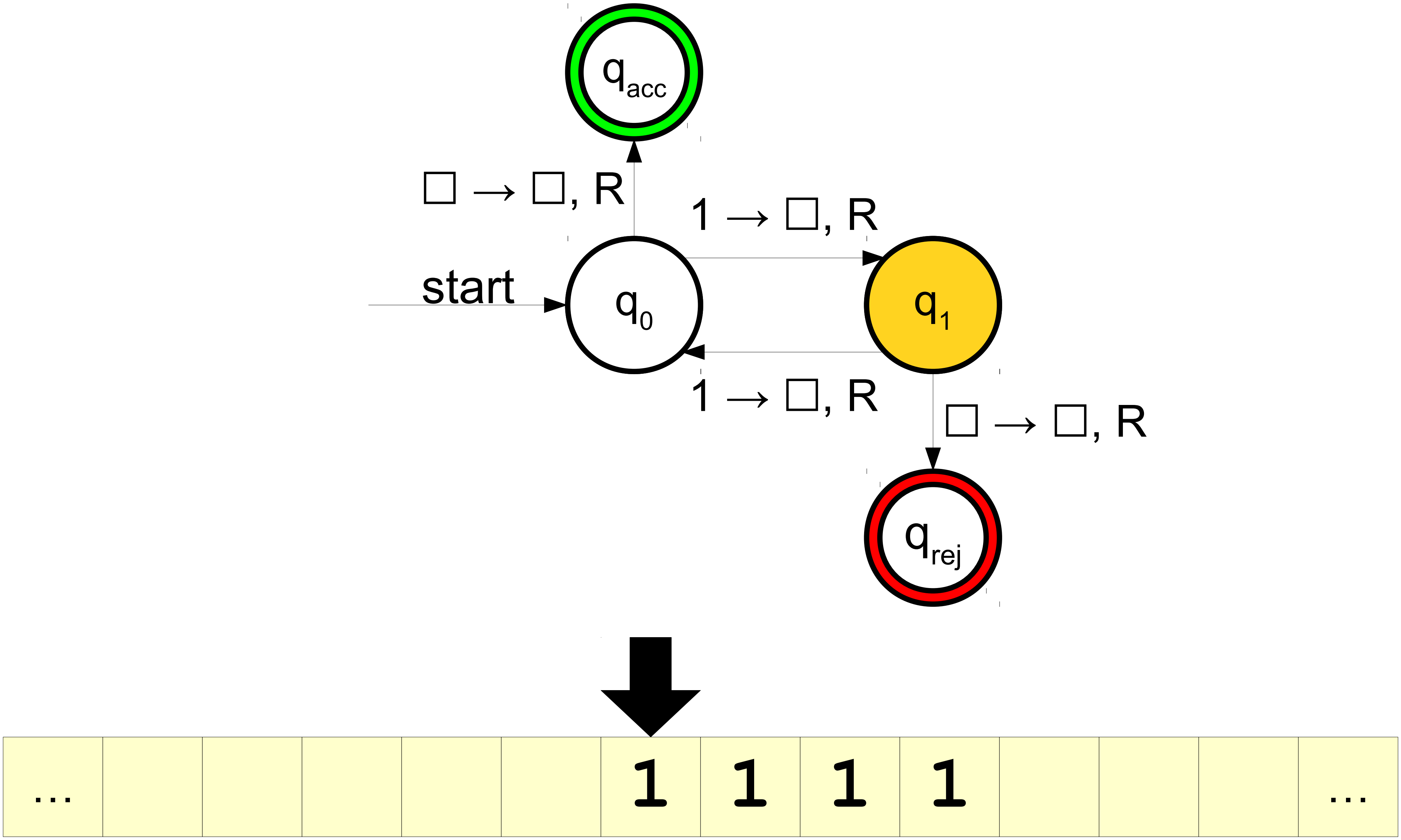

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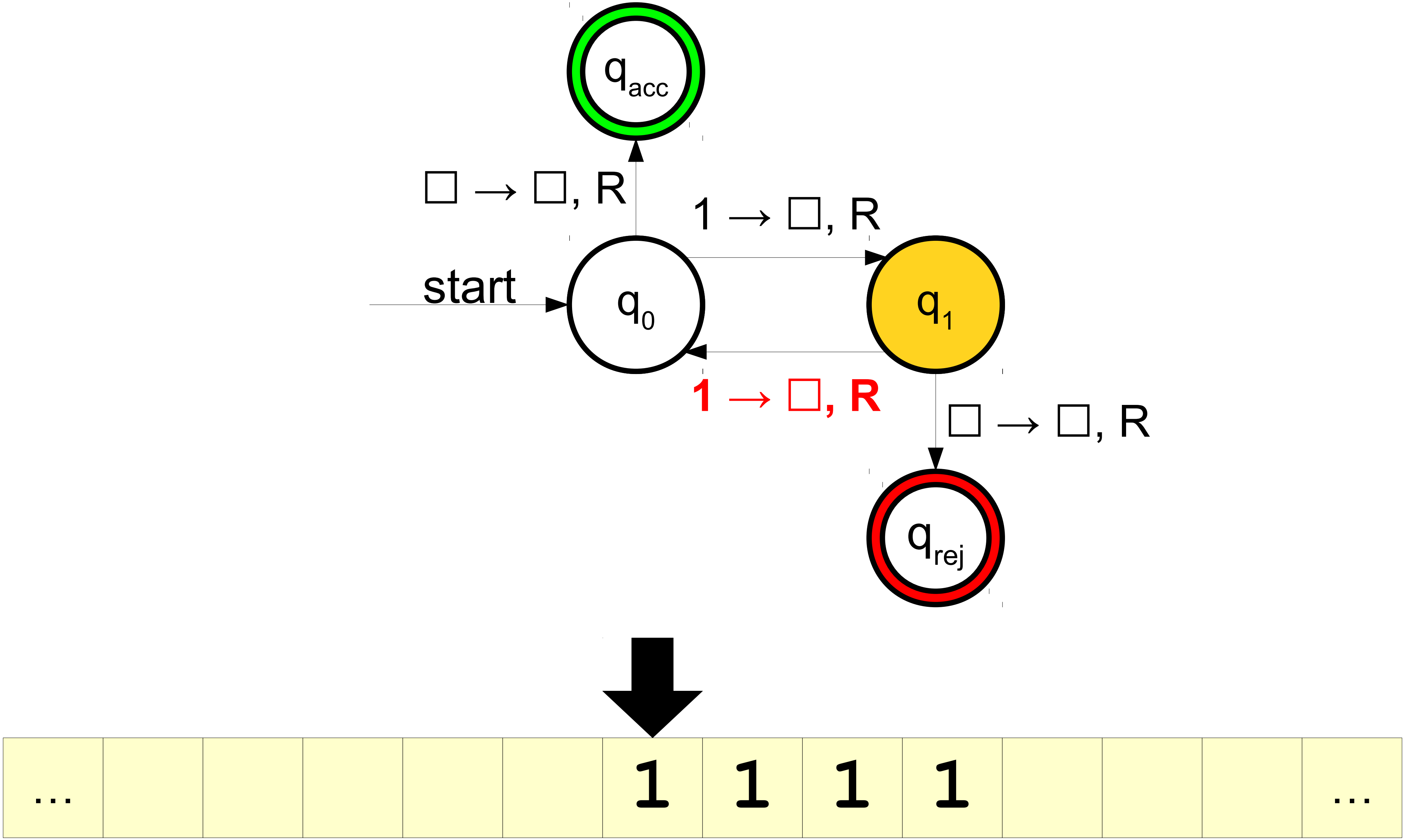

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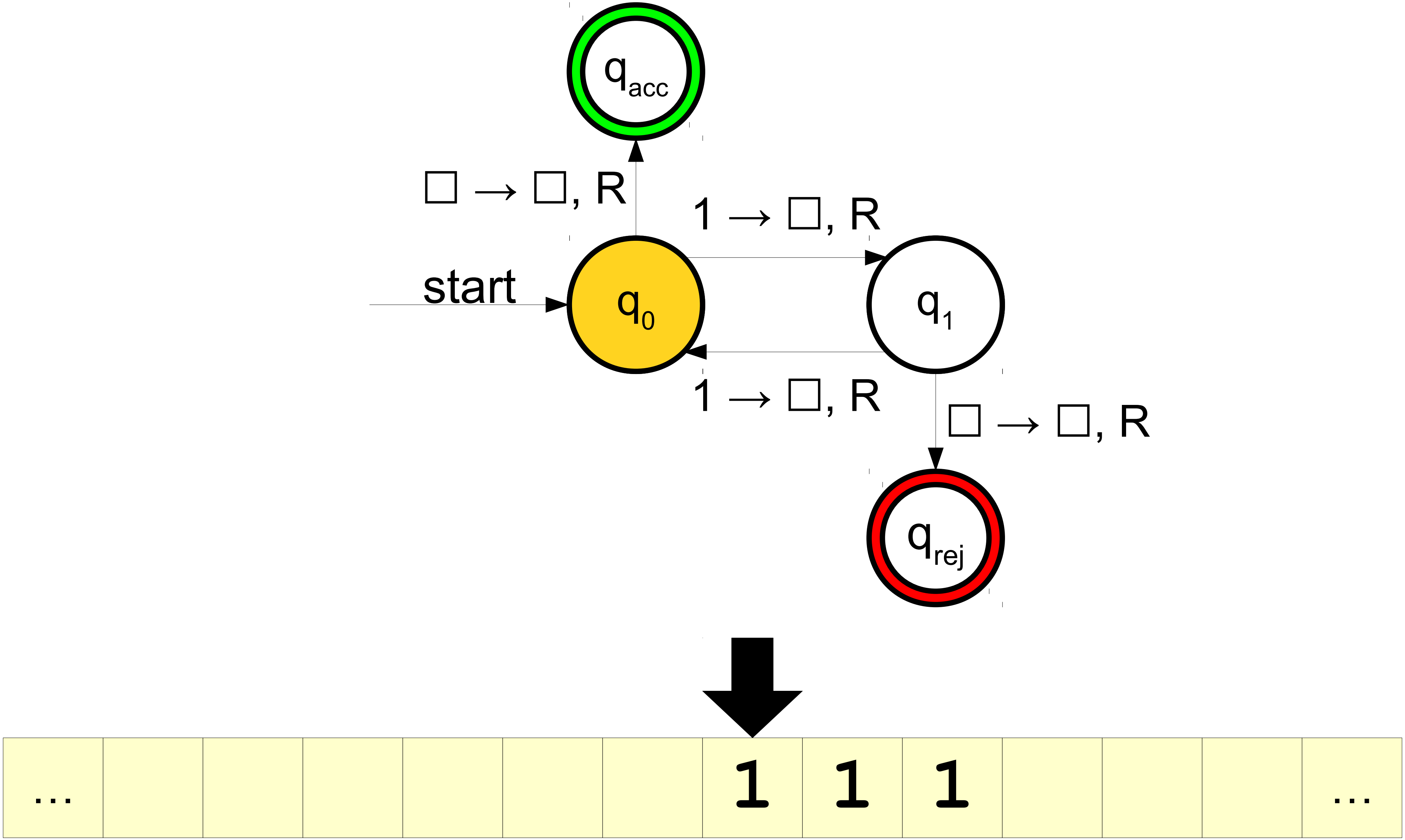

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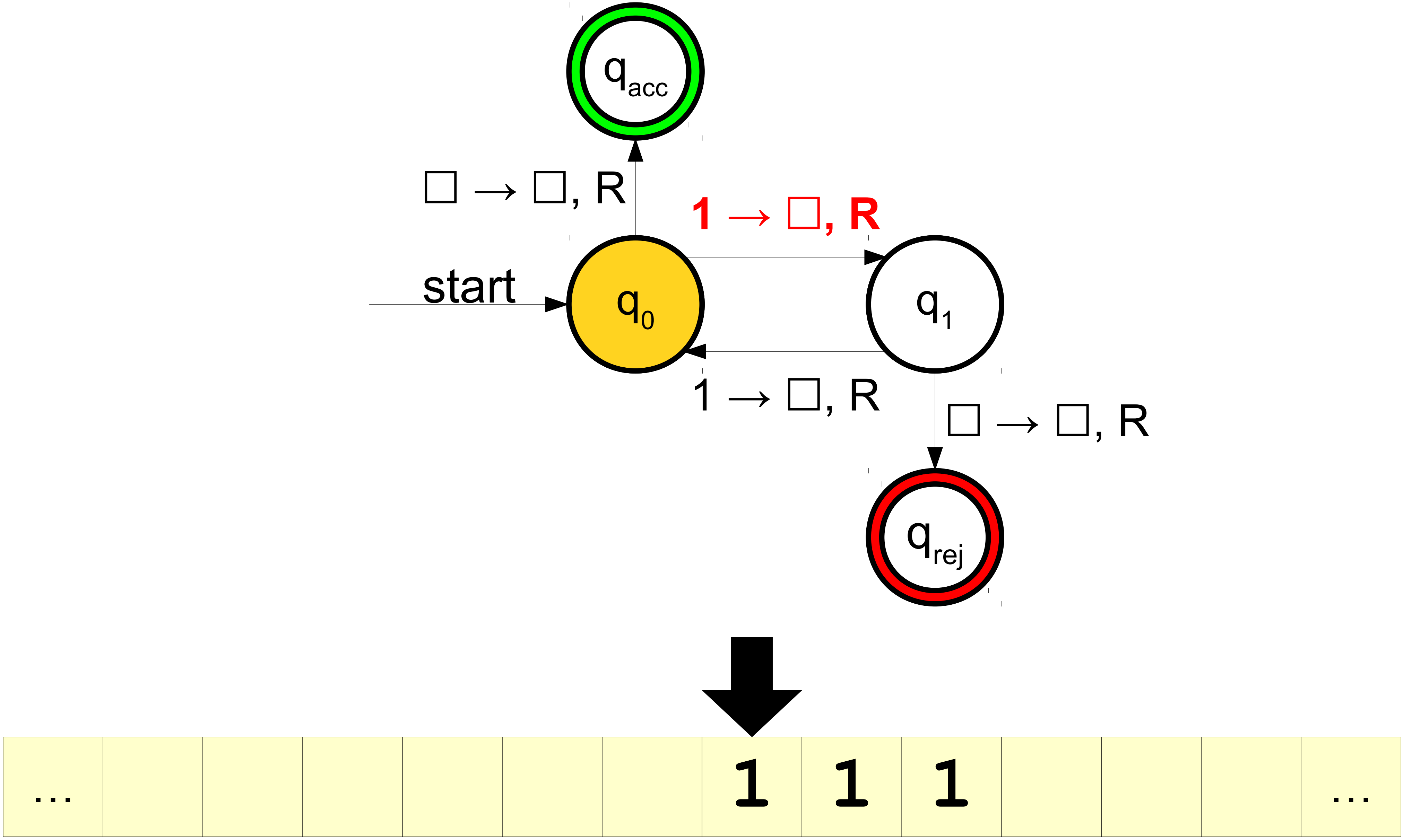

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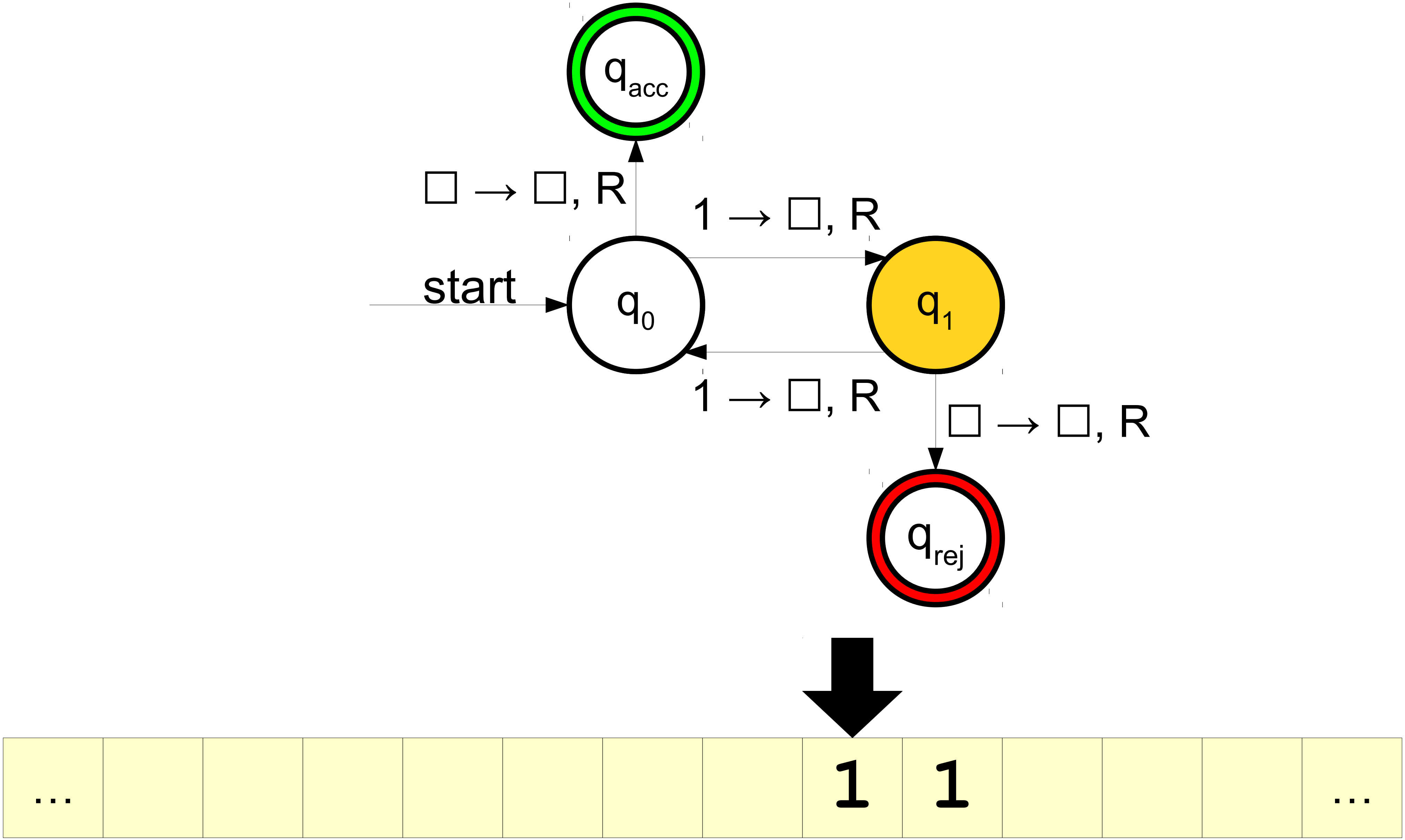

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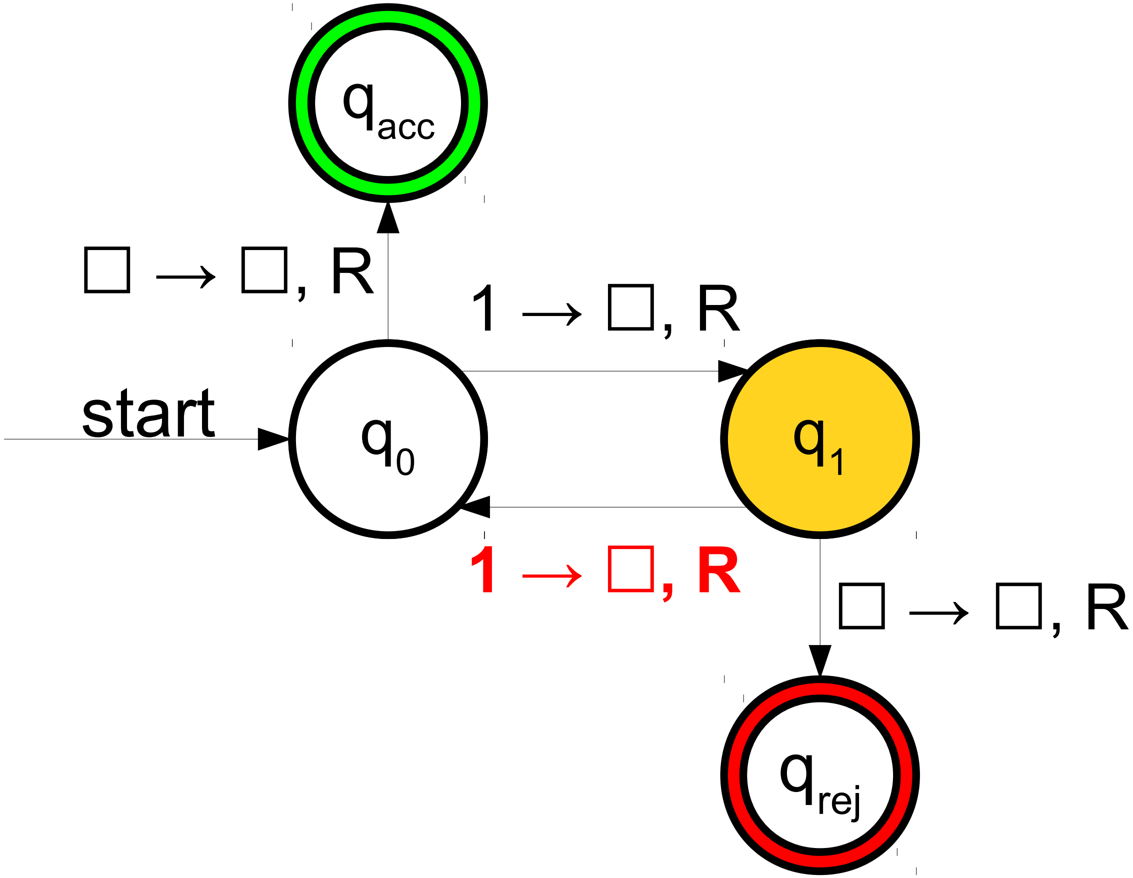

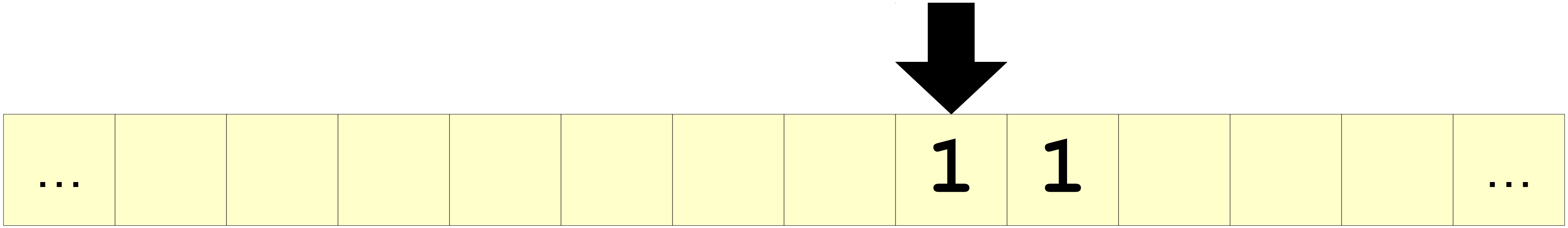

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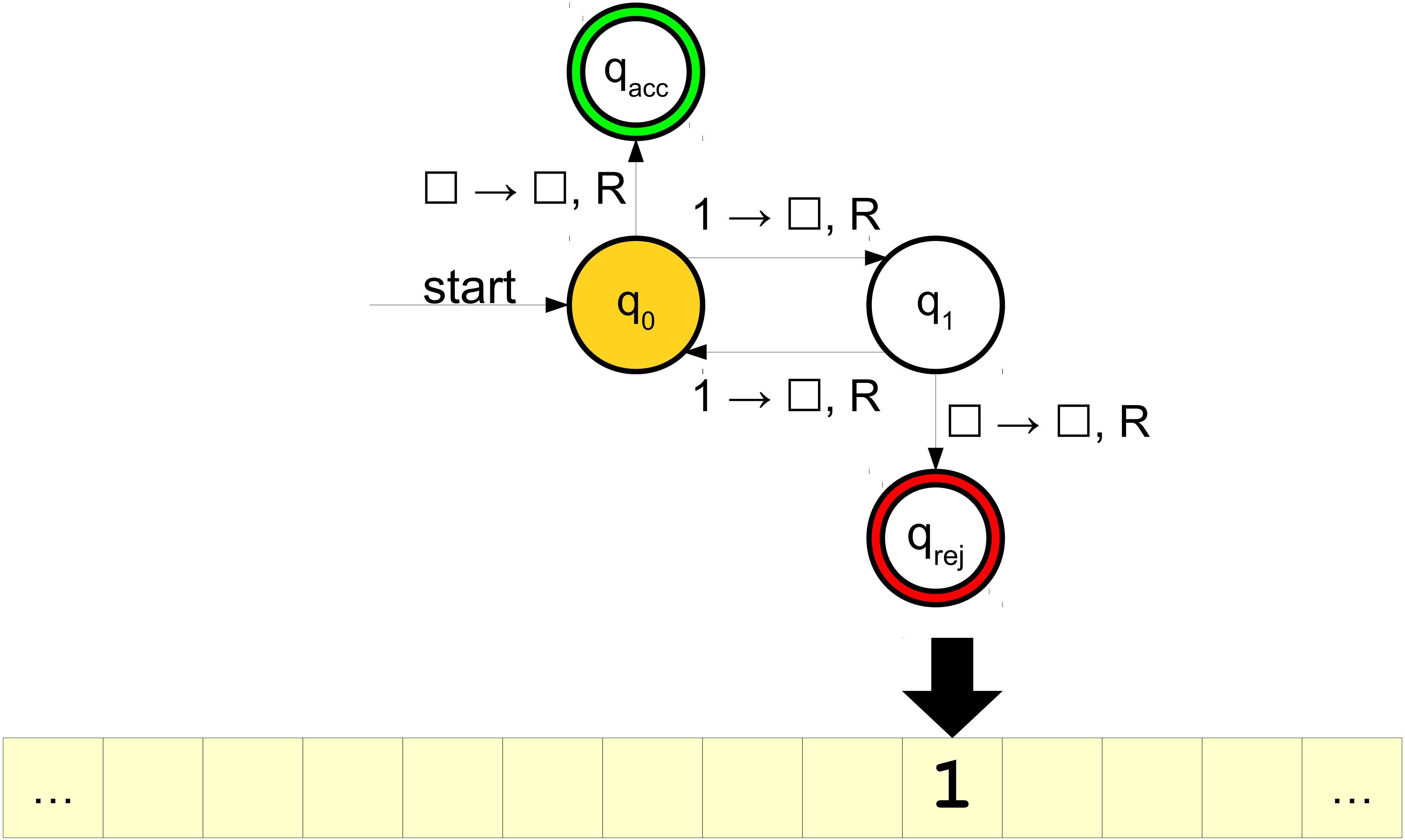

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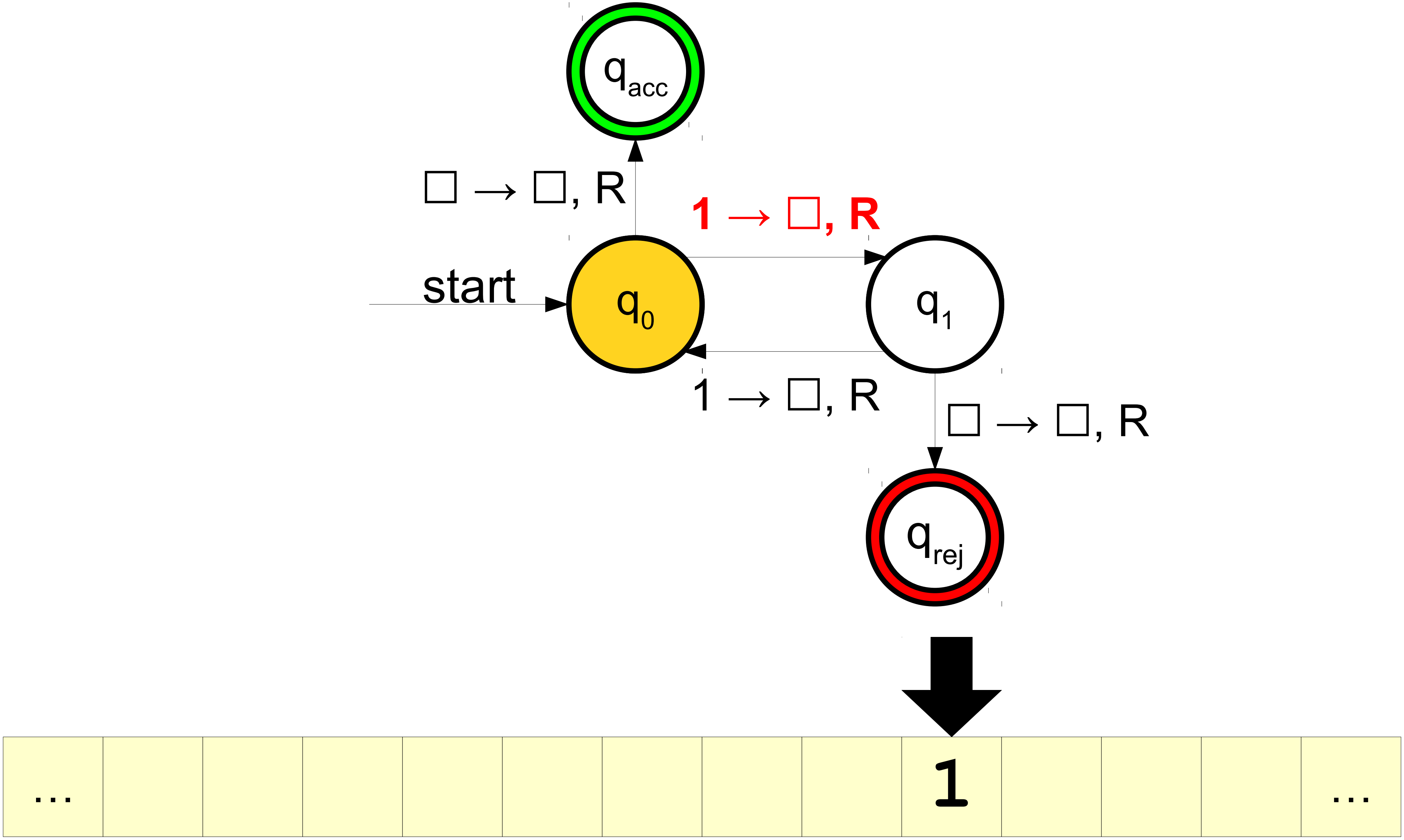

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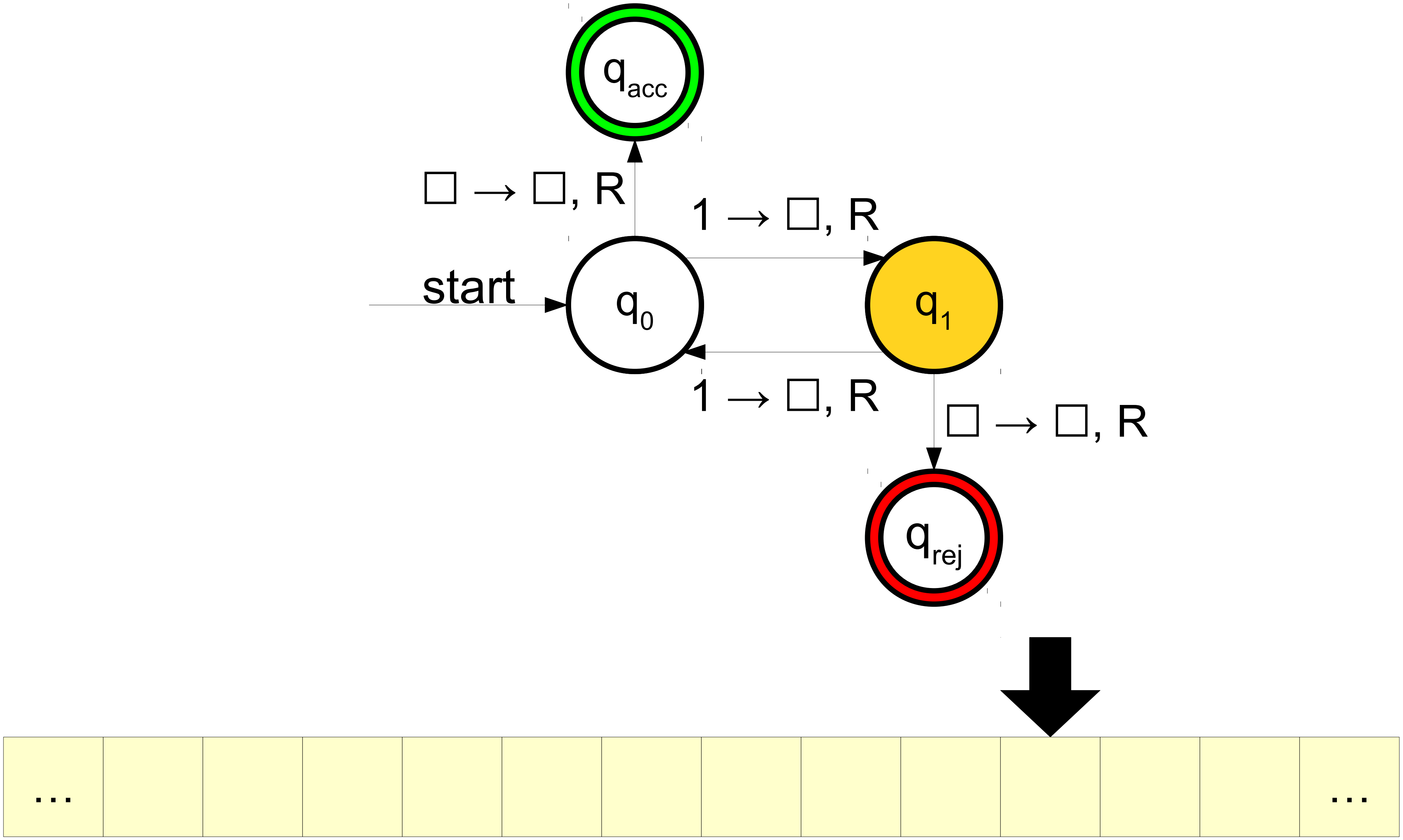

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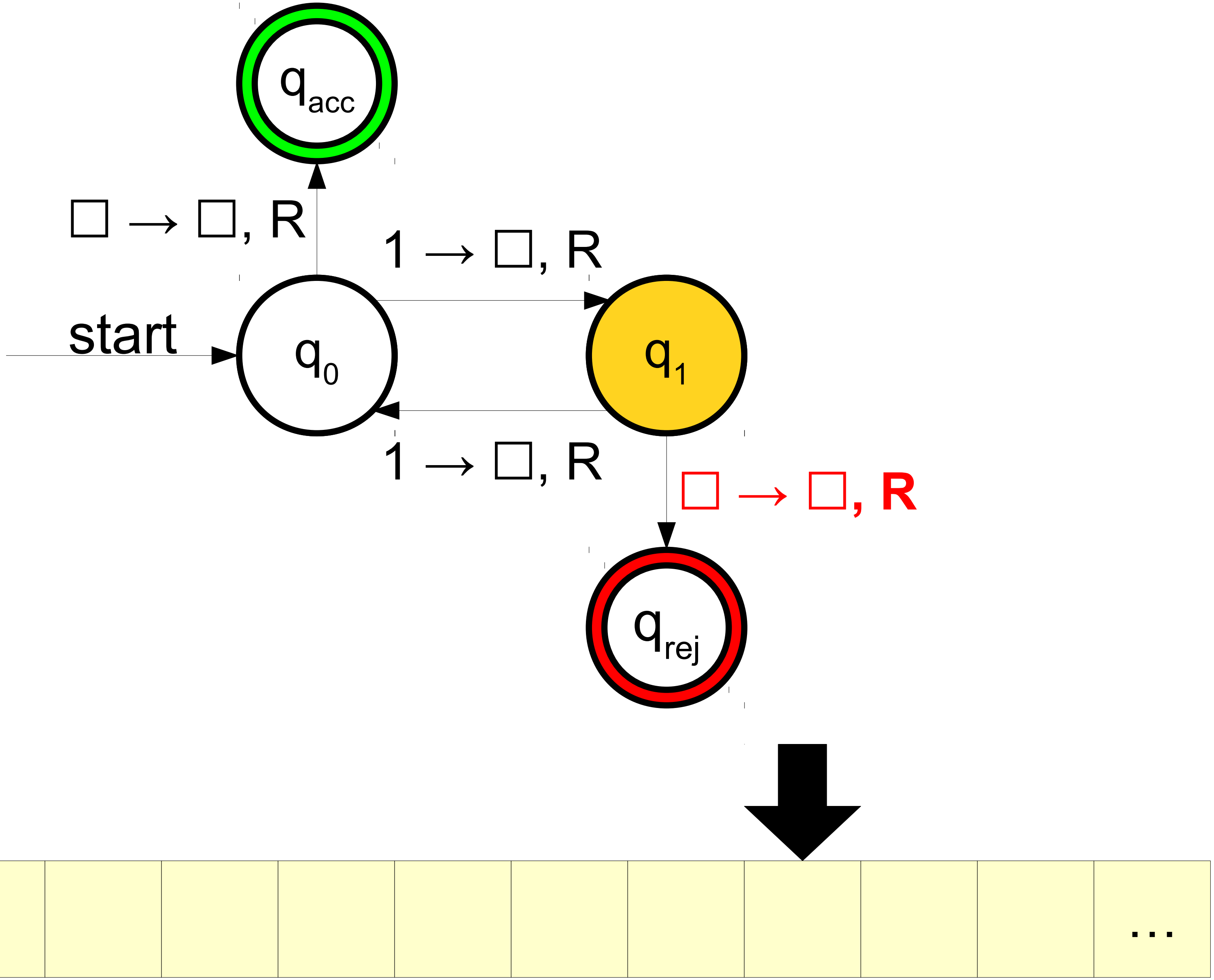

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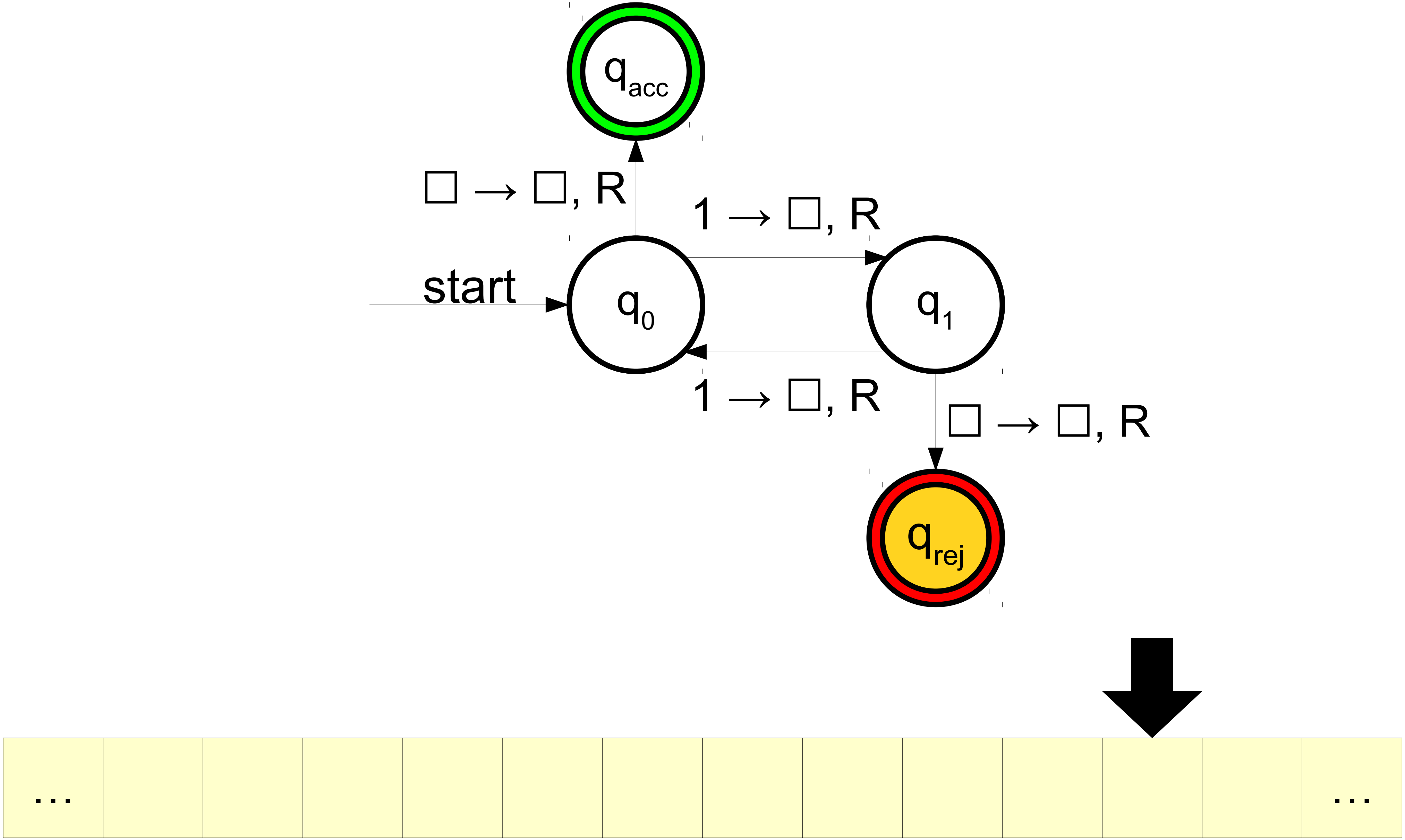

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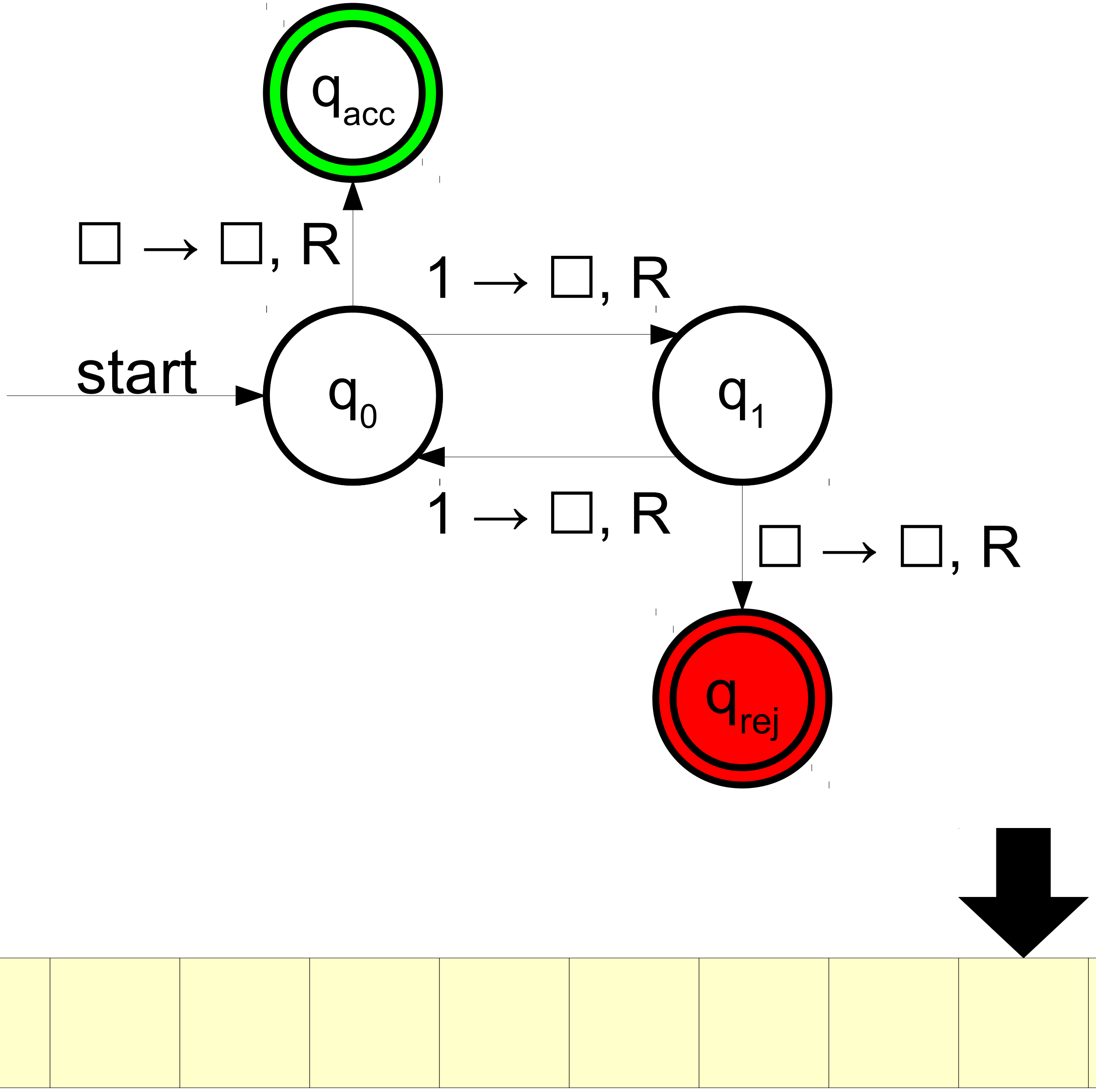

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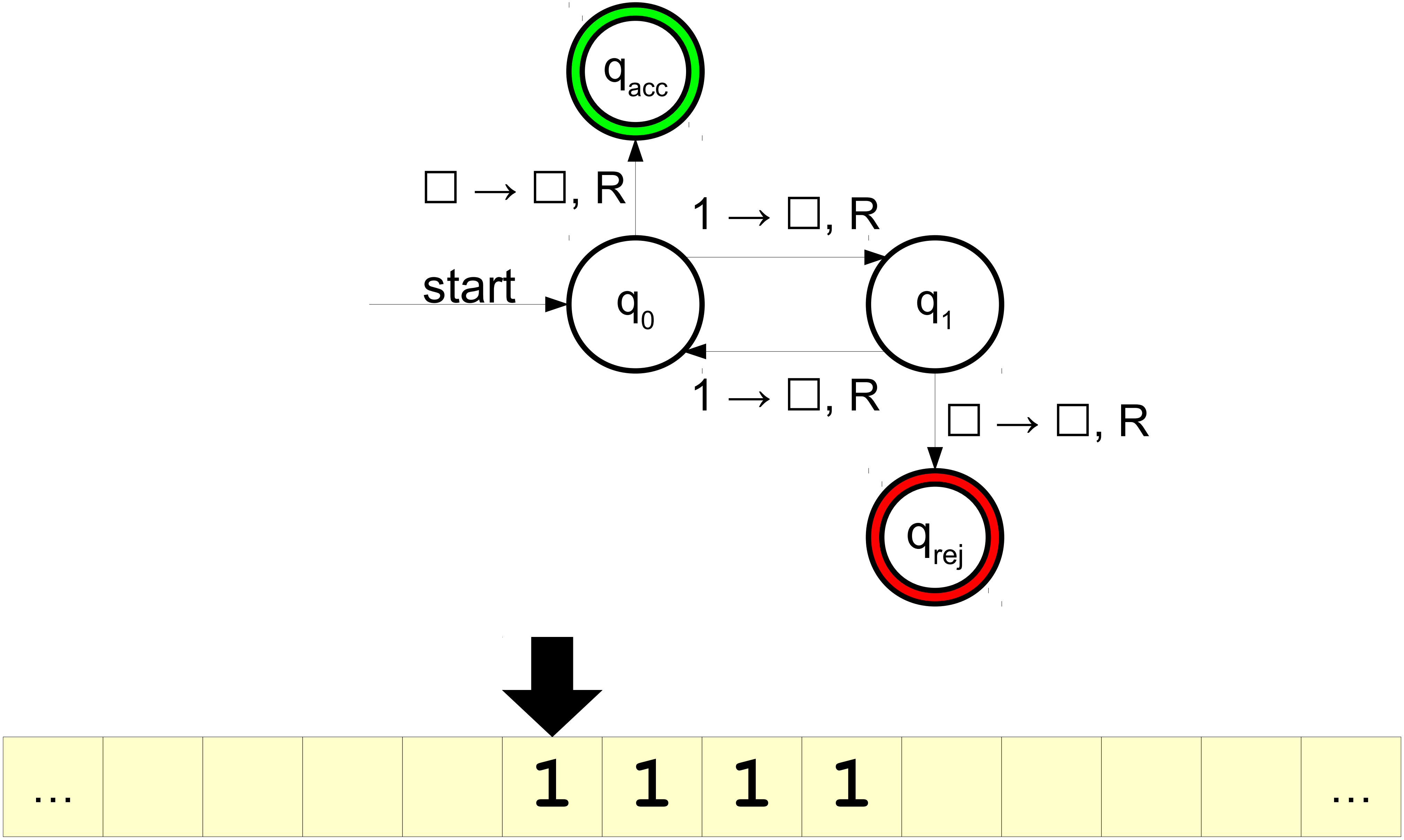

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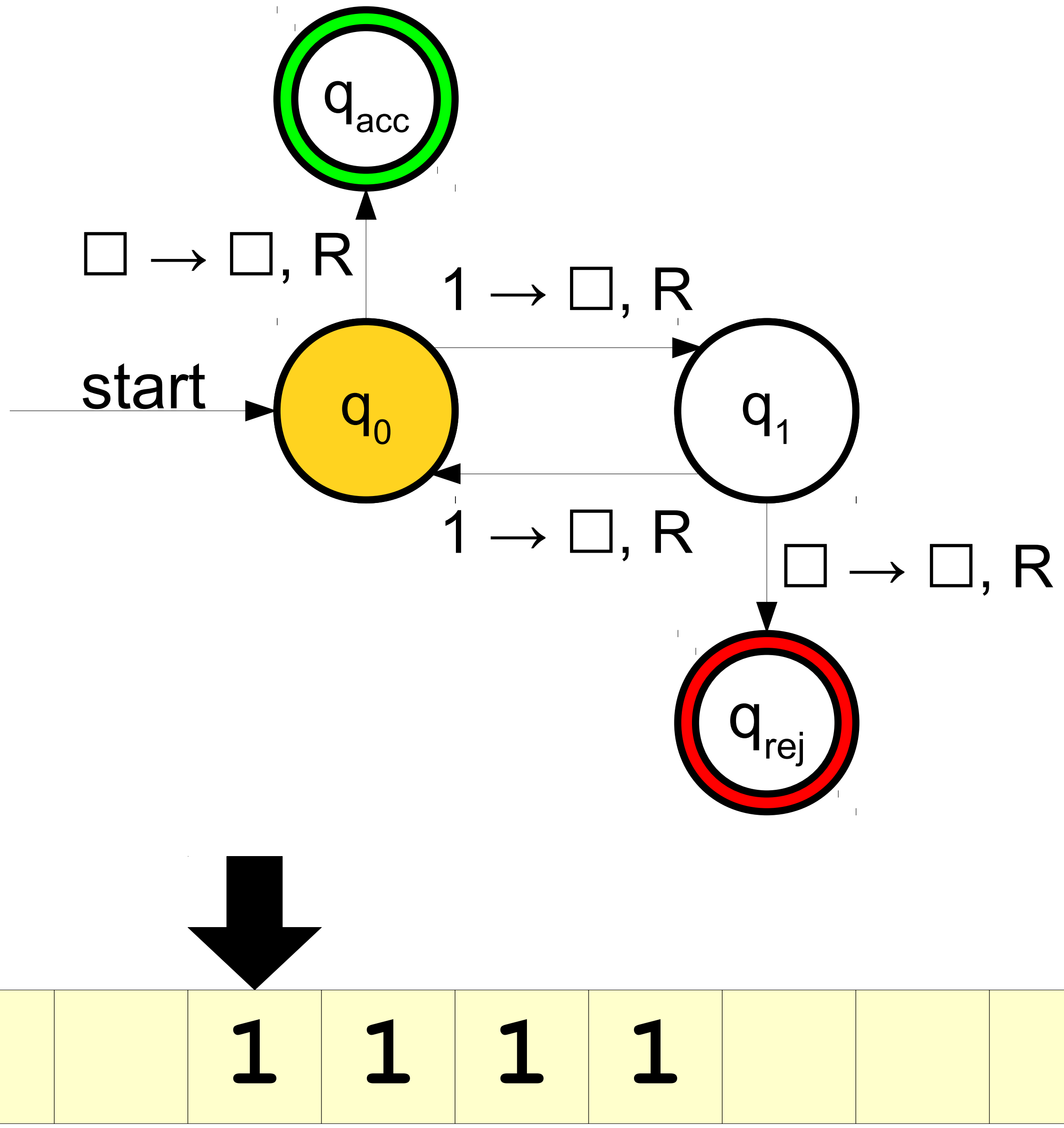

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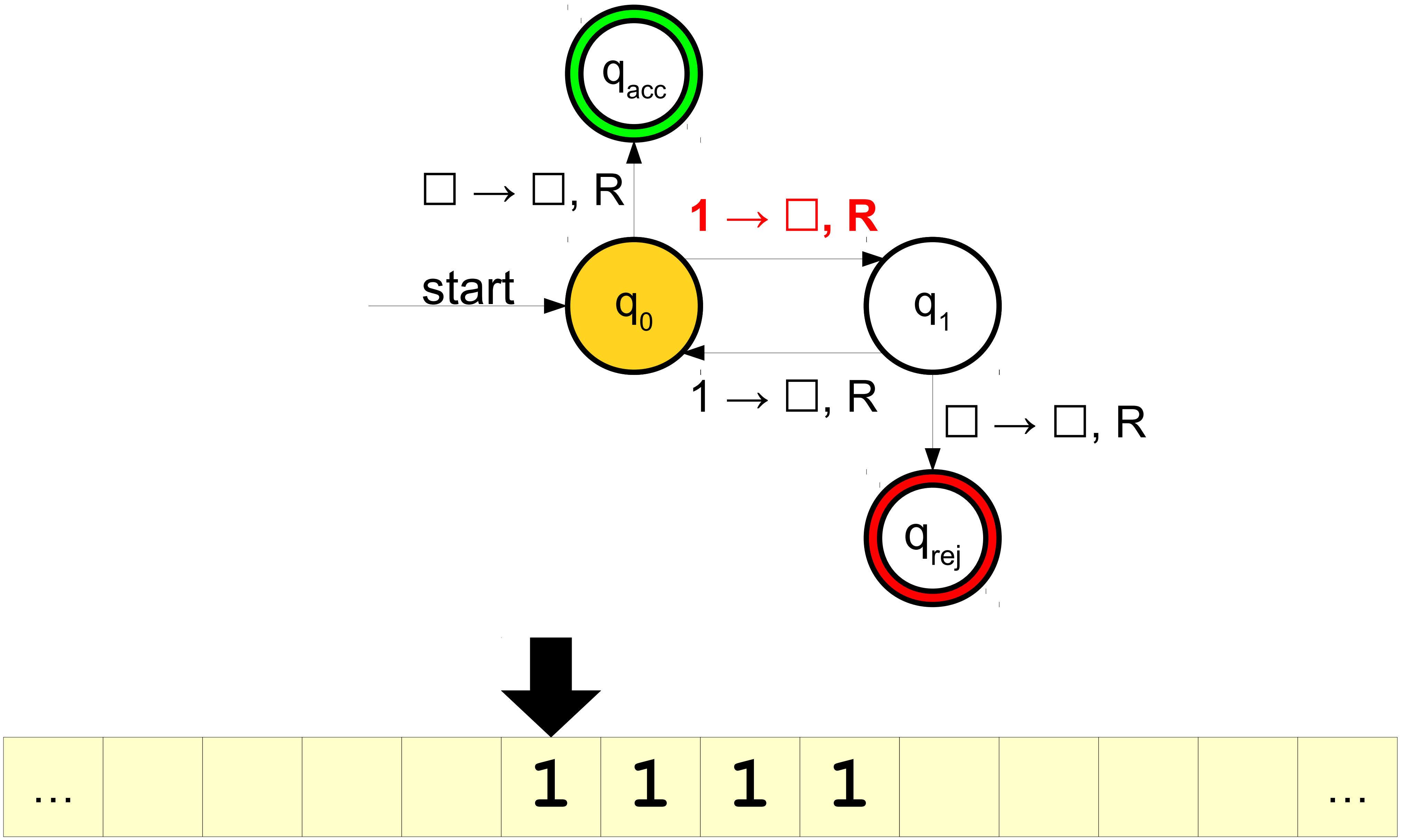

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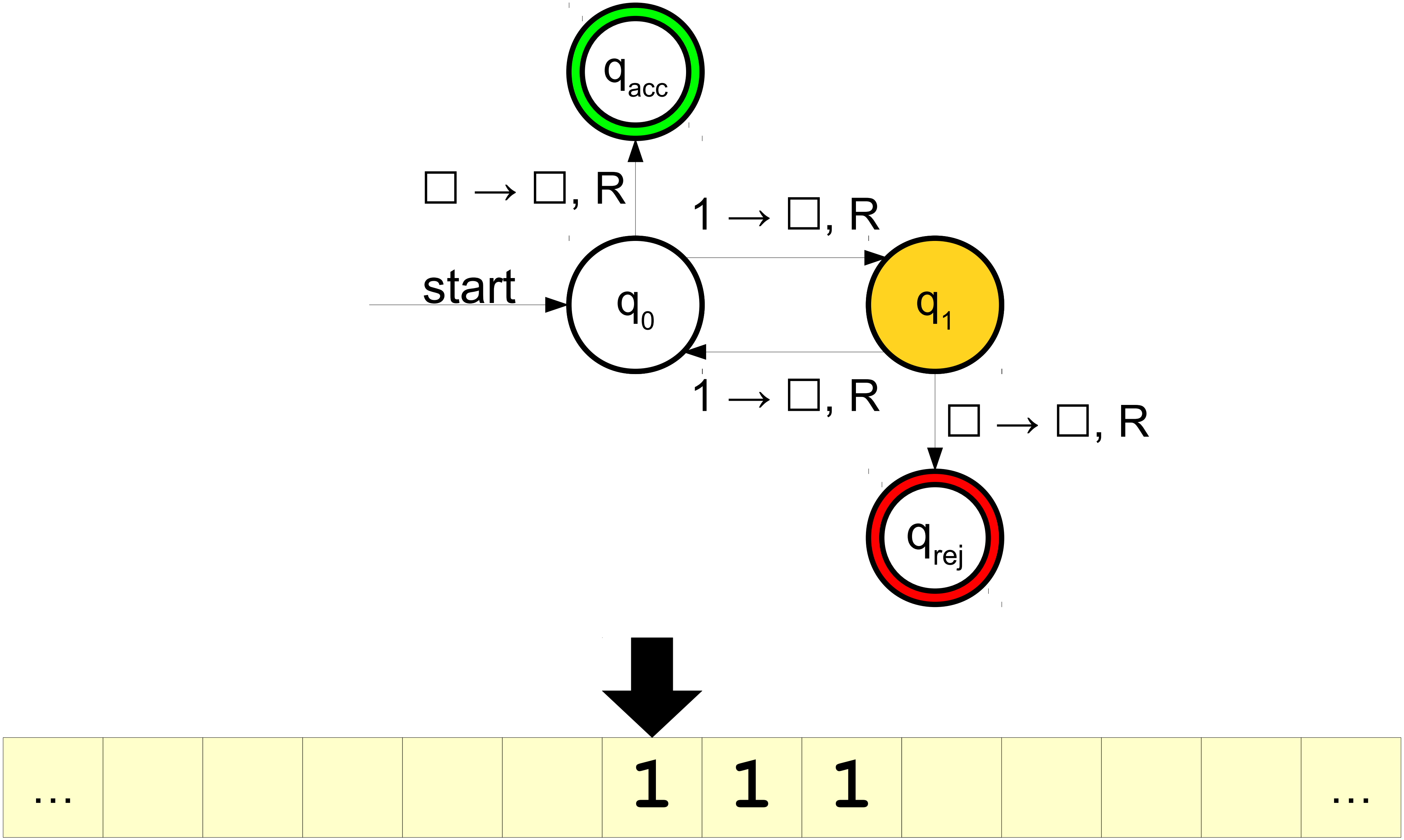

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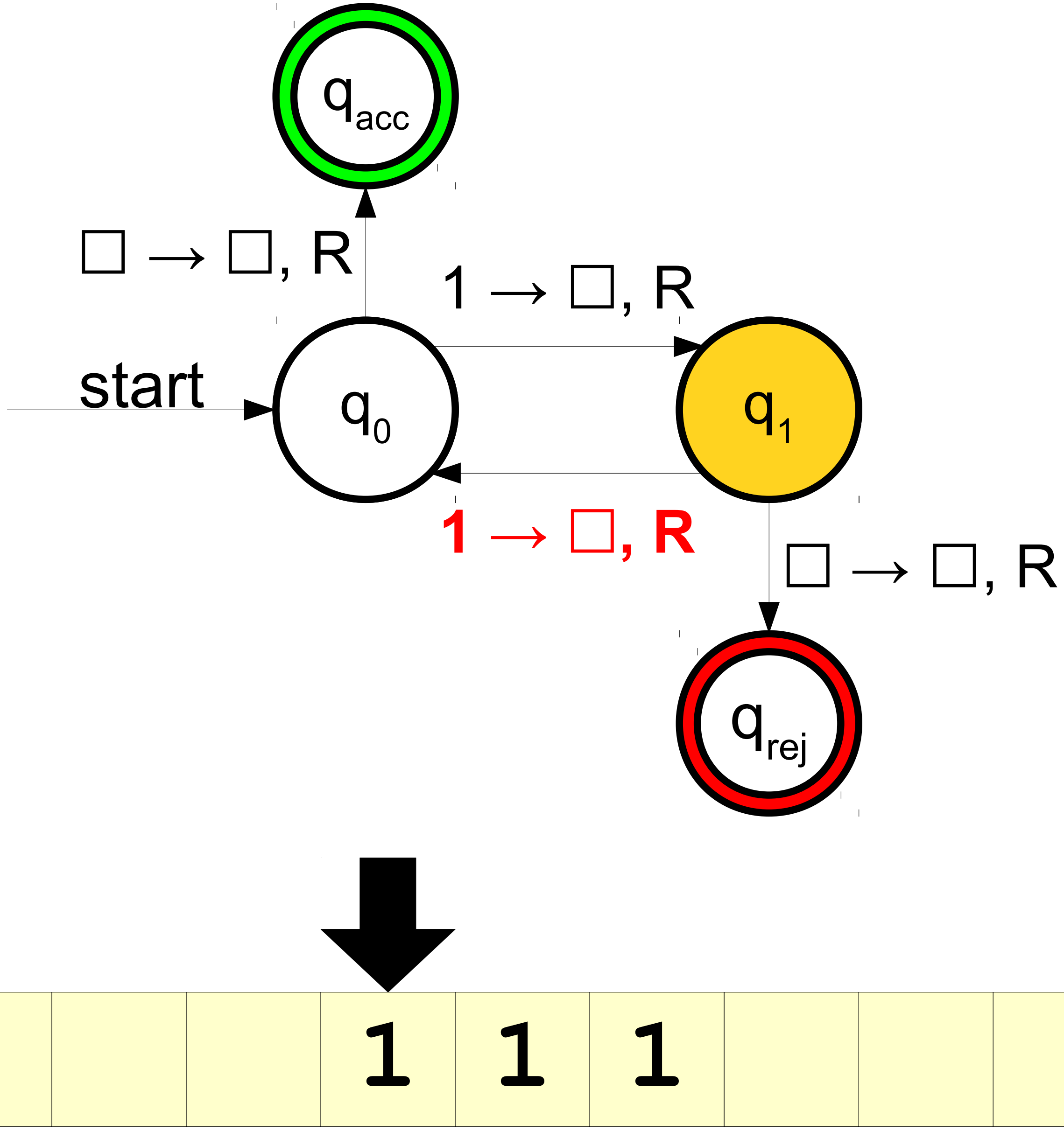

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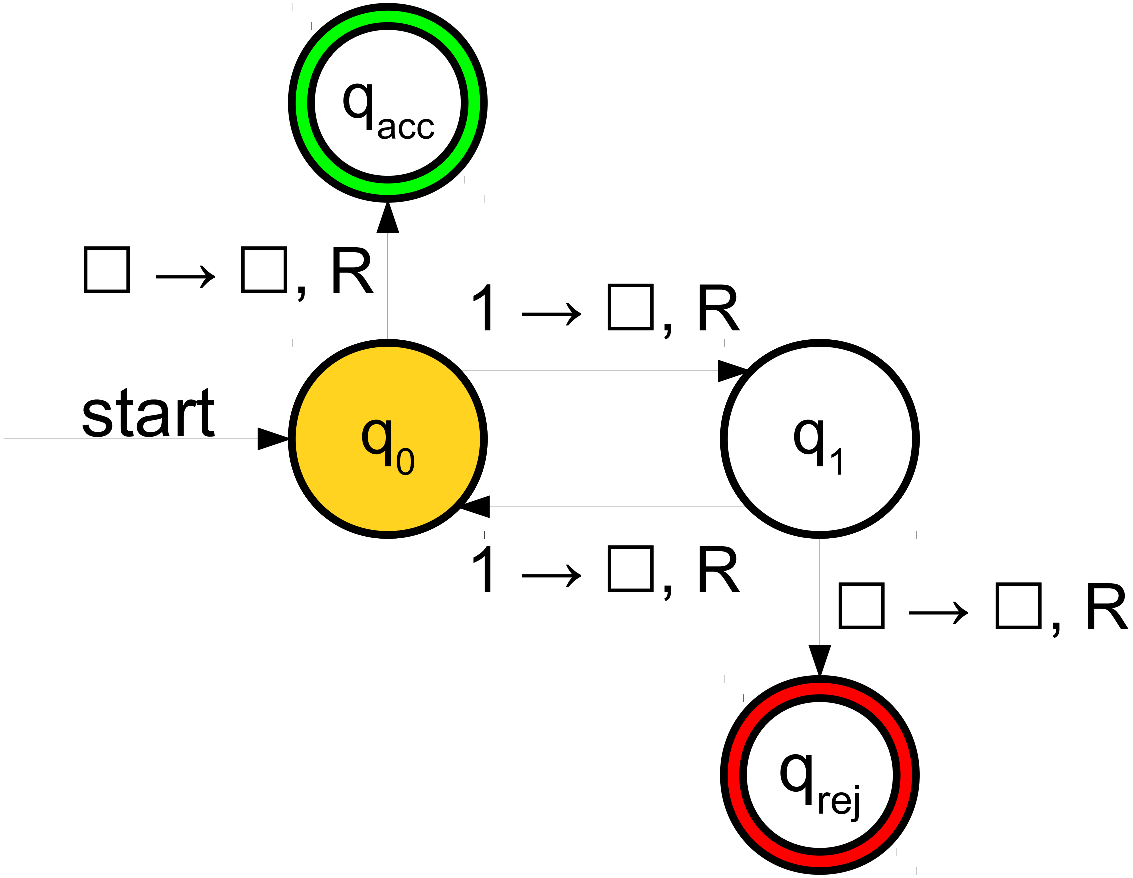

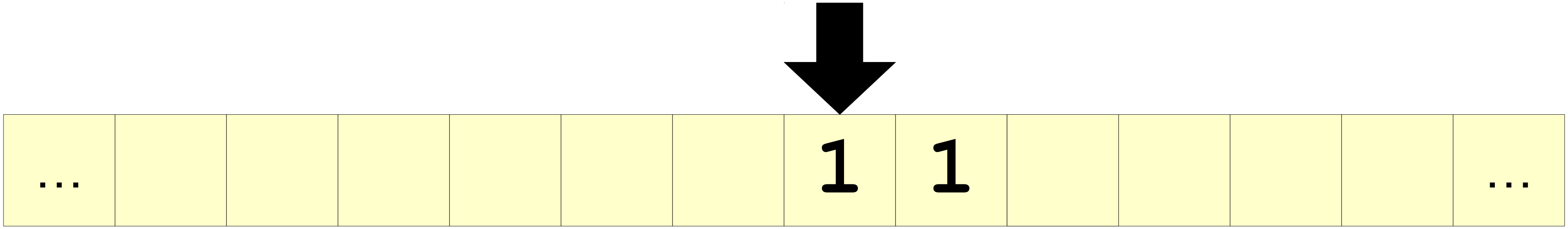

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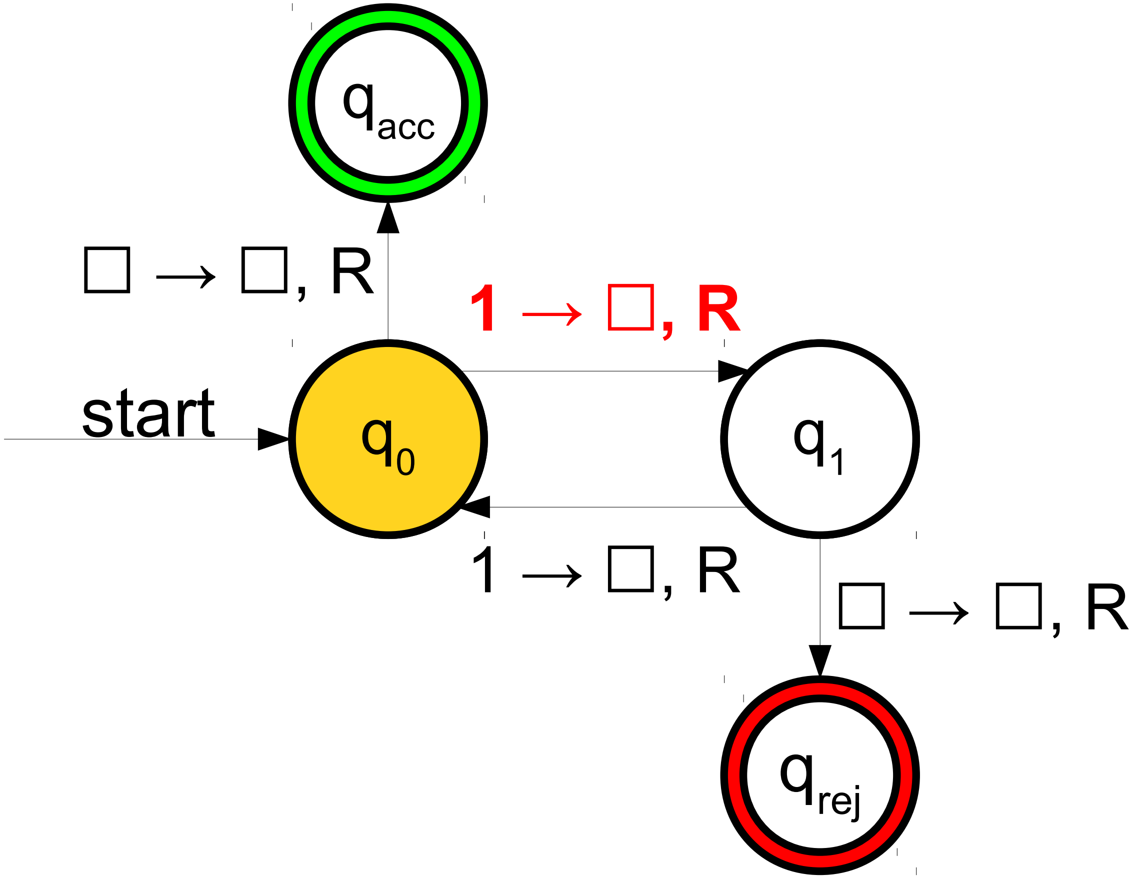

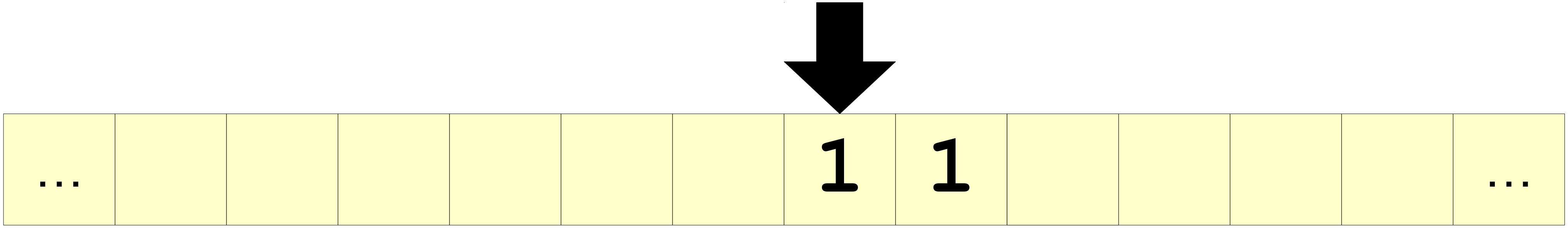

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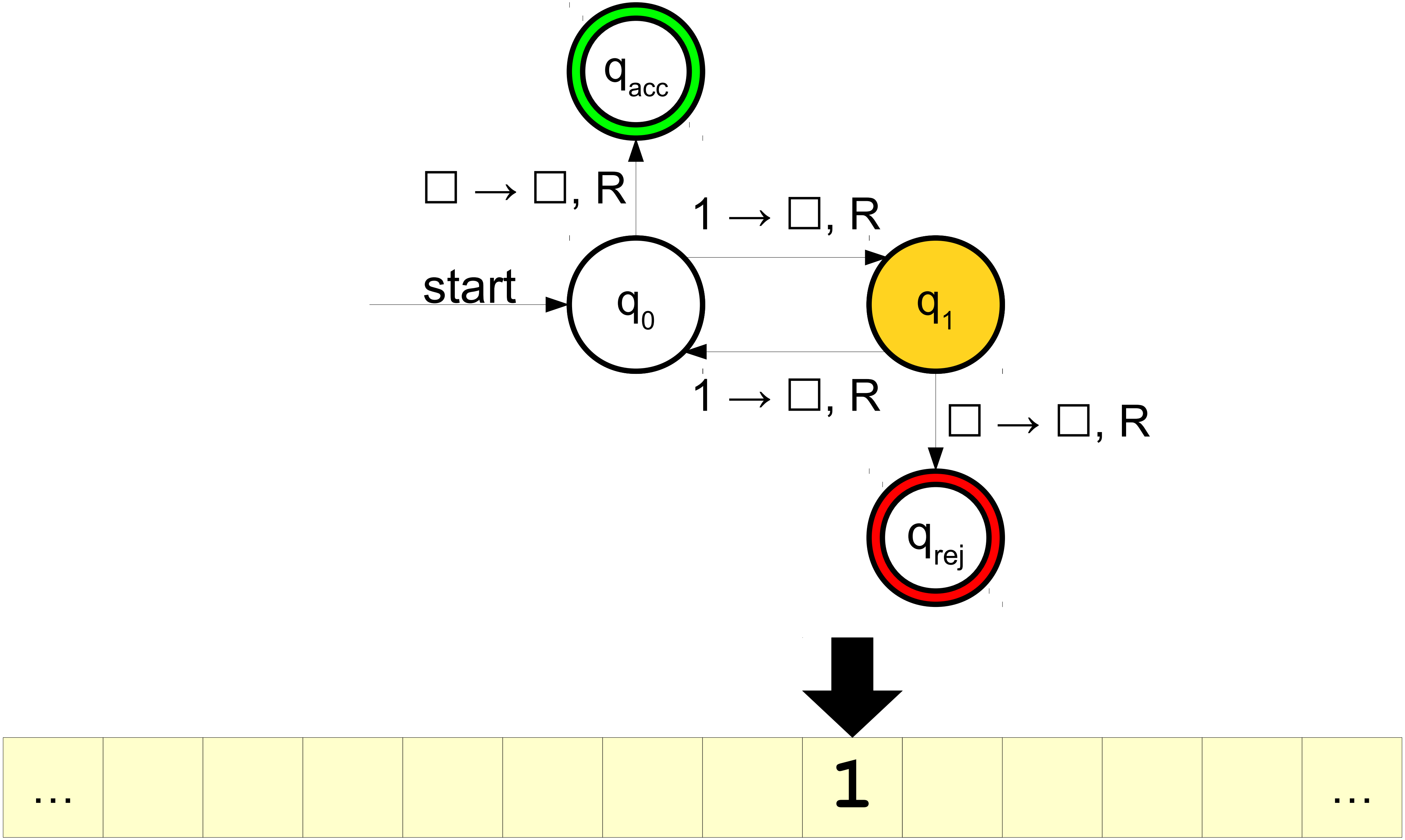

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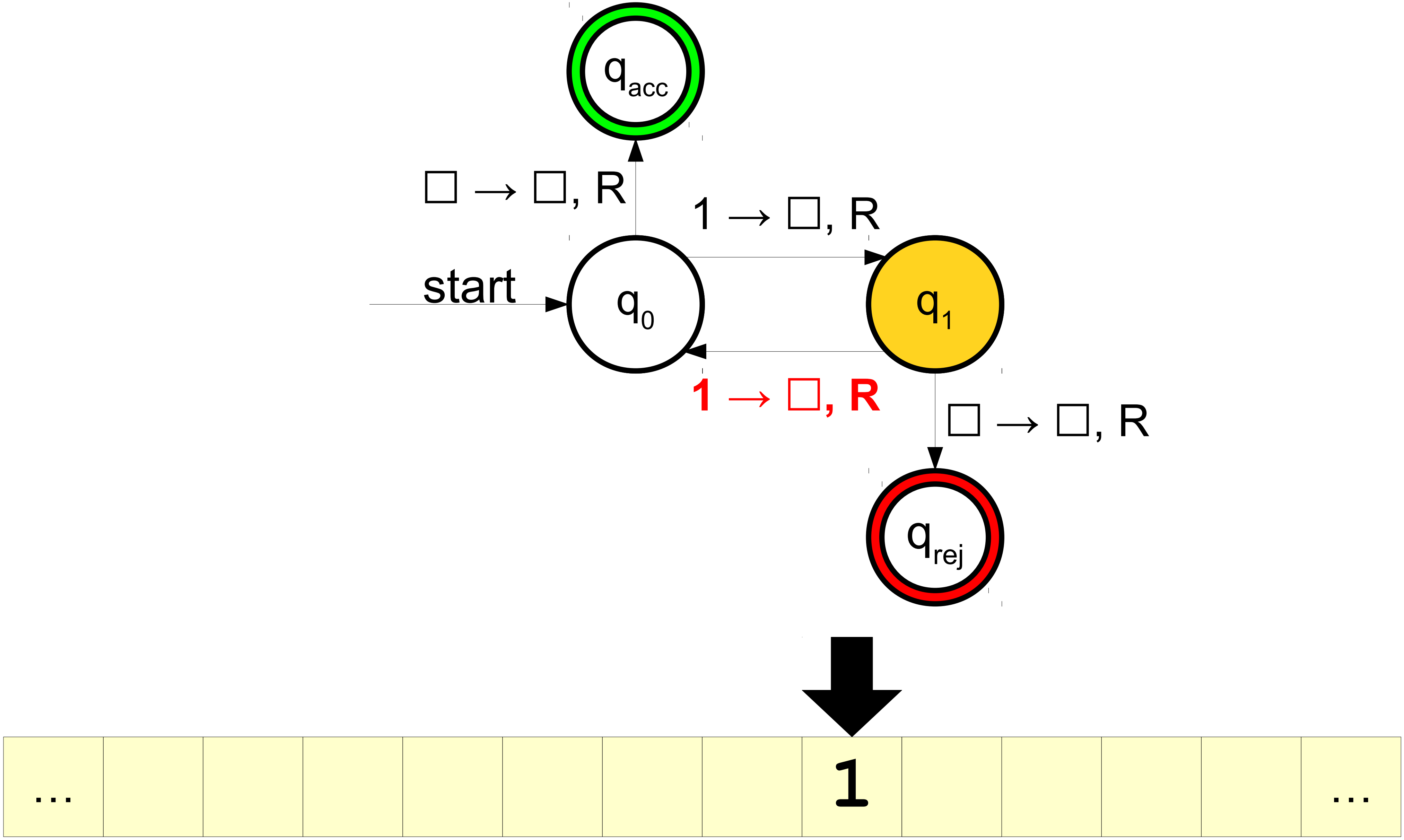

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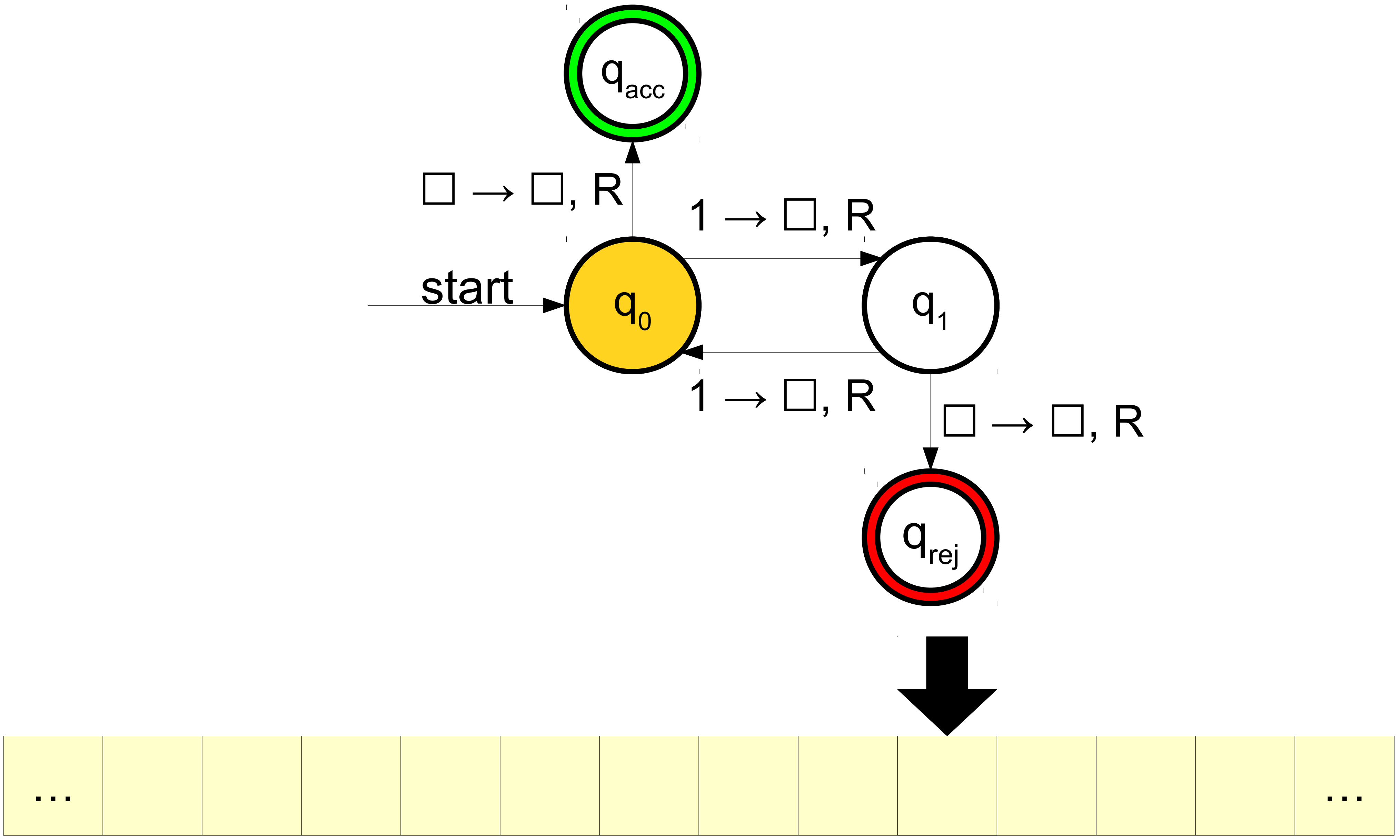

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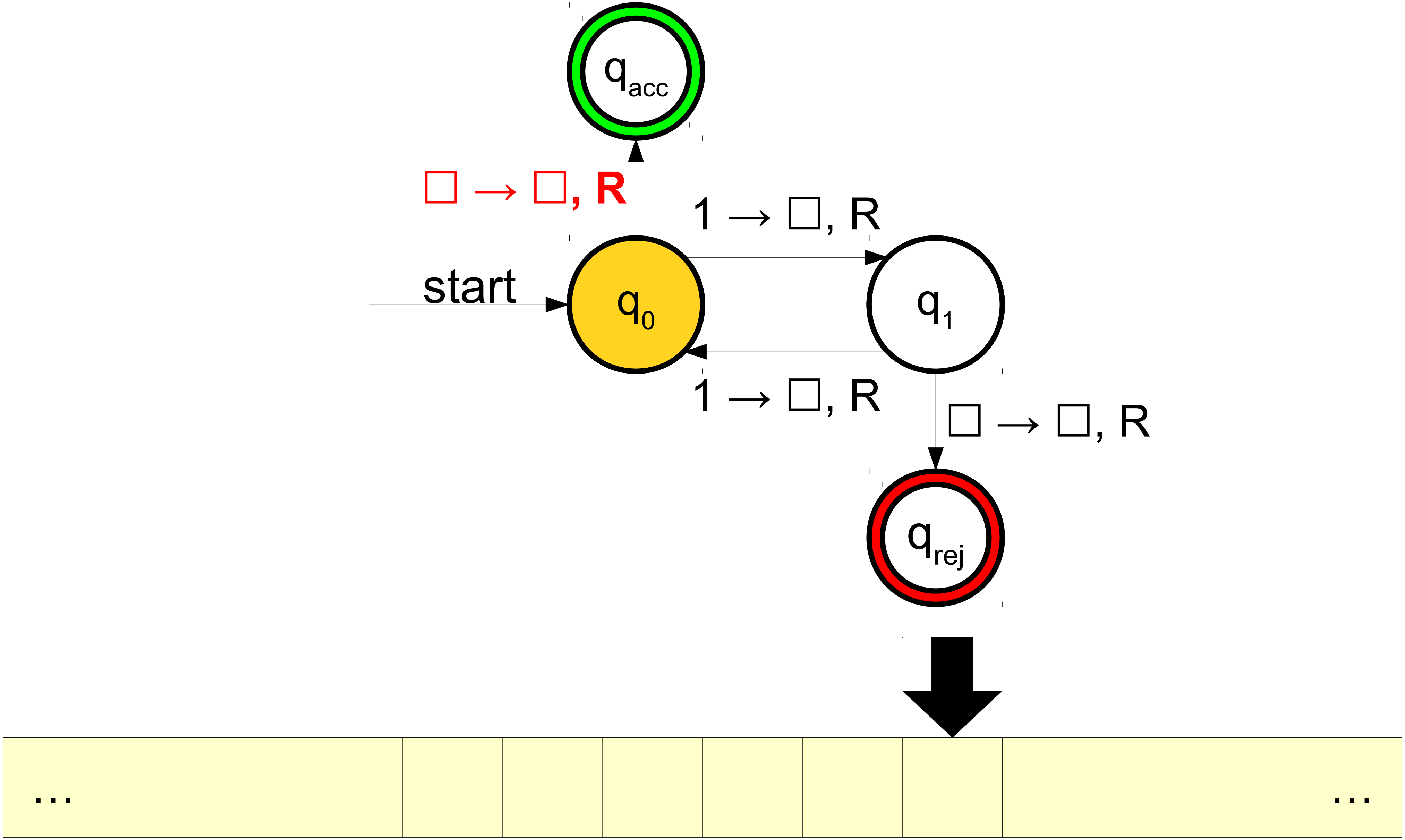

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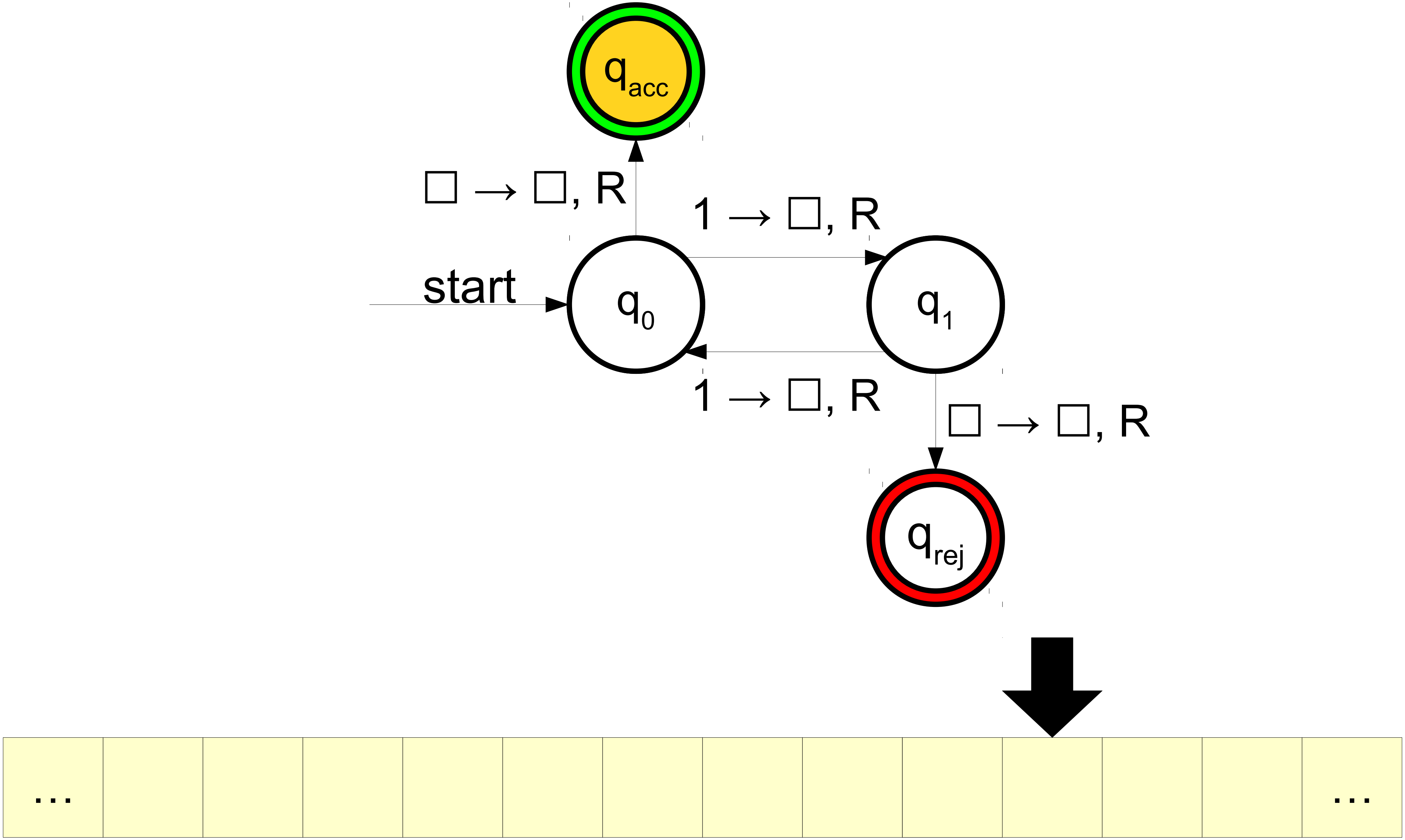

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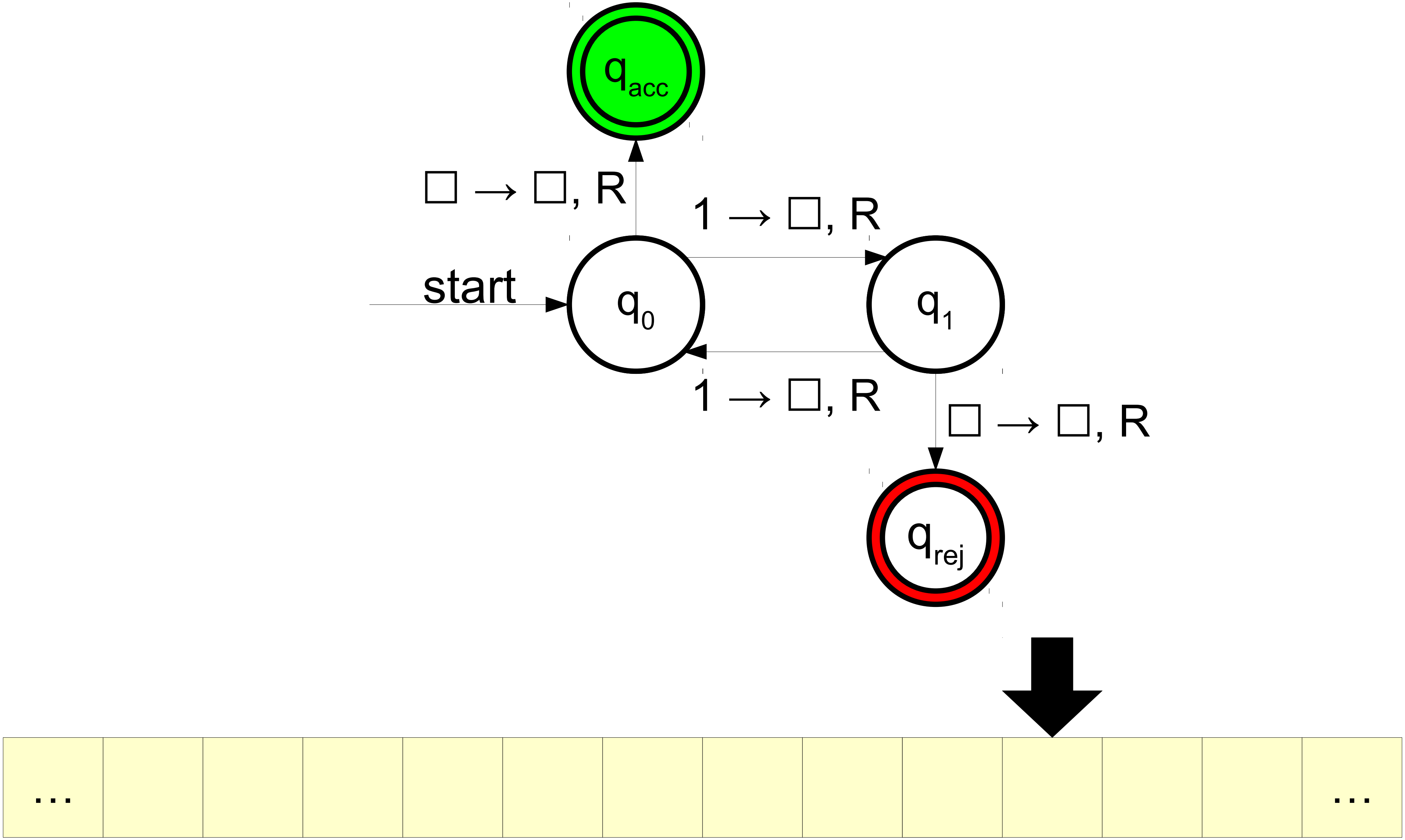


Accepting and Rejecting States

- Unlike DFAs, Turing machines do not stop processing the input when they finish reading it.
- Turing machines decide when (and if!) they will accept or reject their input.
- Turing machines can enter infinite loops and never accept or reject; more on that later...

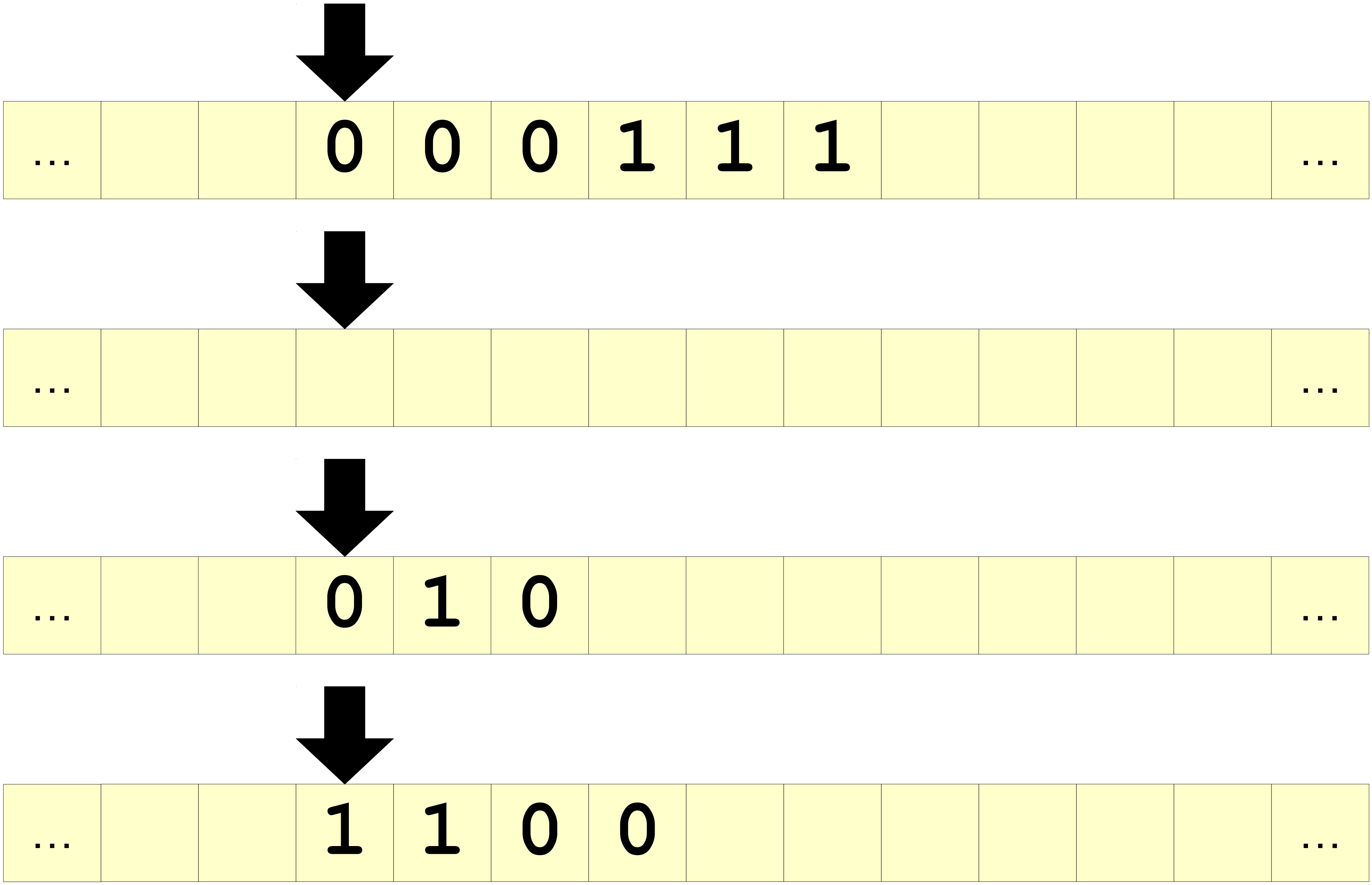
Designing Turing Machines

- Despite their simplicity, Turing machines are very powerful computing devices.
- Today's lecture explores how to design Turing machines for various languages.

Designing Turing Machines

- Let $\Sigma = \{\mathtt{0}, \mathtt{1}\}$ and consider the language $L = \{\mathtt{0}^n\mathtt{1}^n \mid n \in \mathbb{N}\}$.
- We know that L is context-free.
- How might we build a Turing machine for it?

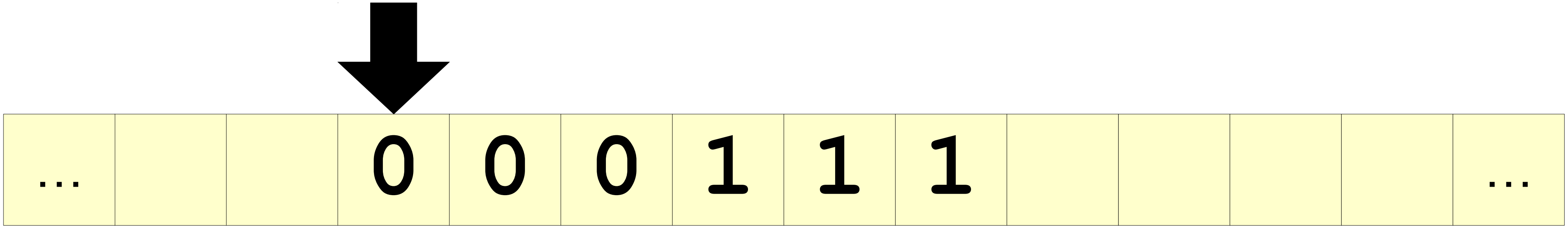
$$L = \{ \mathtt{0}^n\mathtt{1}^n \mid n \in \mathbb{N} \}$$



A Recursive Approach

- The string ε is in *L*.
- The string `0`*w*`1` is in *L* iff *w* is in *L*.
- Any string starting with `1` is not in *L*.
- Any string ending with `0` is not in *L*.

A Sketch of the TM



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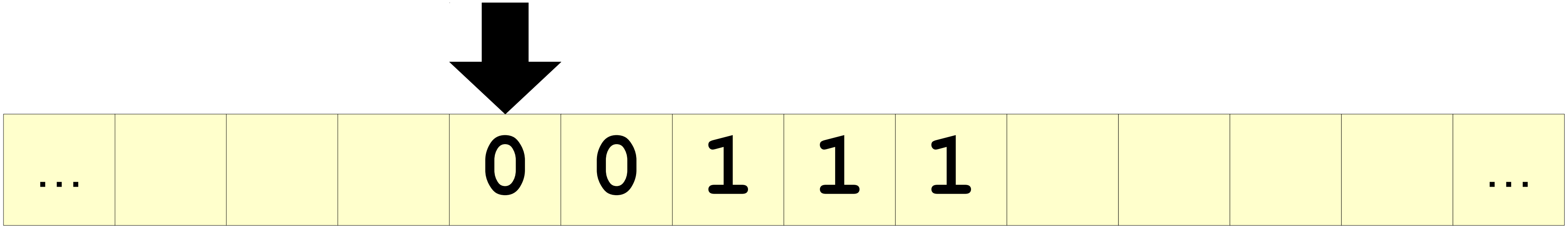

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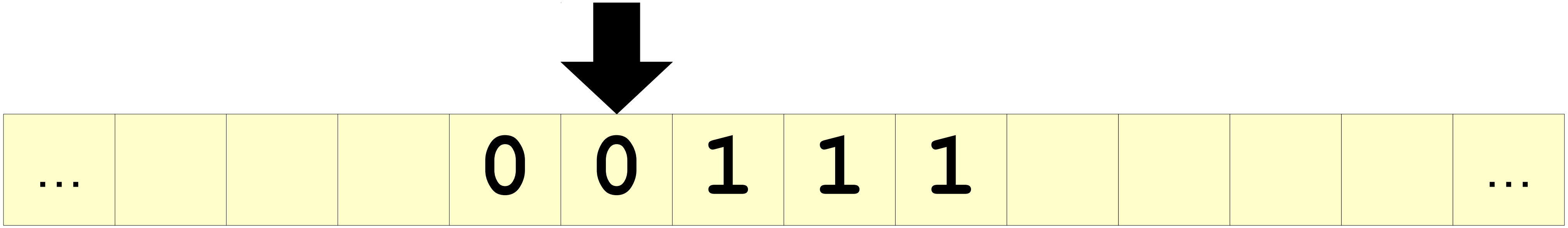

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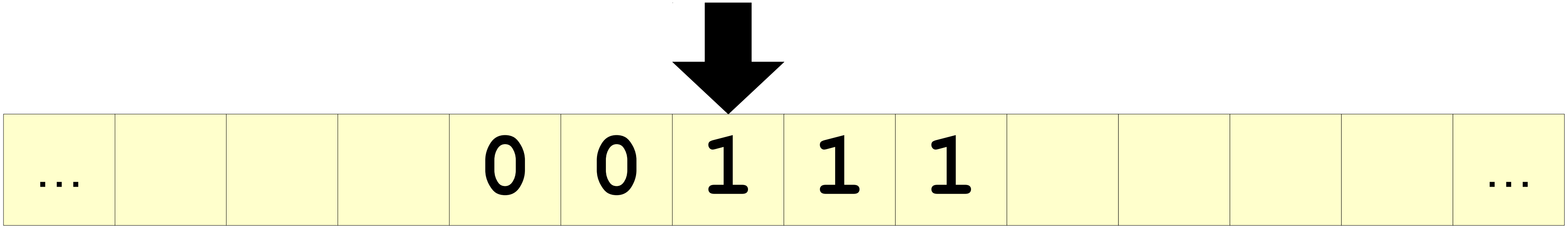

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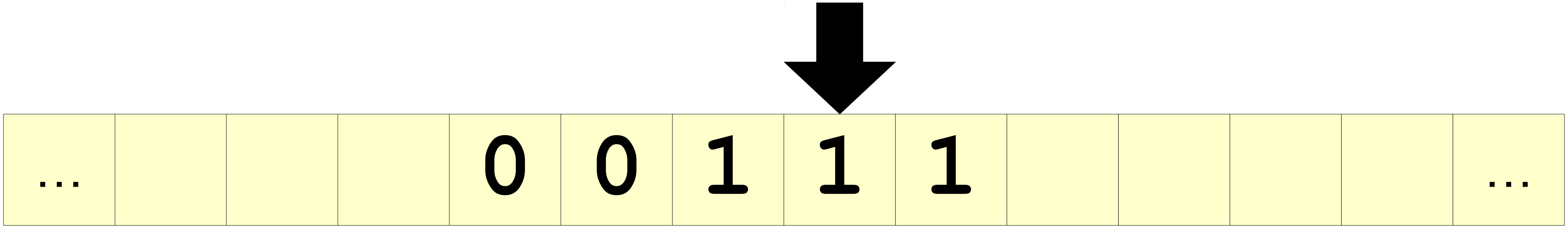

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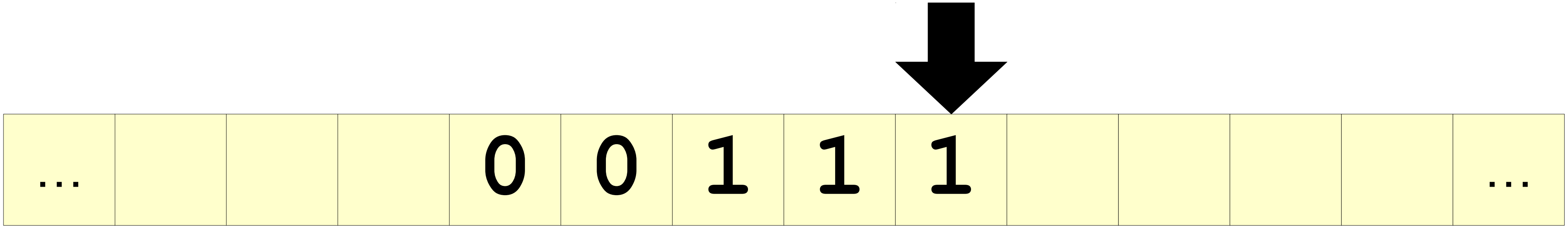

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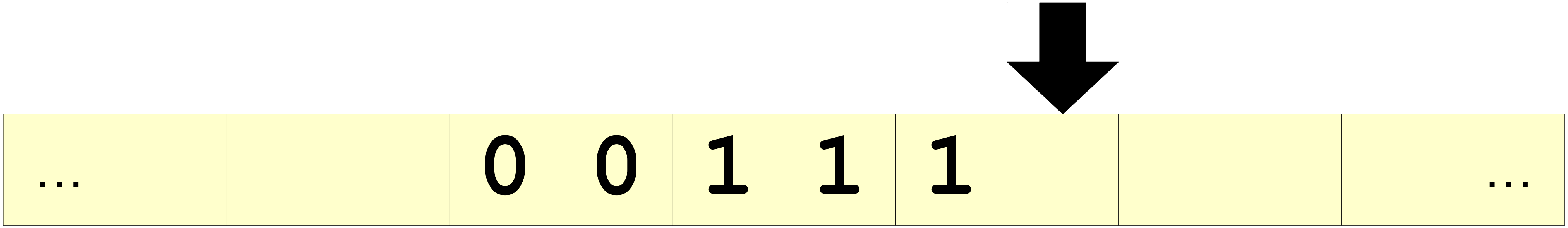

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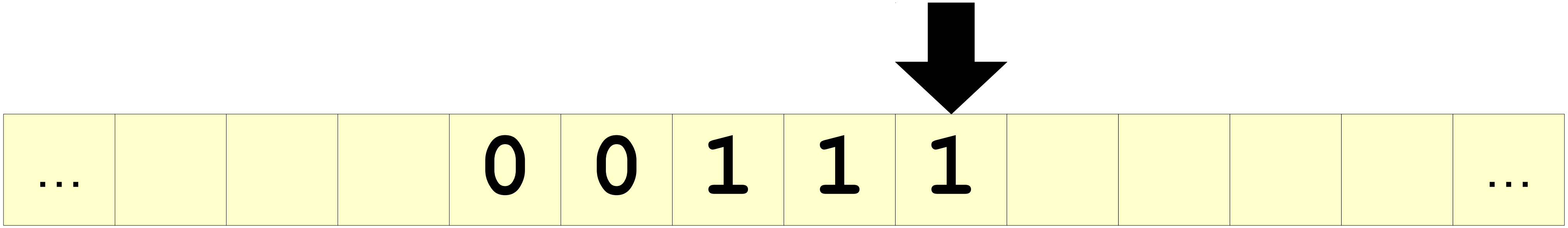

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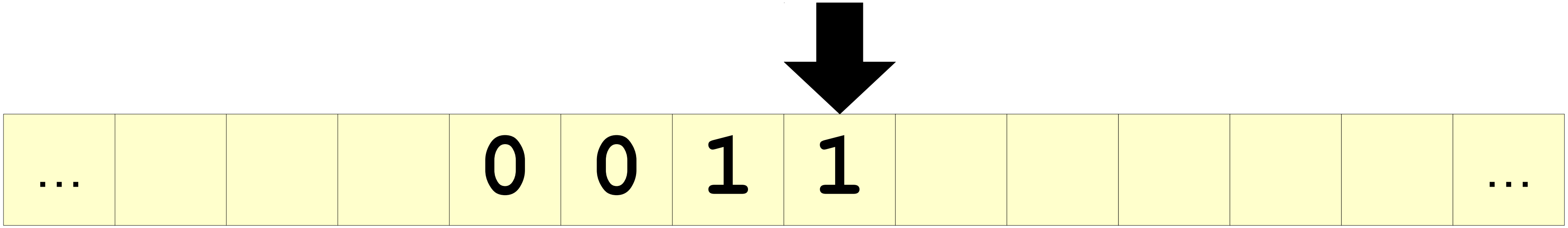

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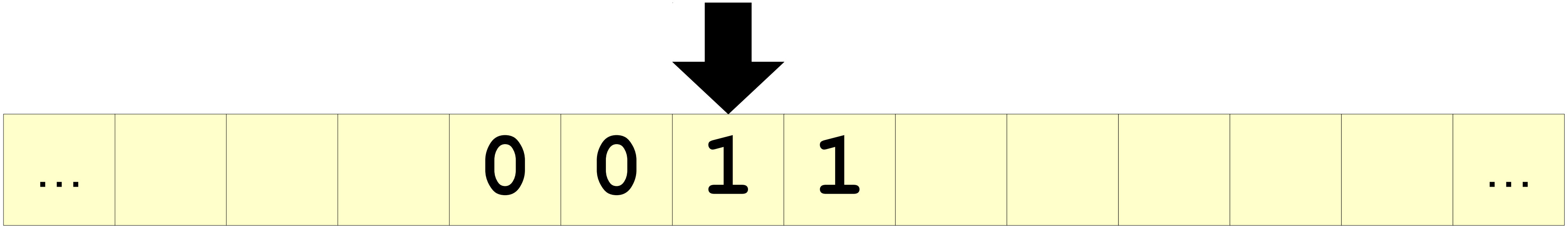

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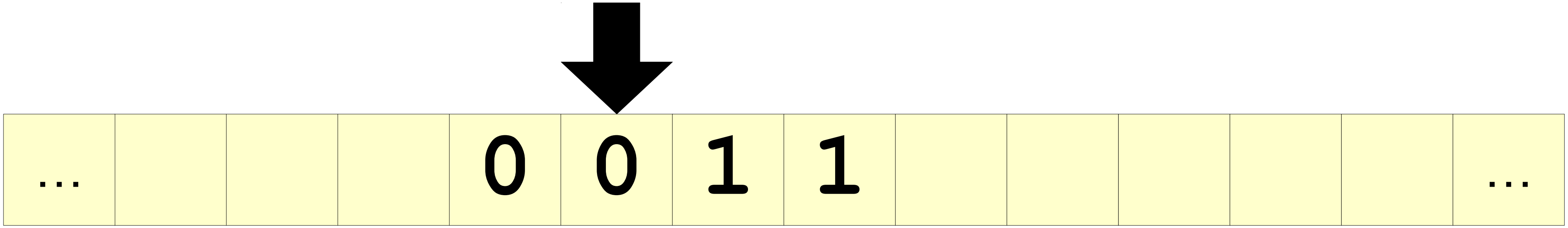

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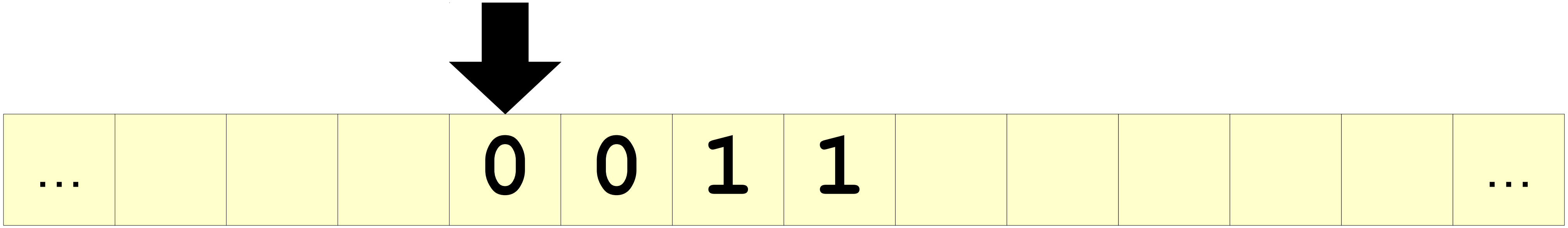
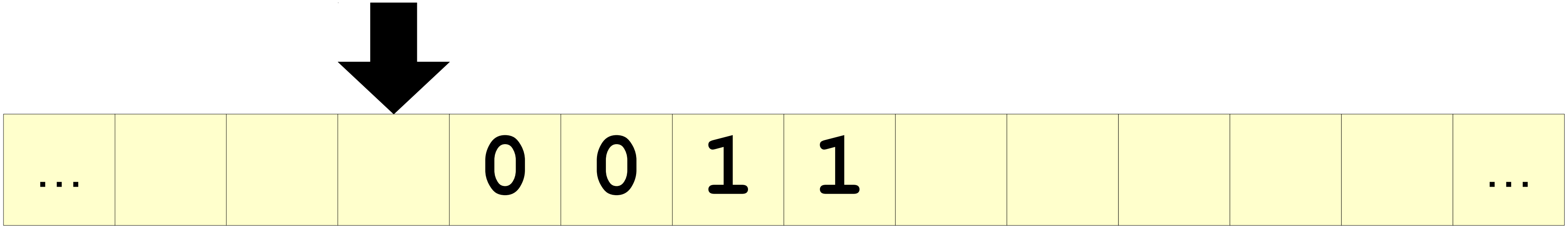


… 0 0 1 1 …

A Sketch of the TM



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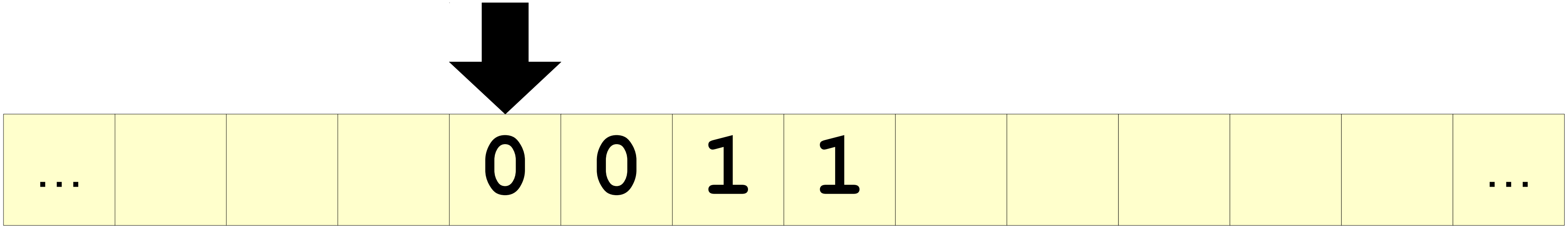

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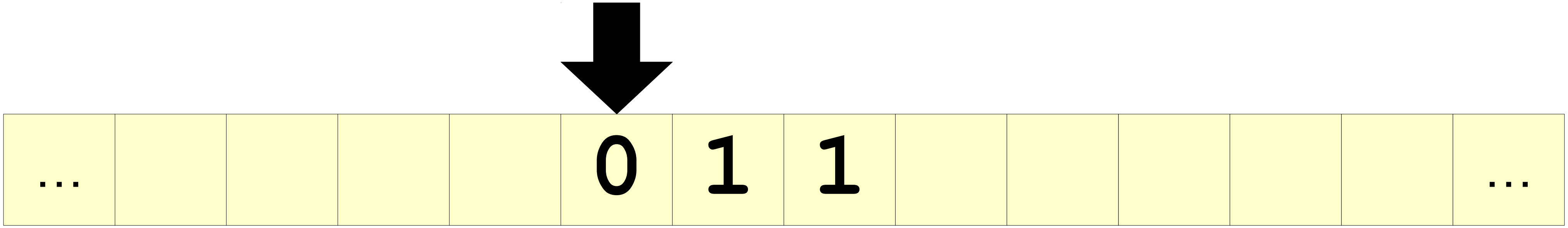

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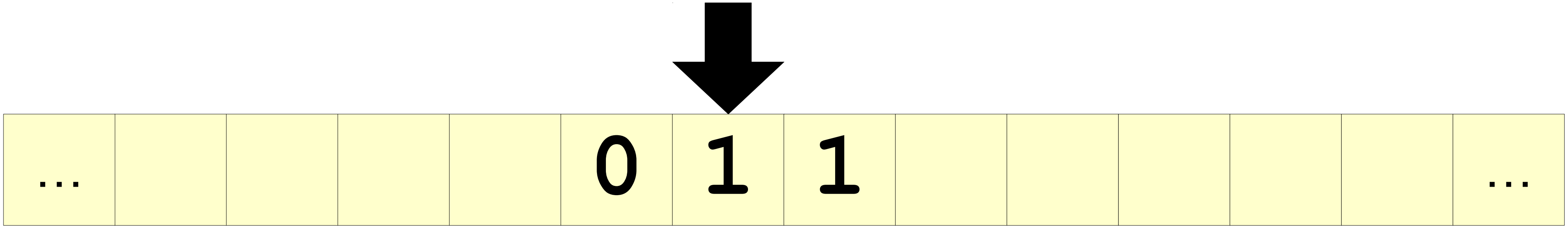

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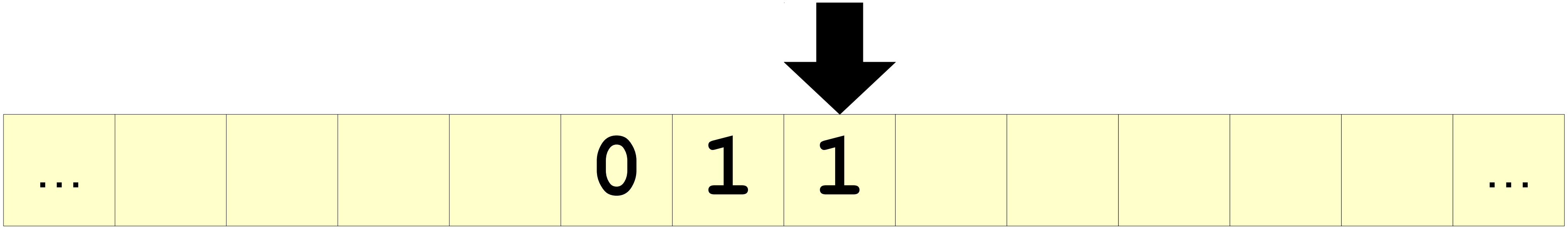

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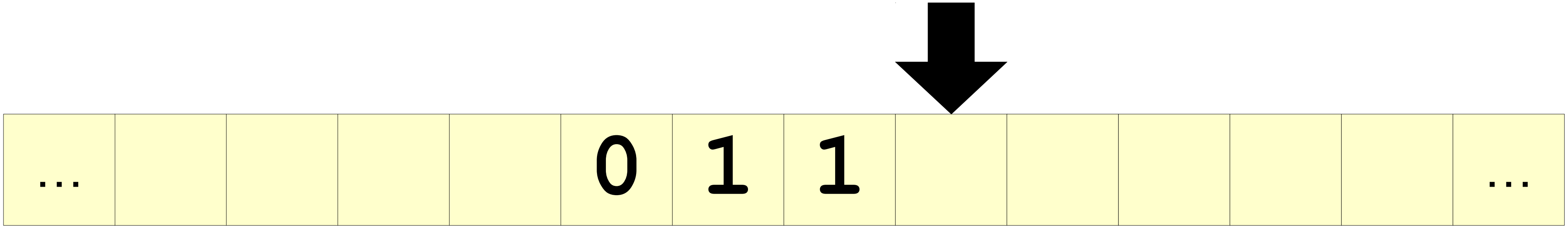

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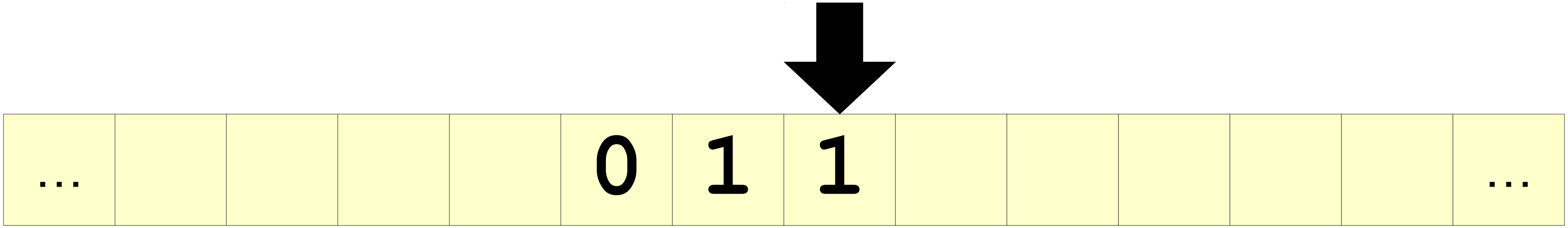

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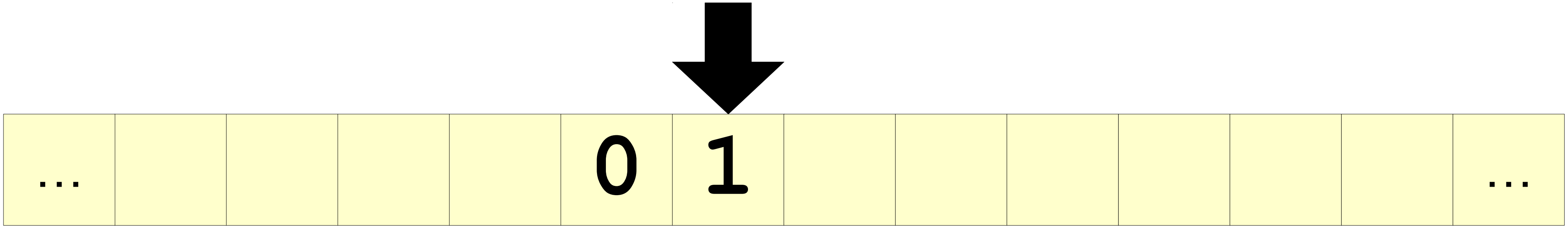

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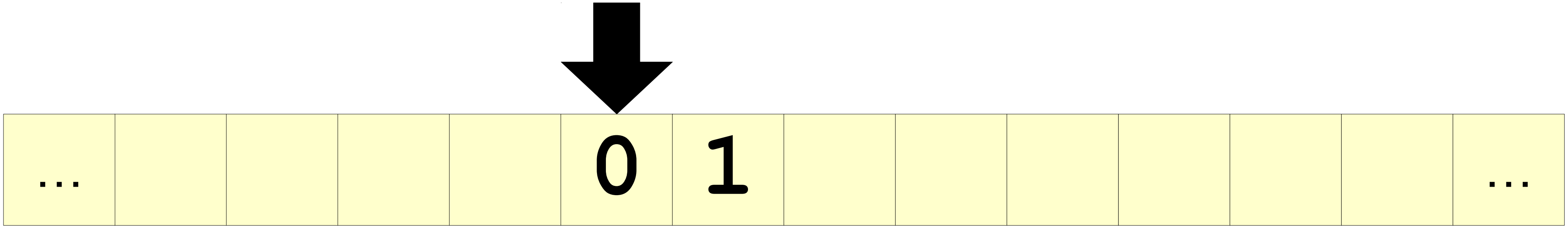

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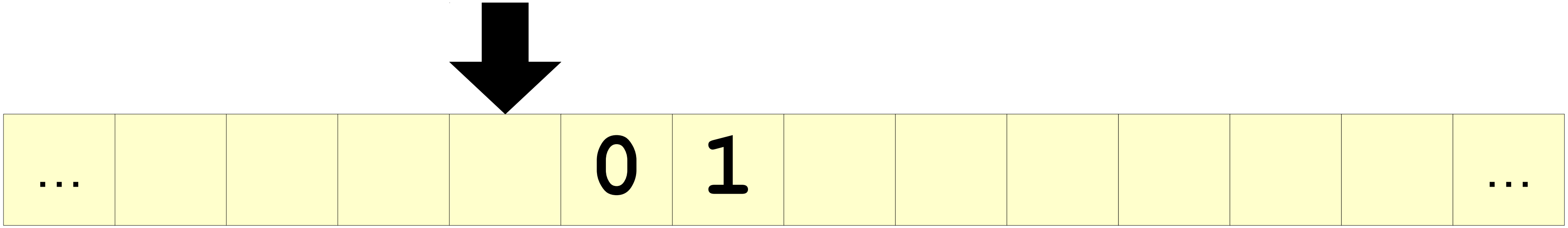

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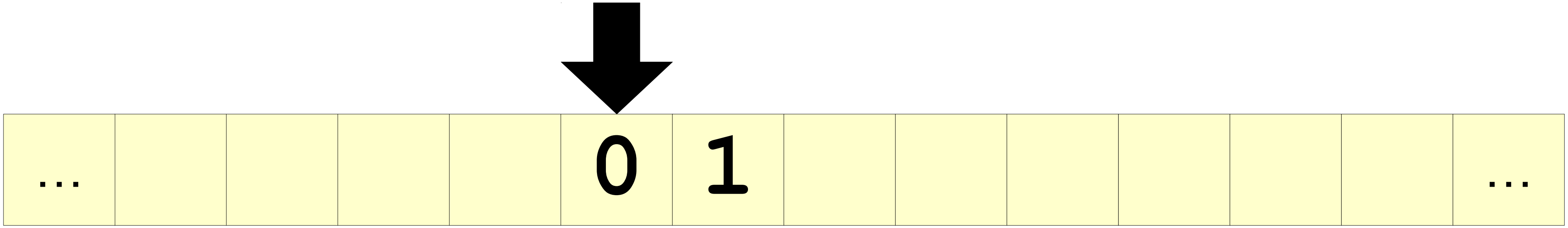

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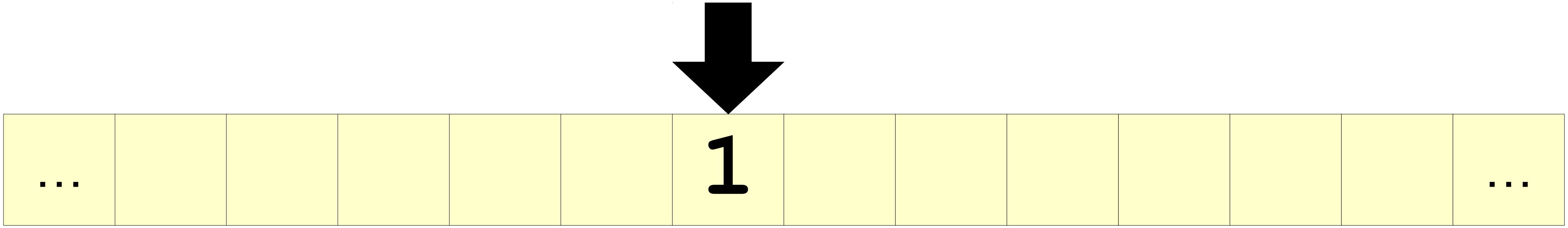

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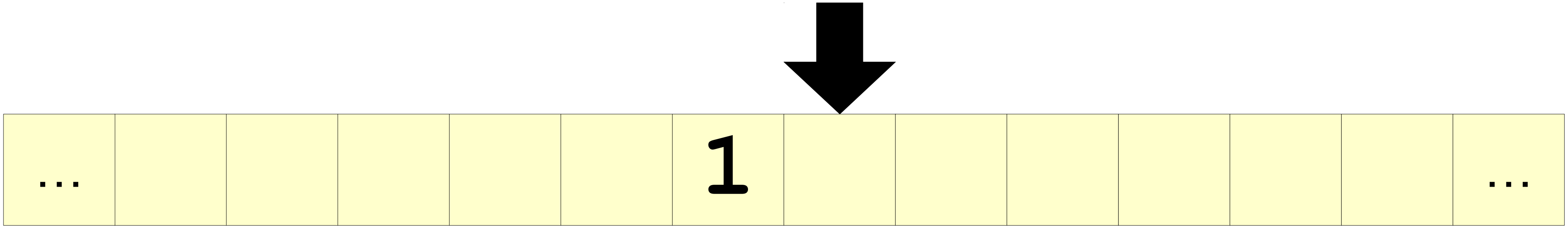

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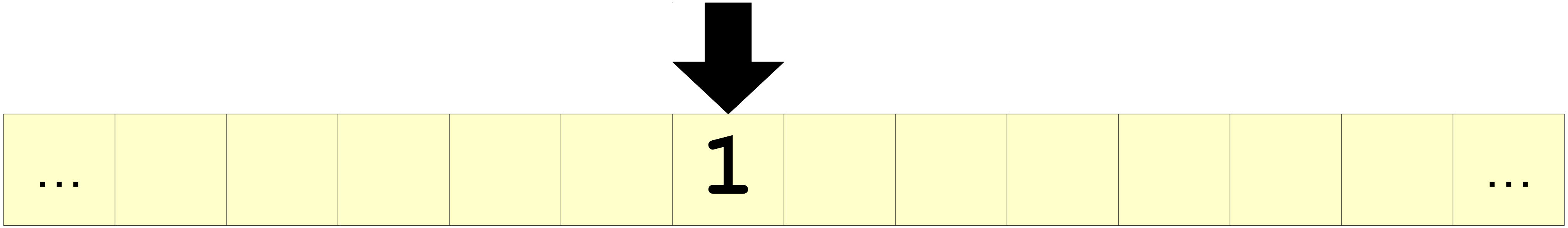

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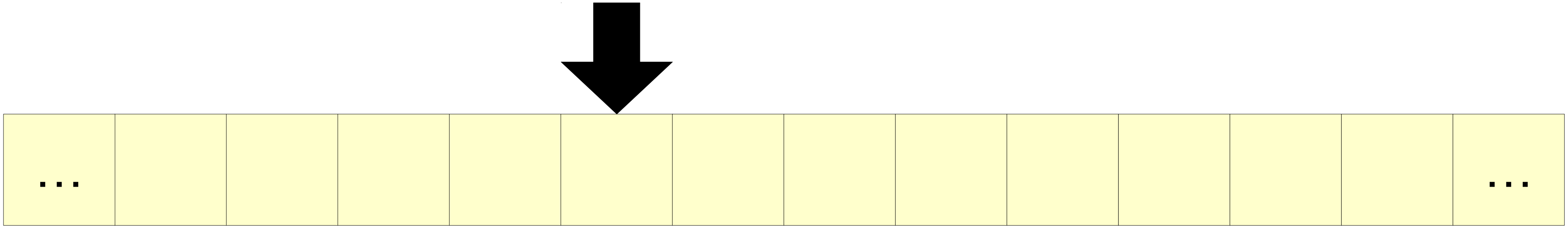

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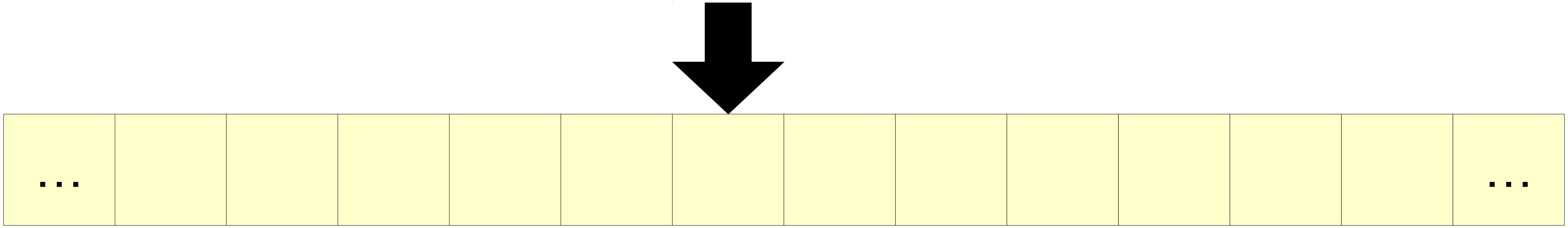

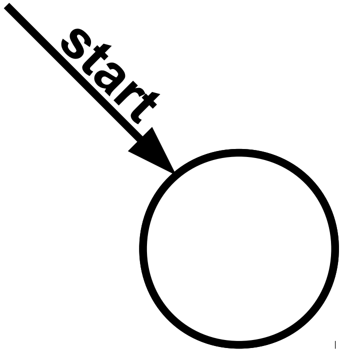

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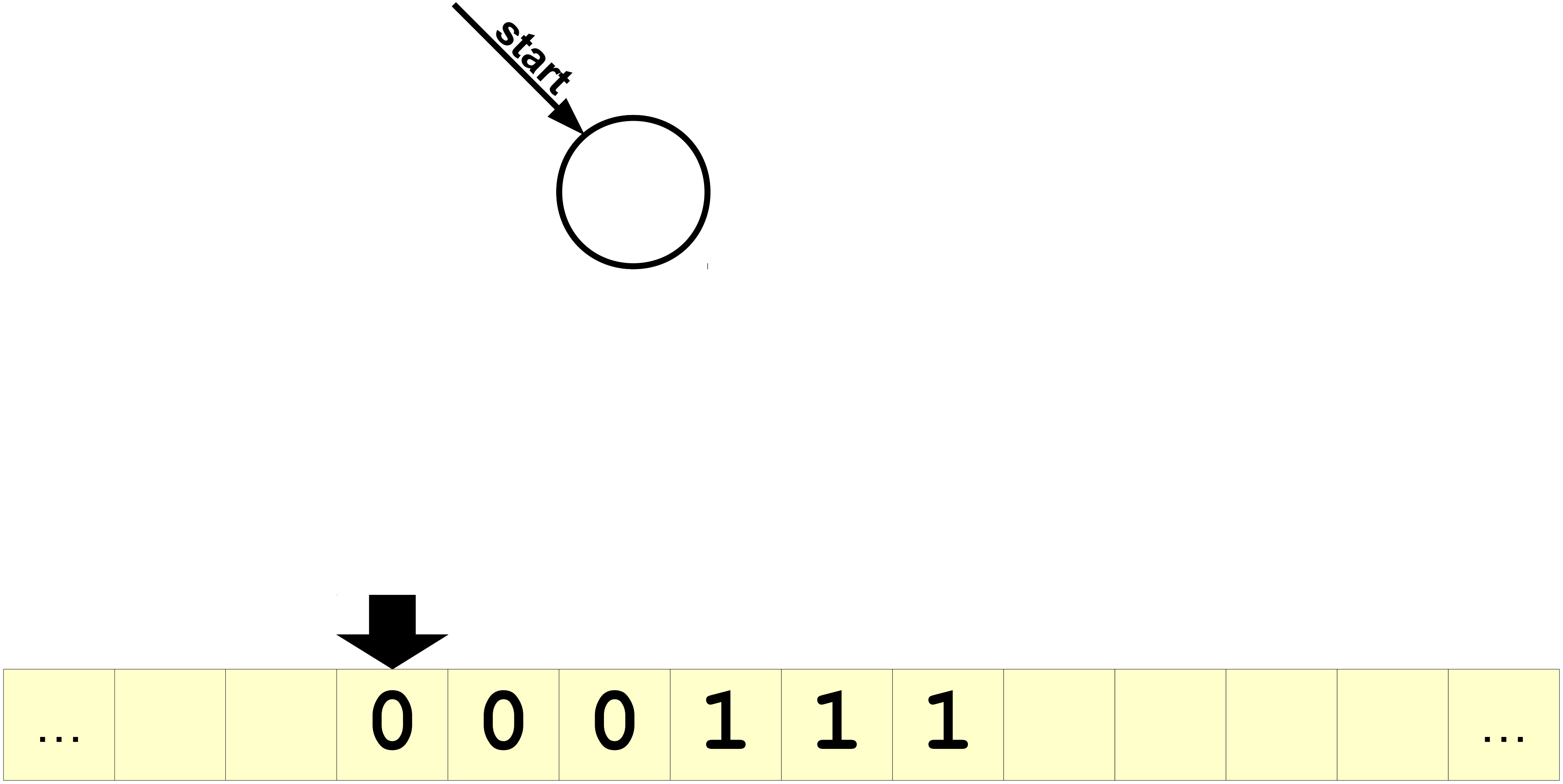
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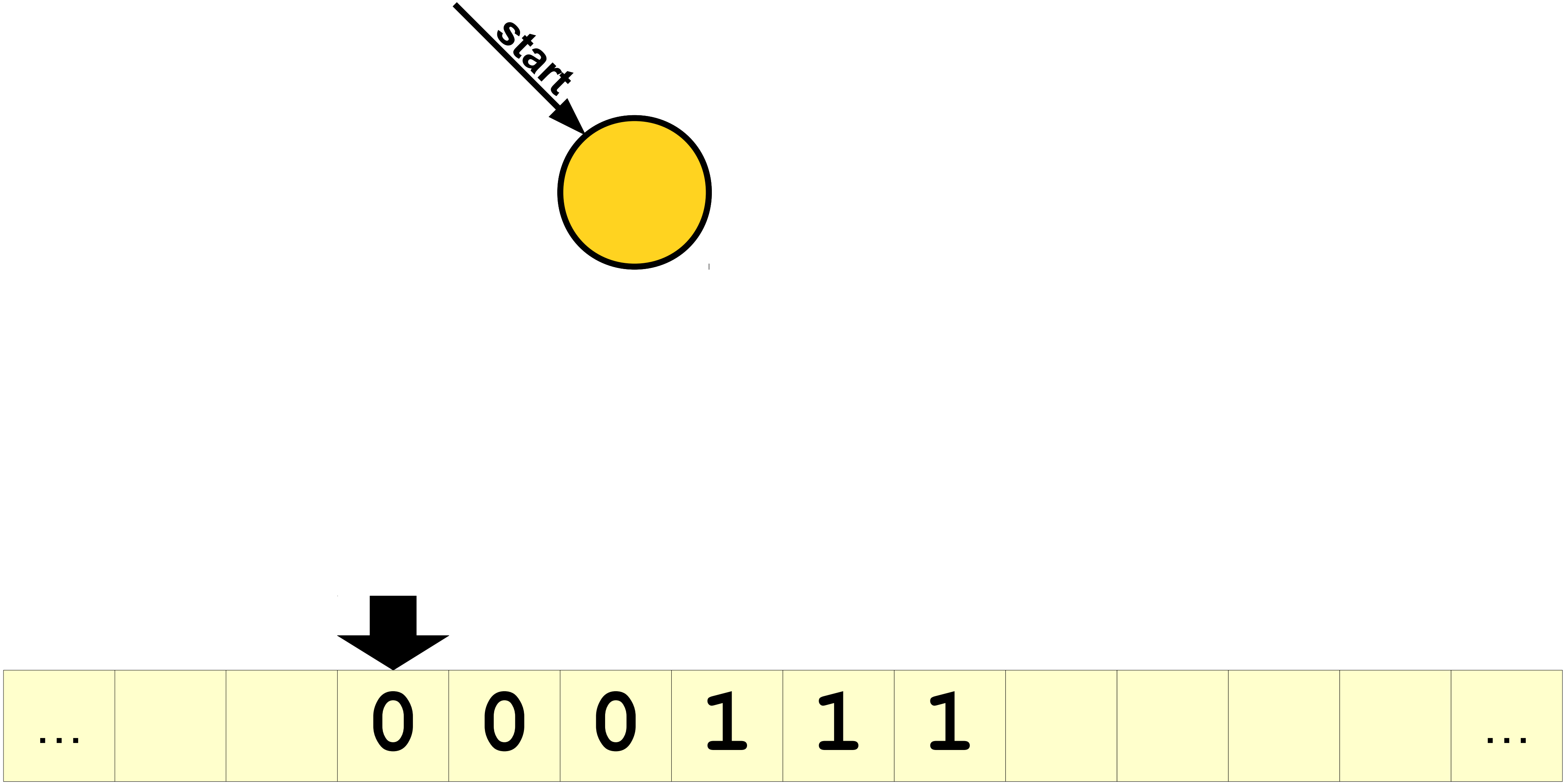
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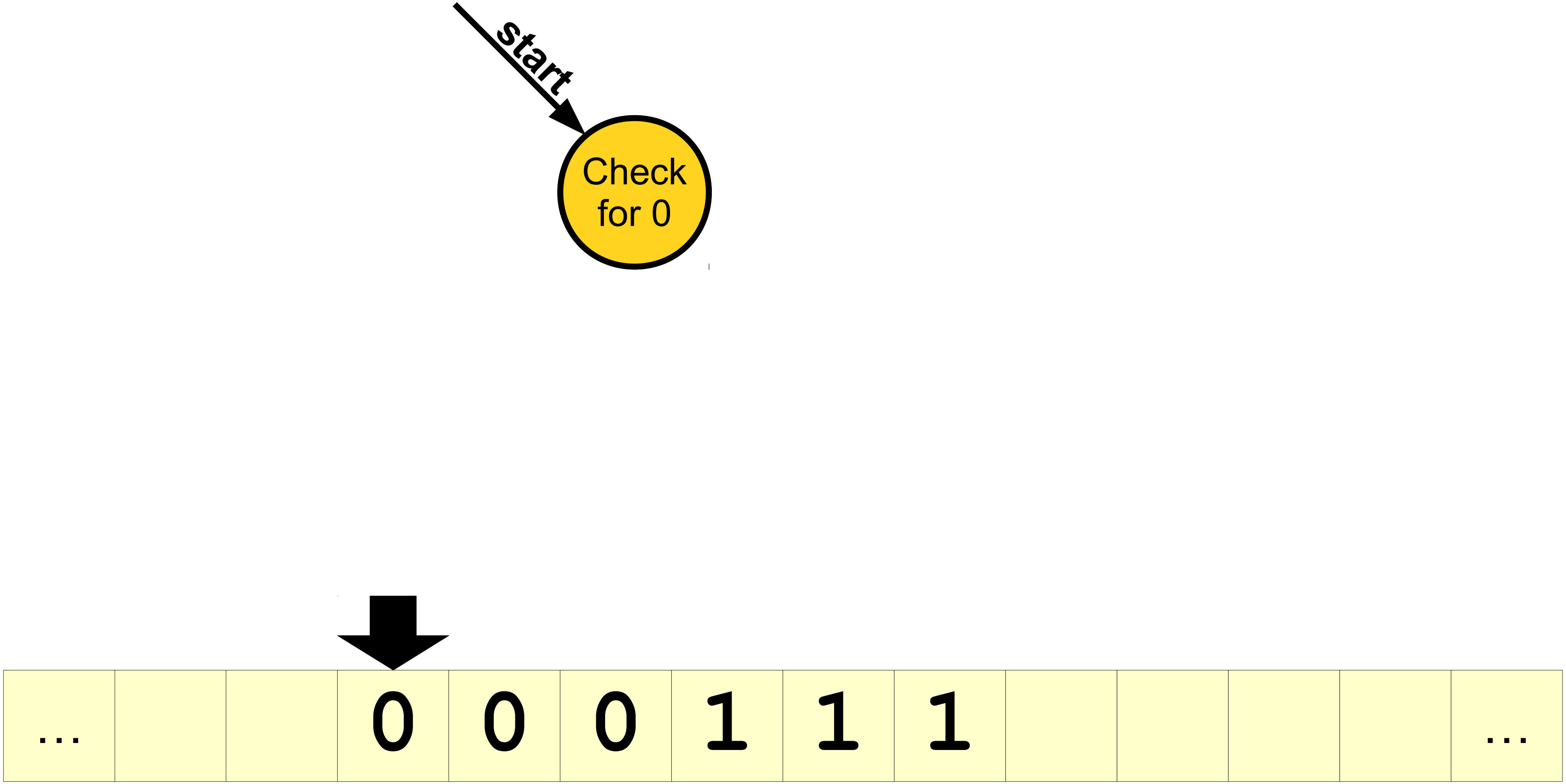
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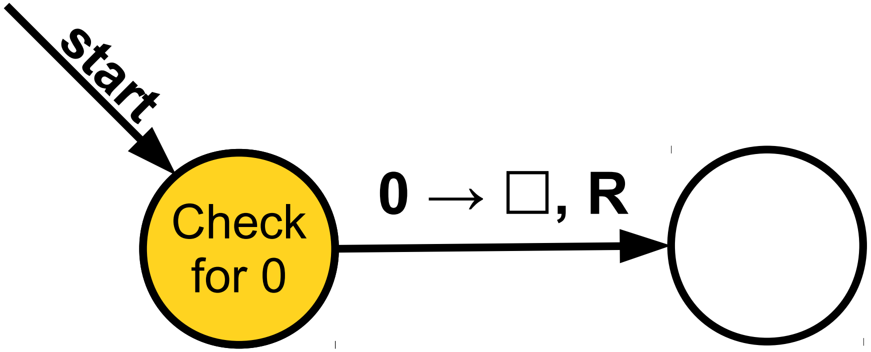

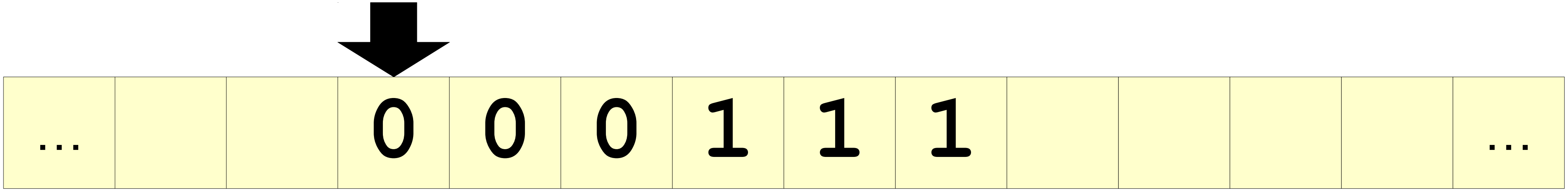

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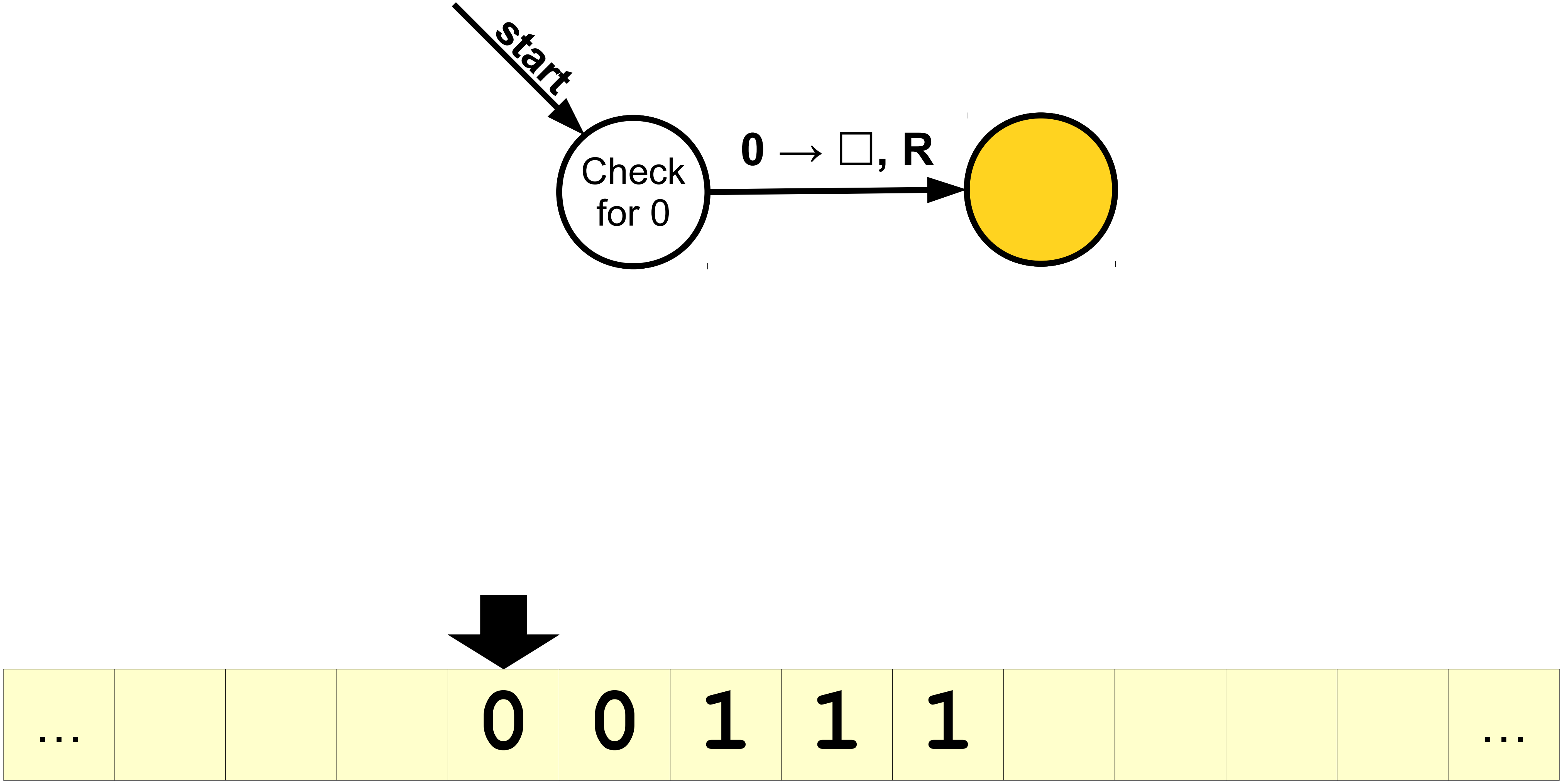
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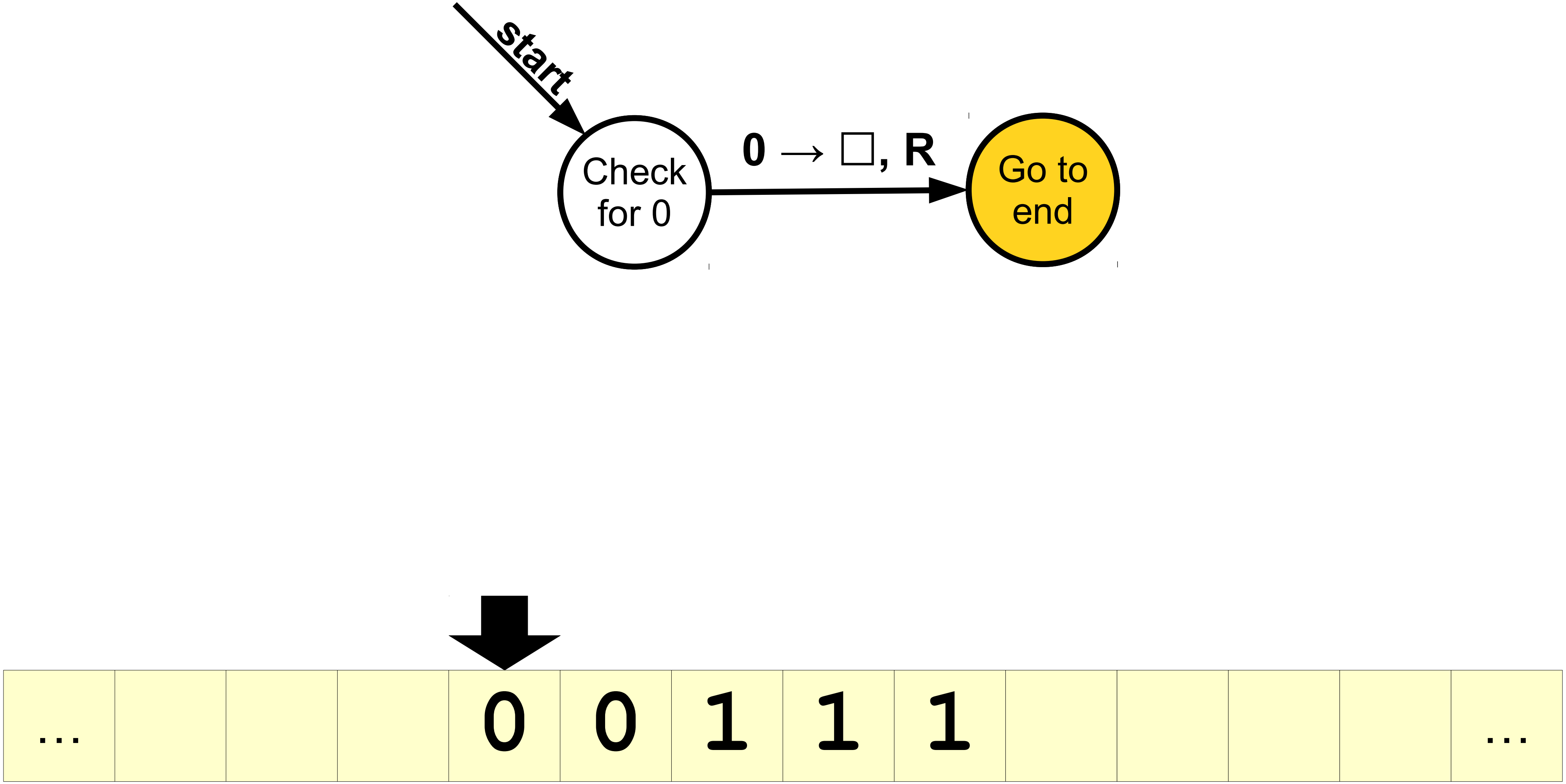
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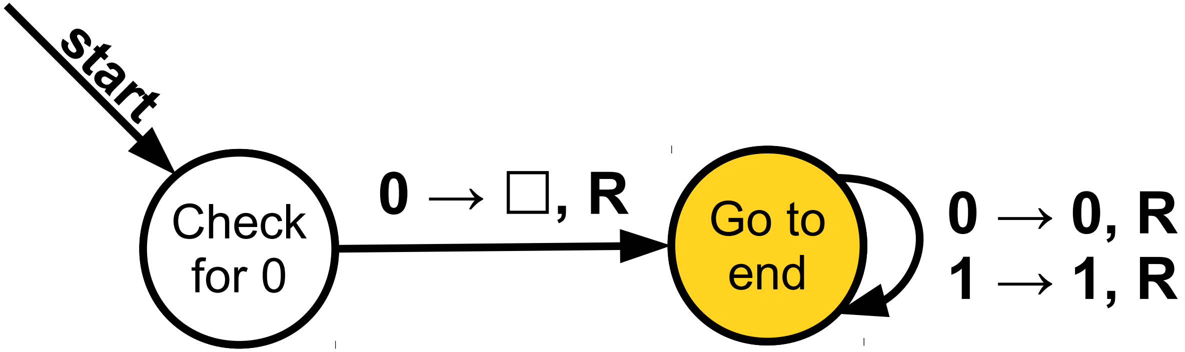

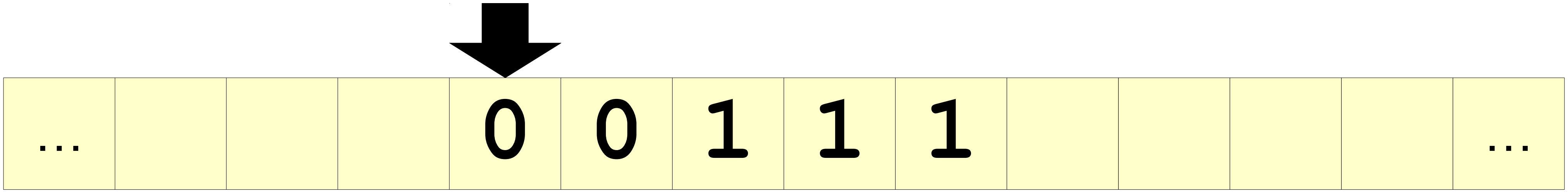

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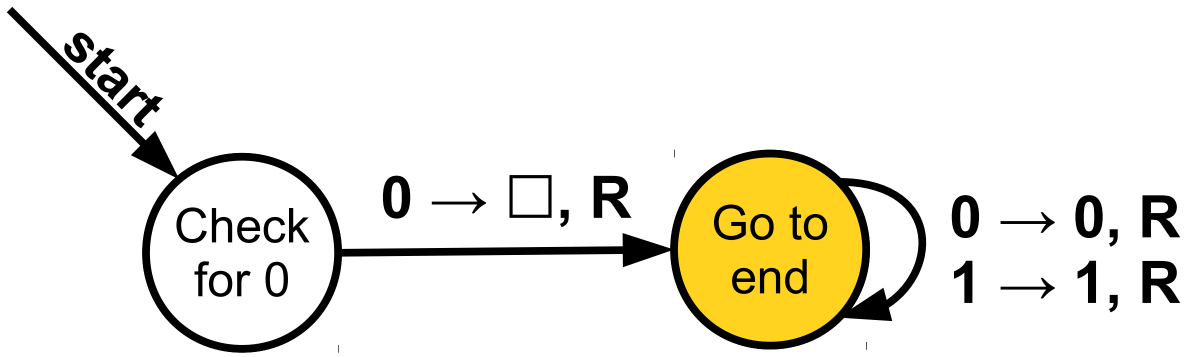

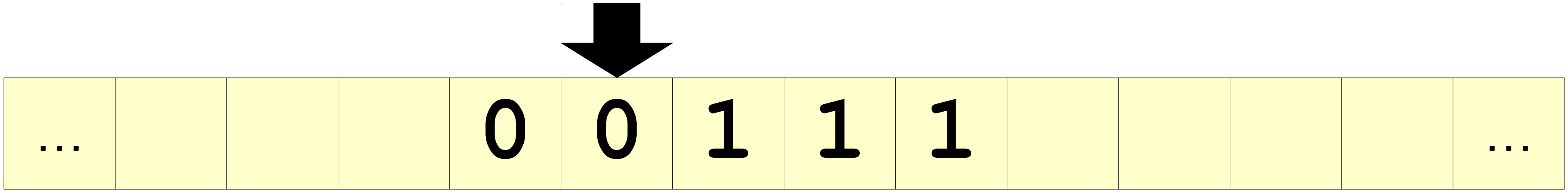

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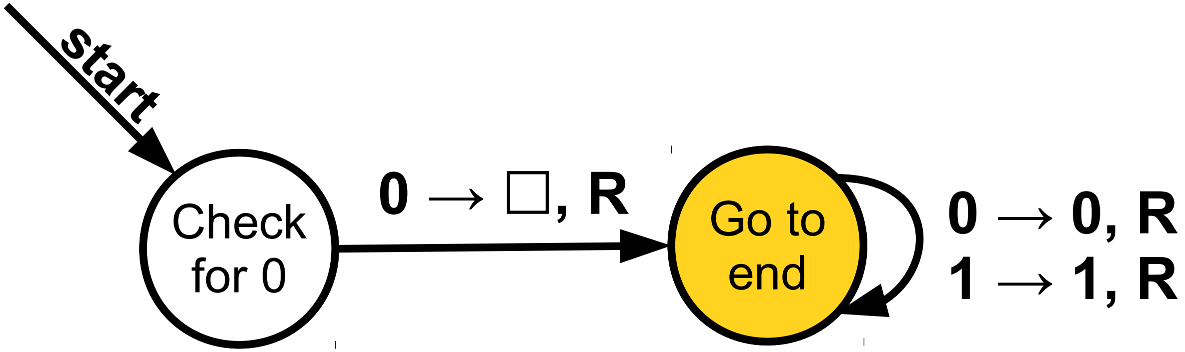

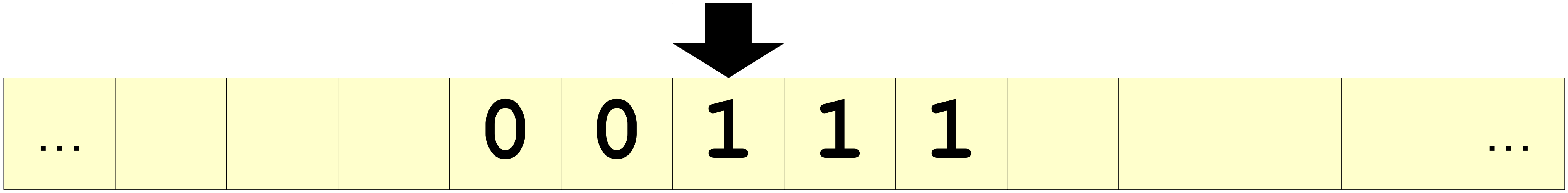

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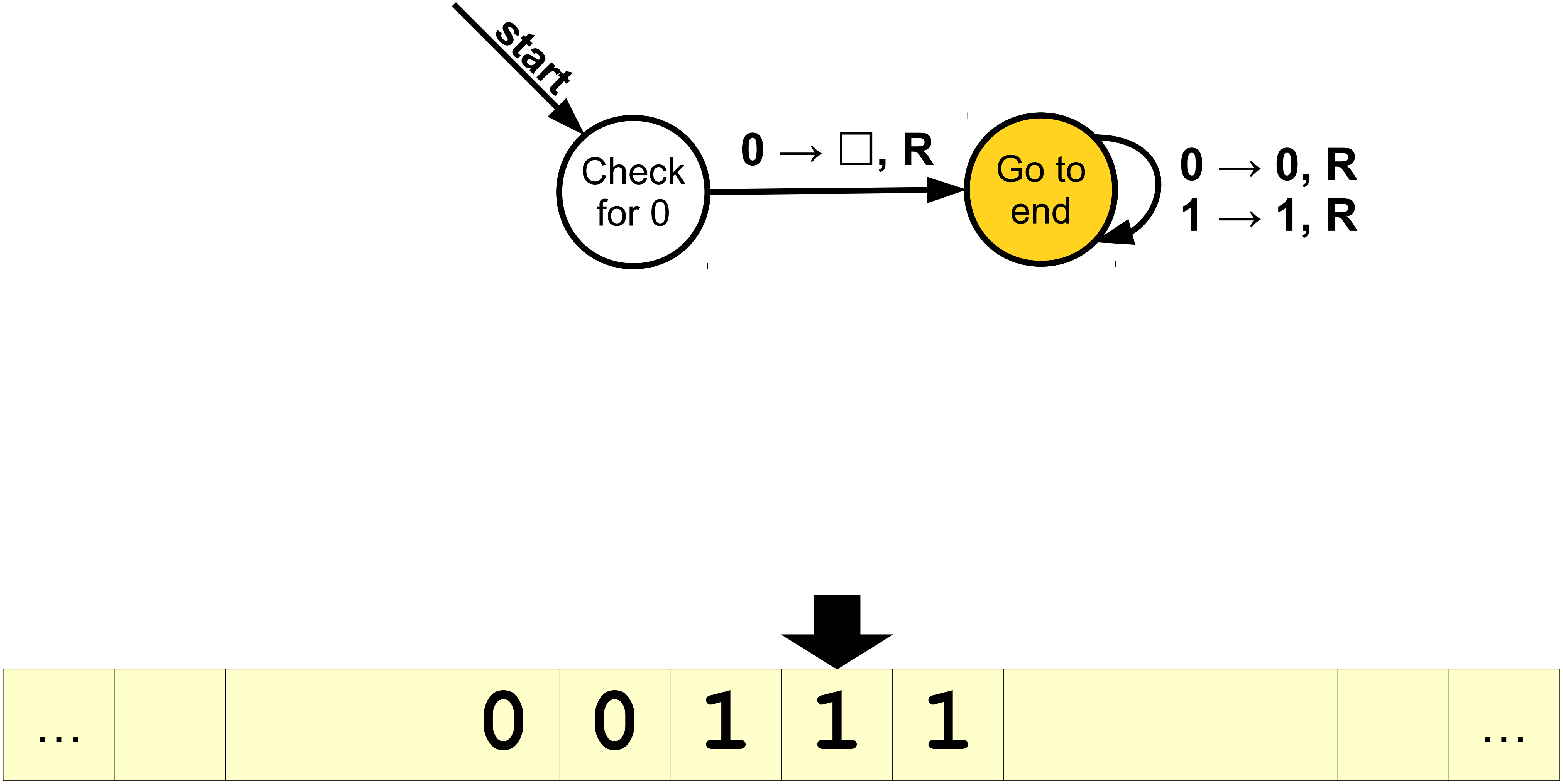
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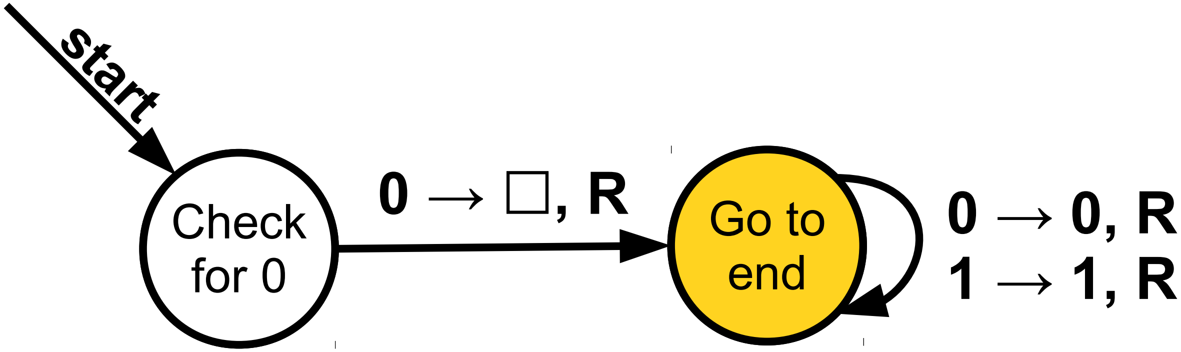

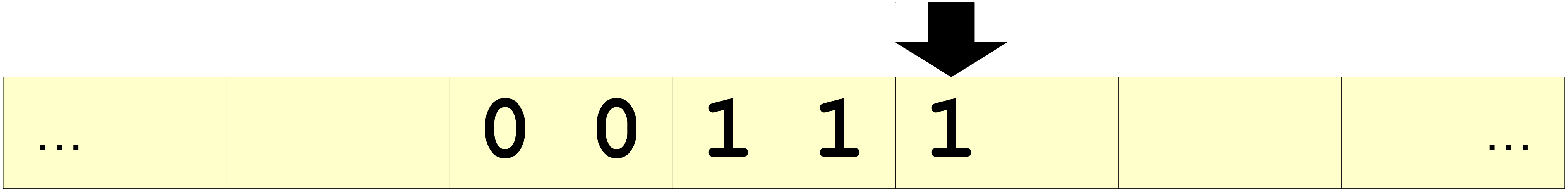

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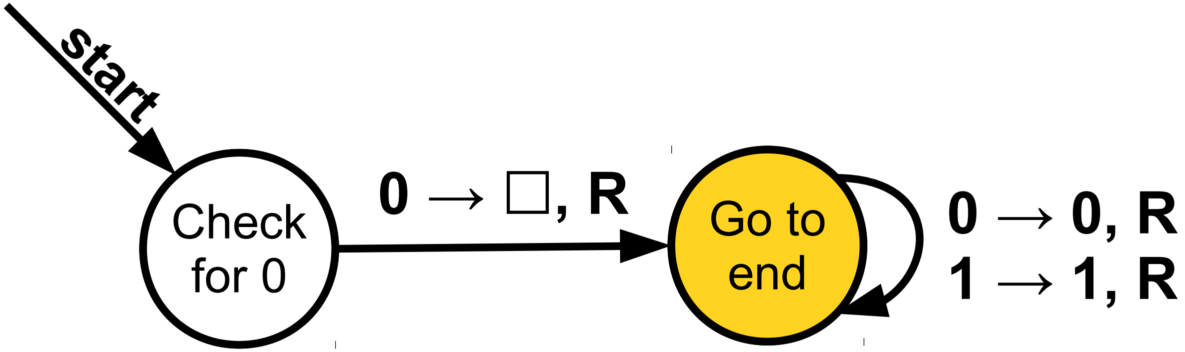
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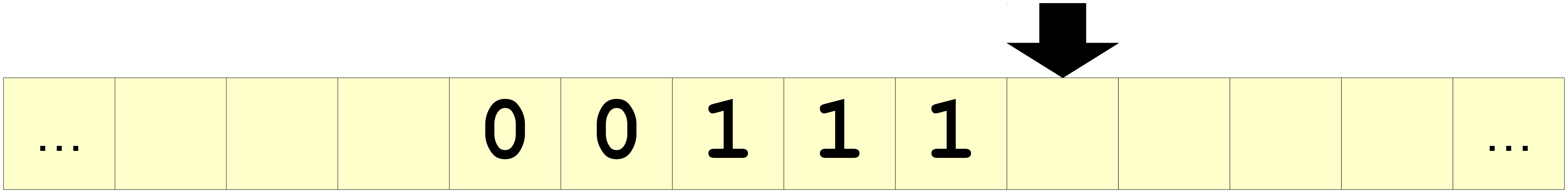
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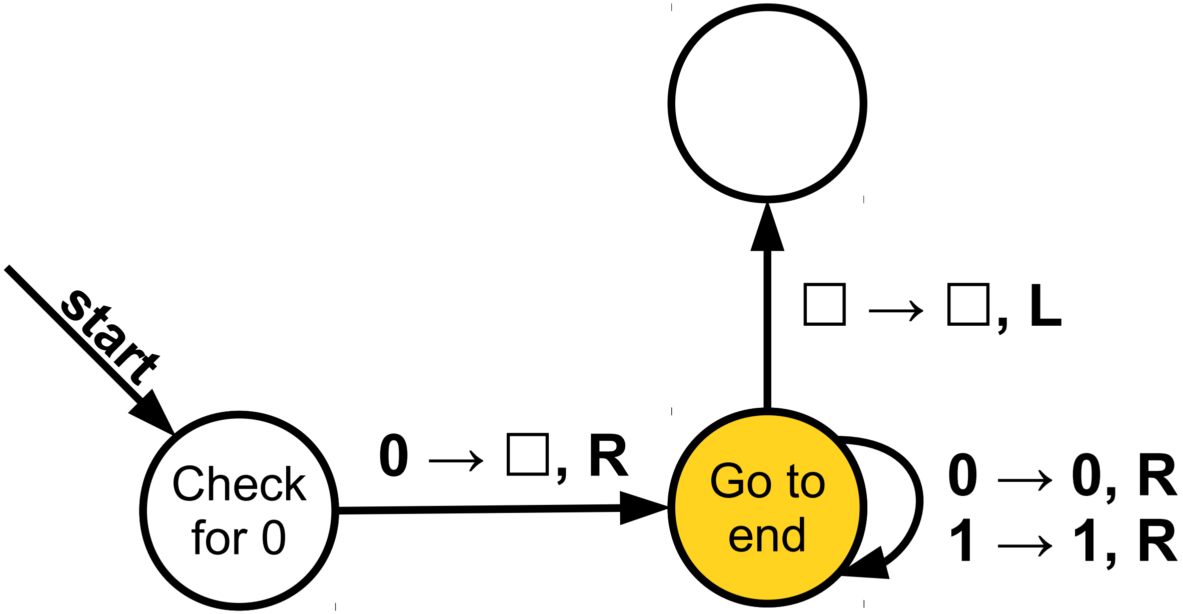

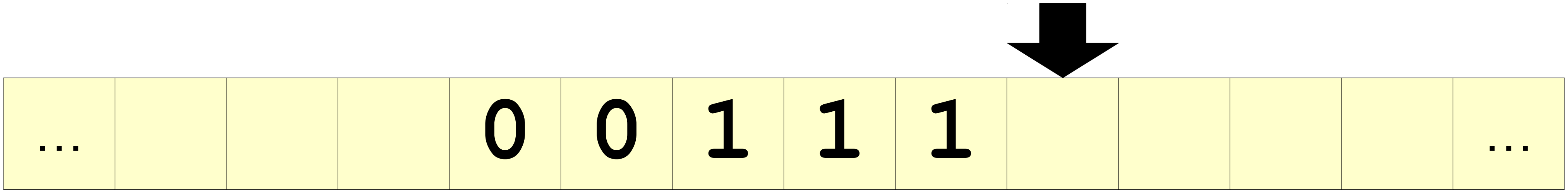

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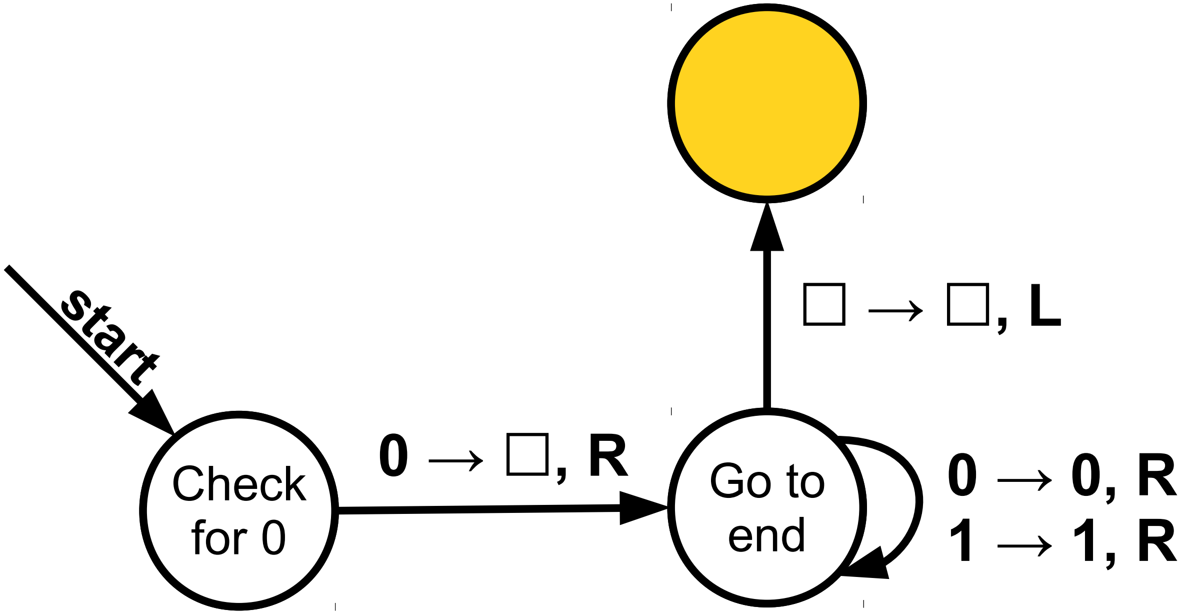
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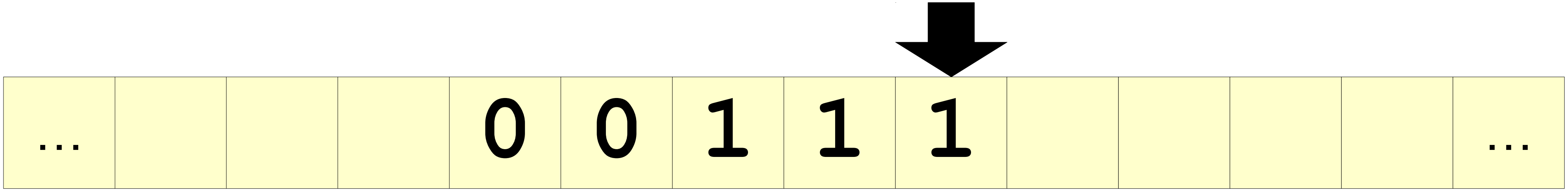
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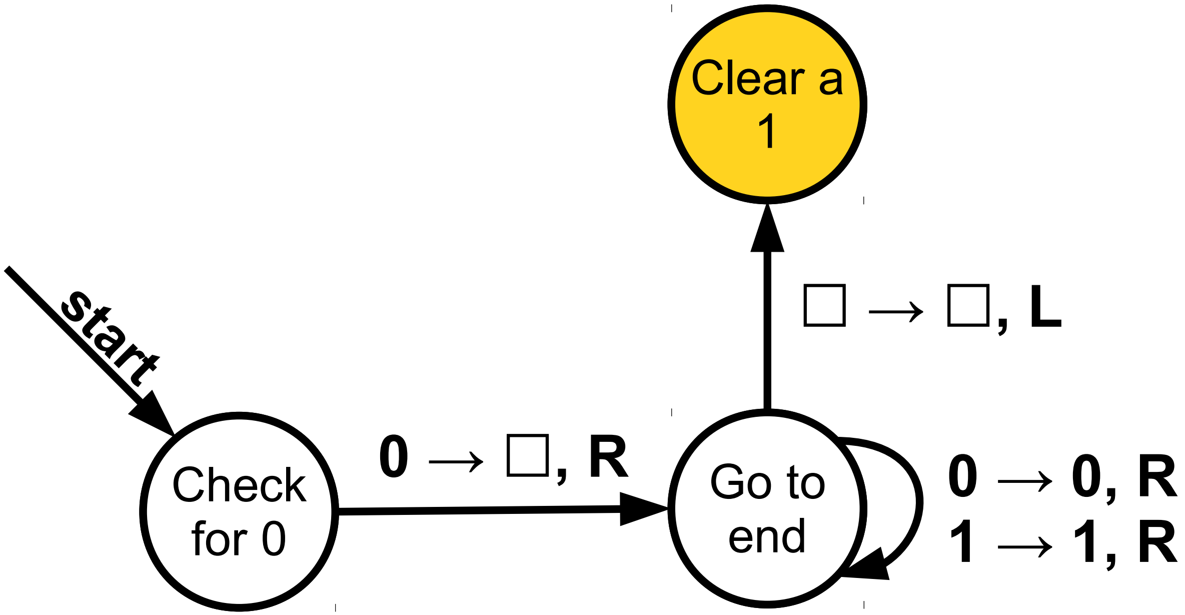

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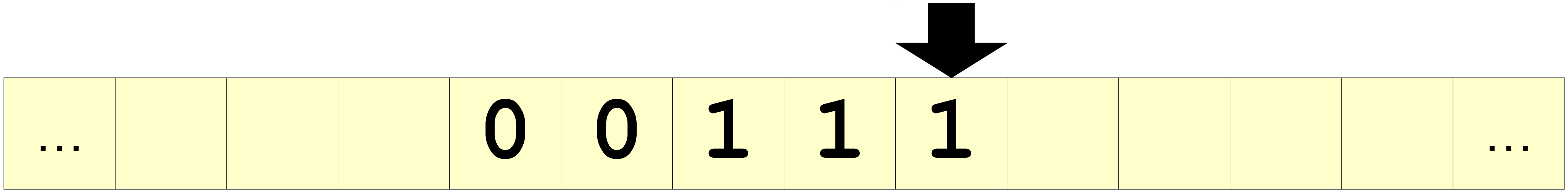

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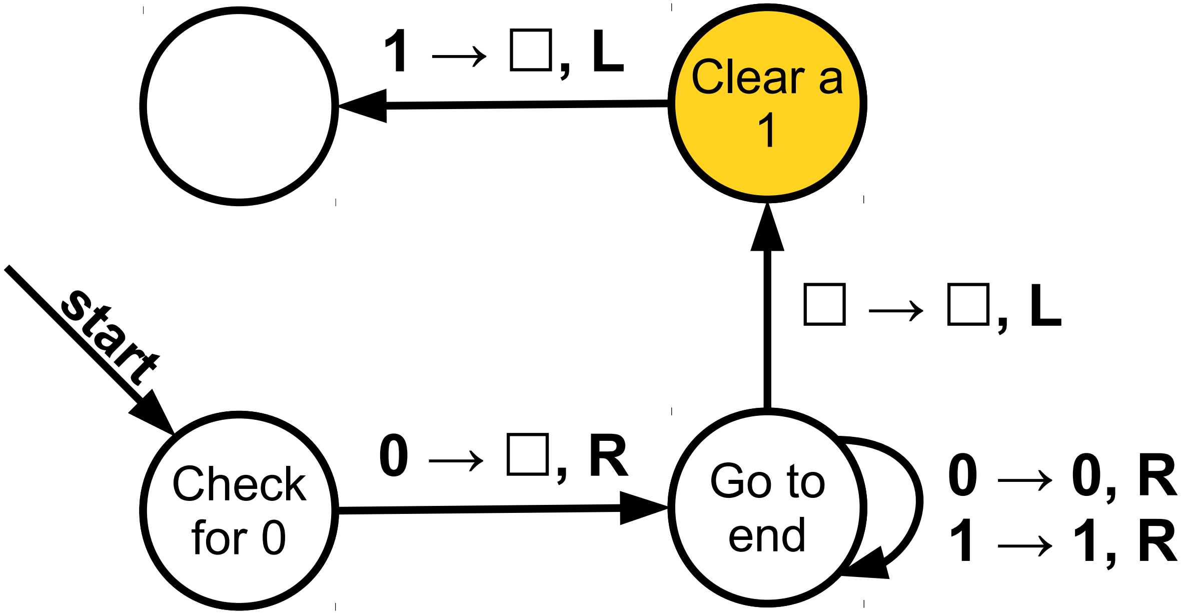
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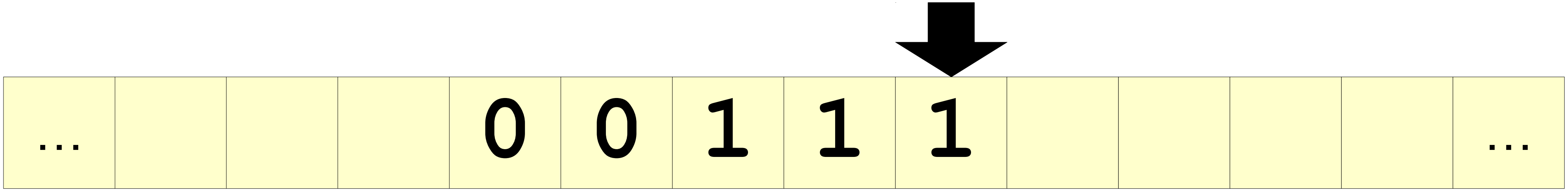
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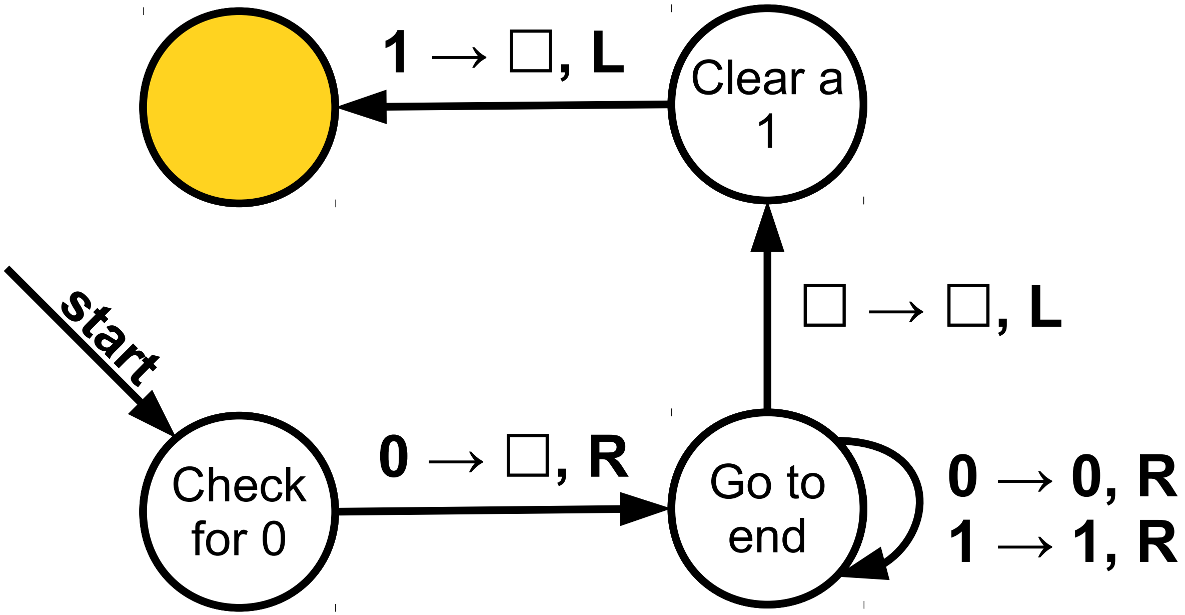
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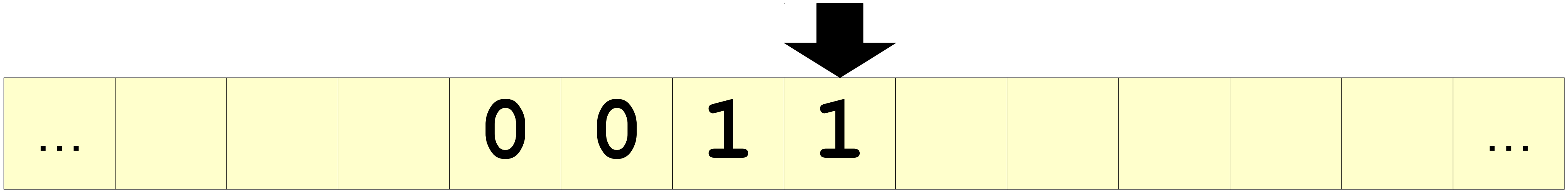
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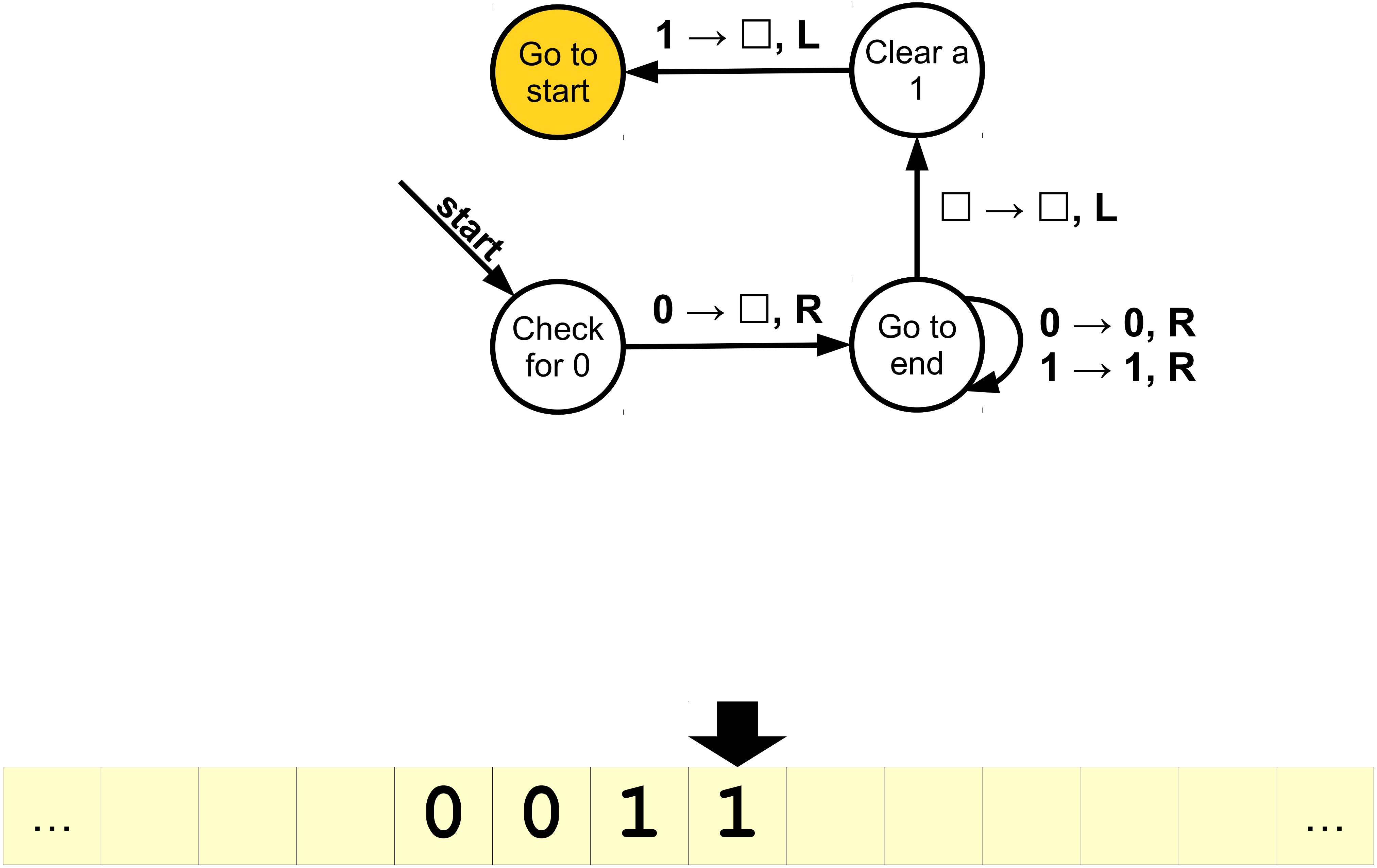
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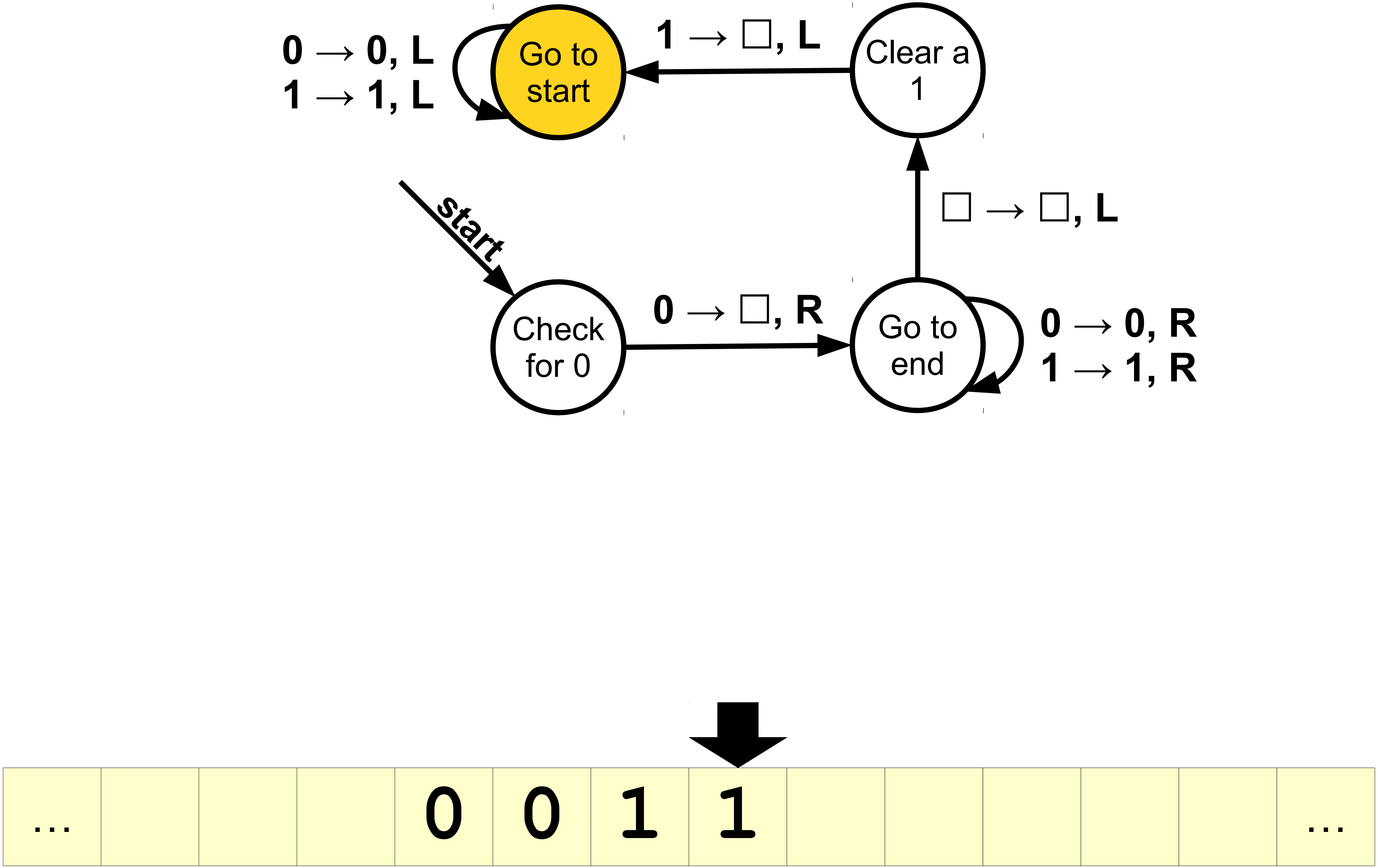
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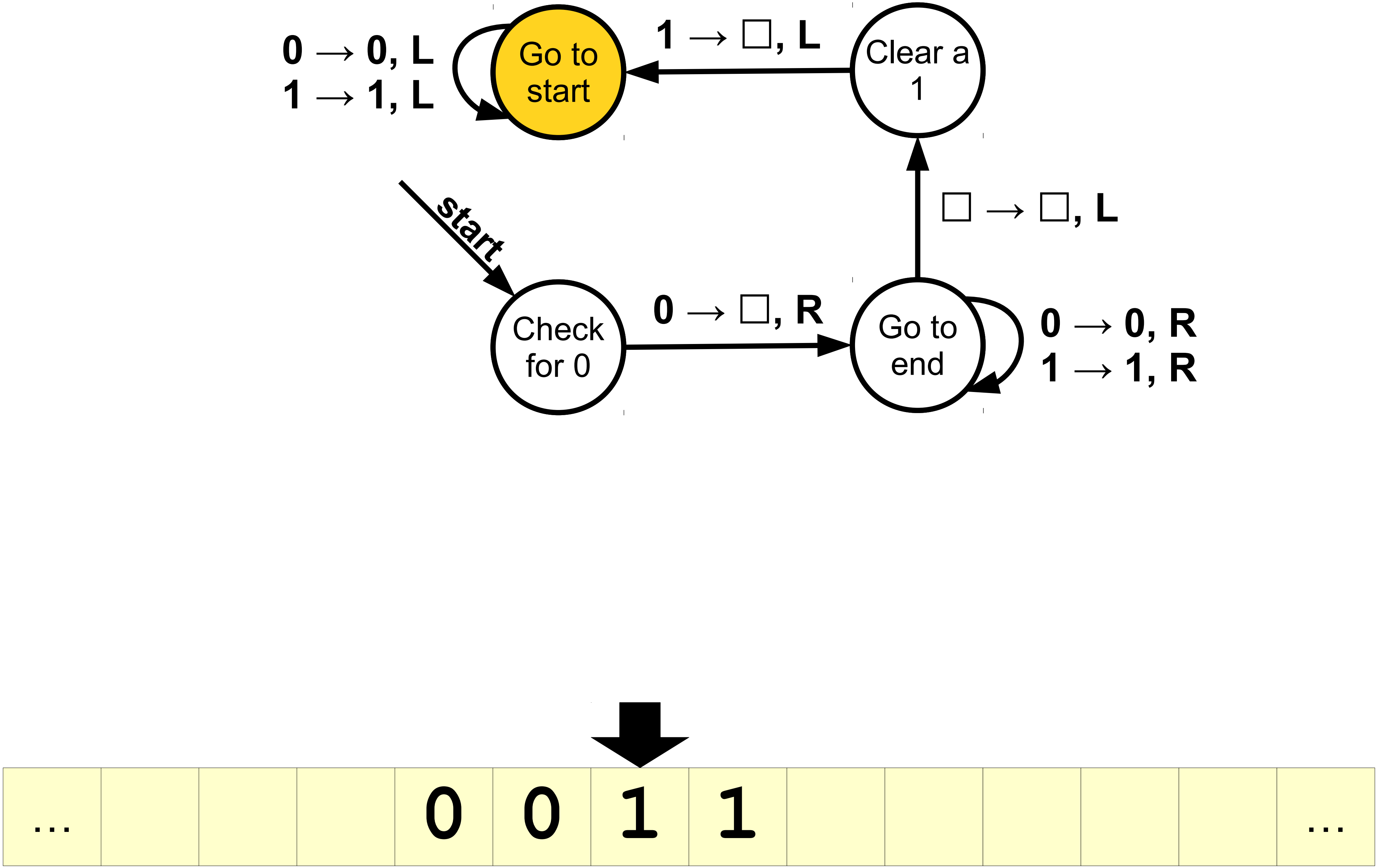
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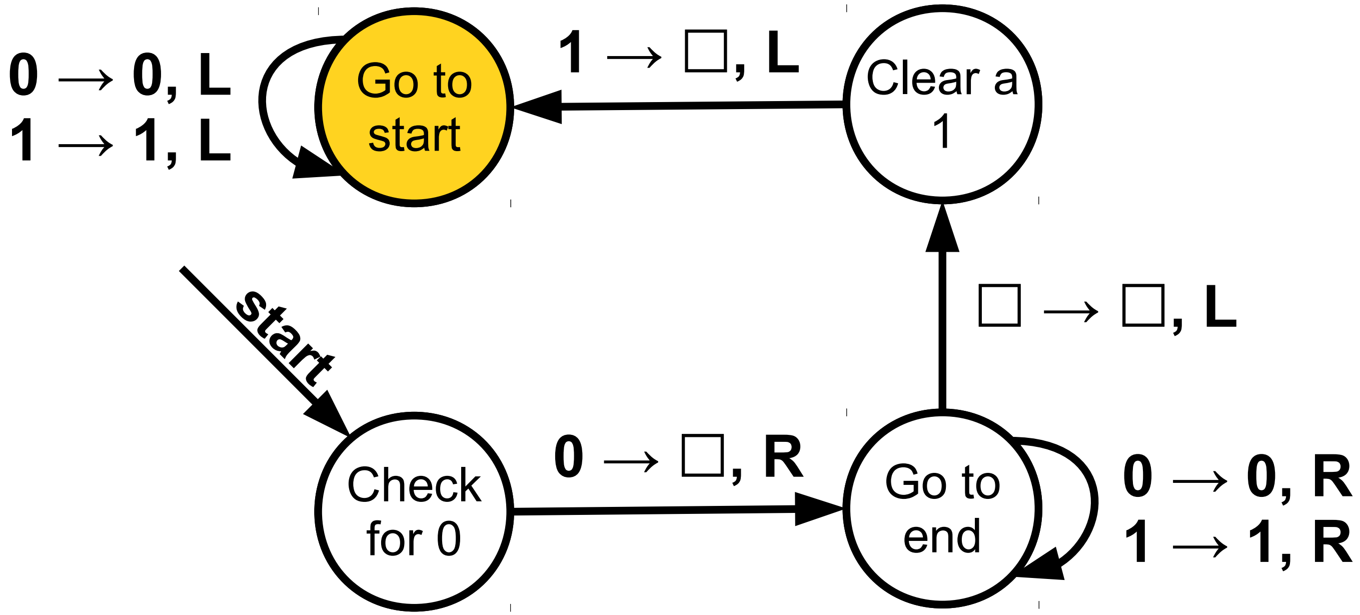
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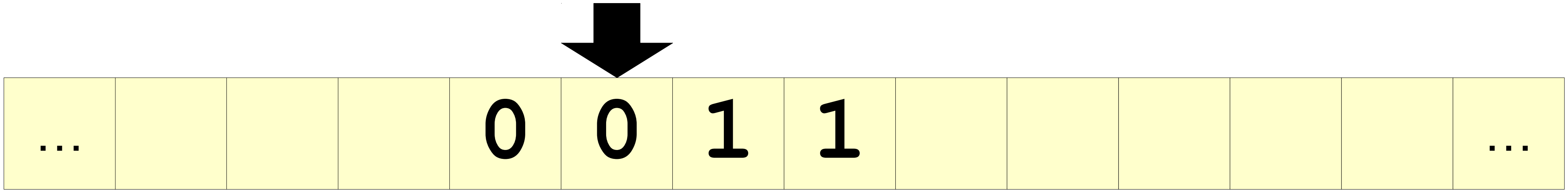
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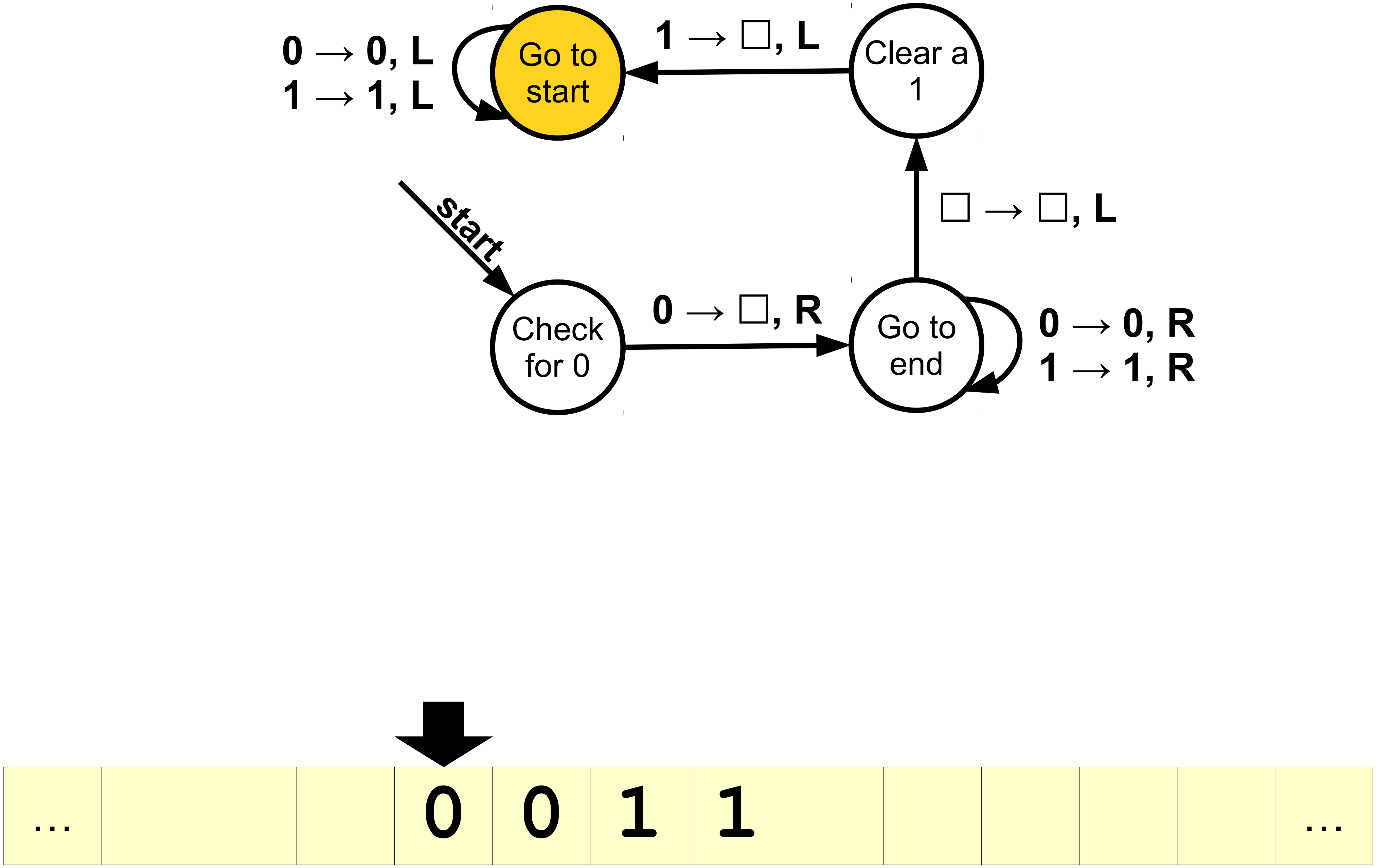
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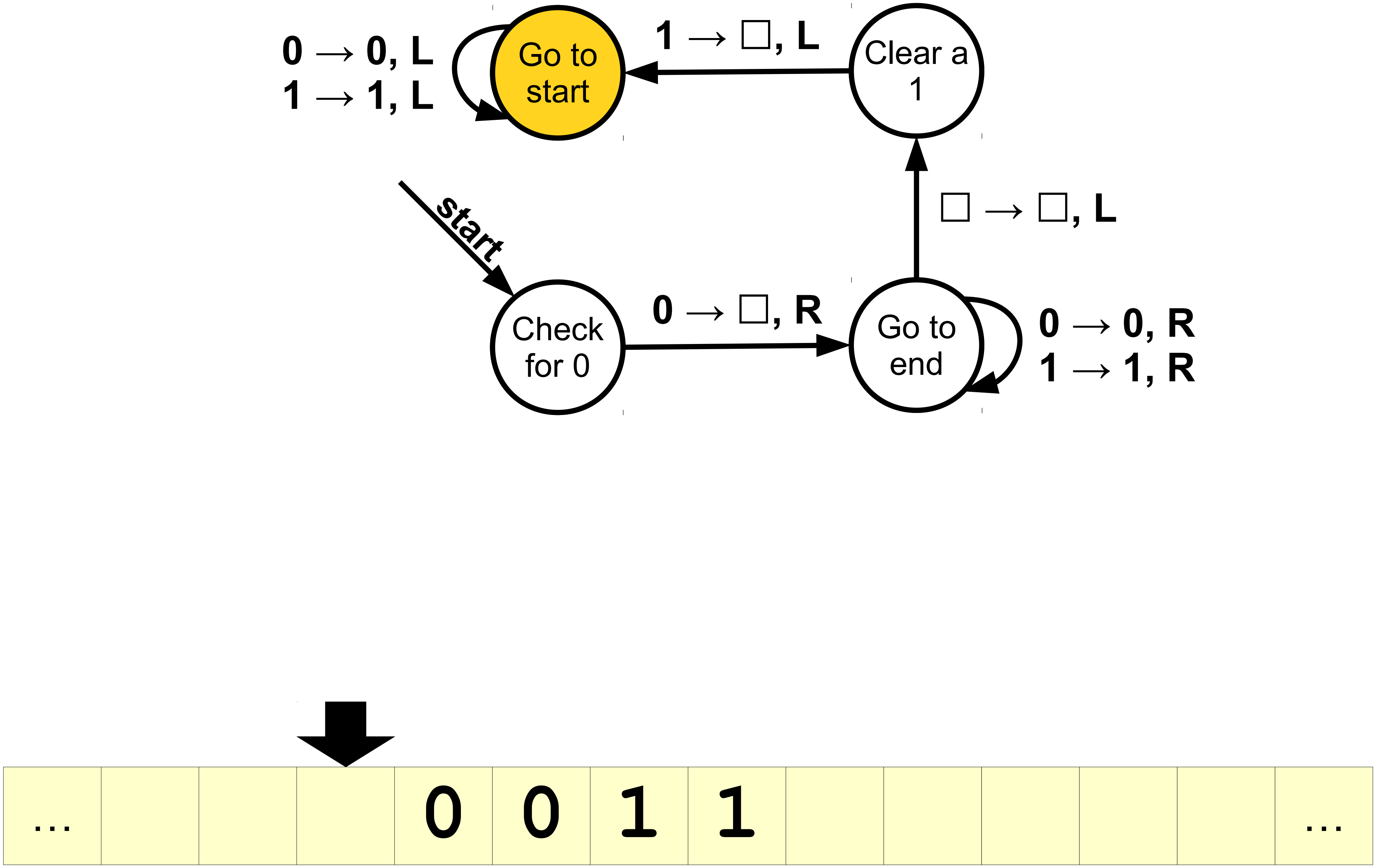
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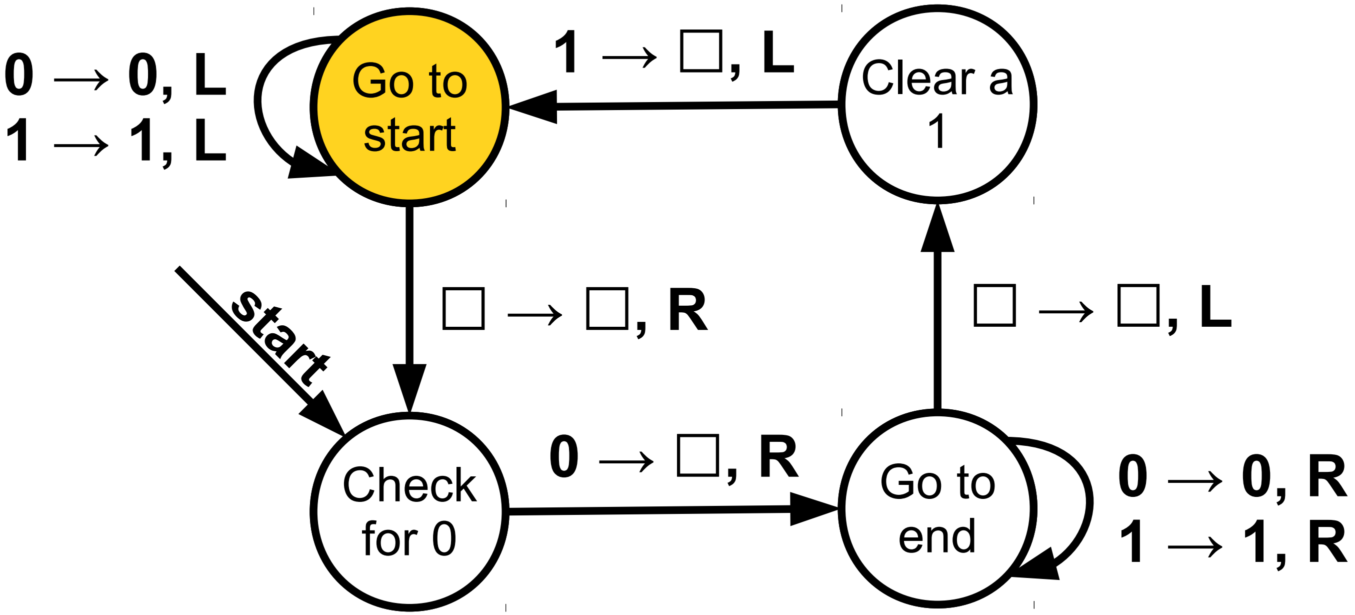
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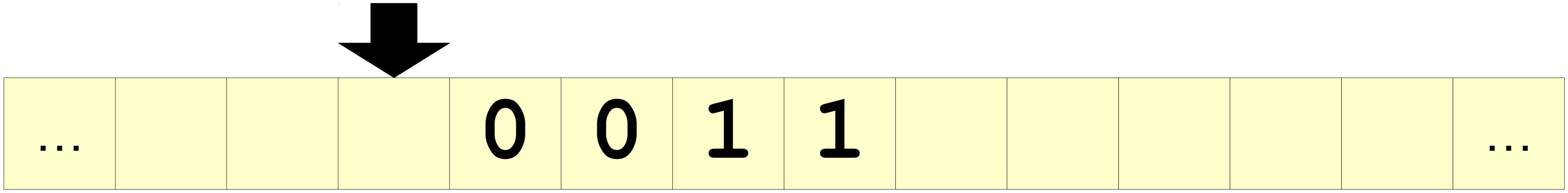
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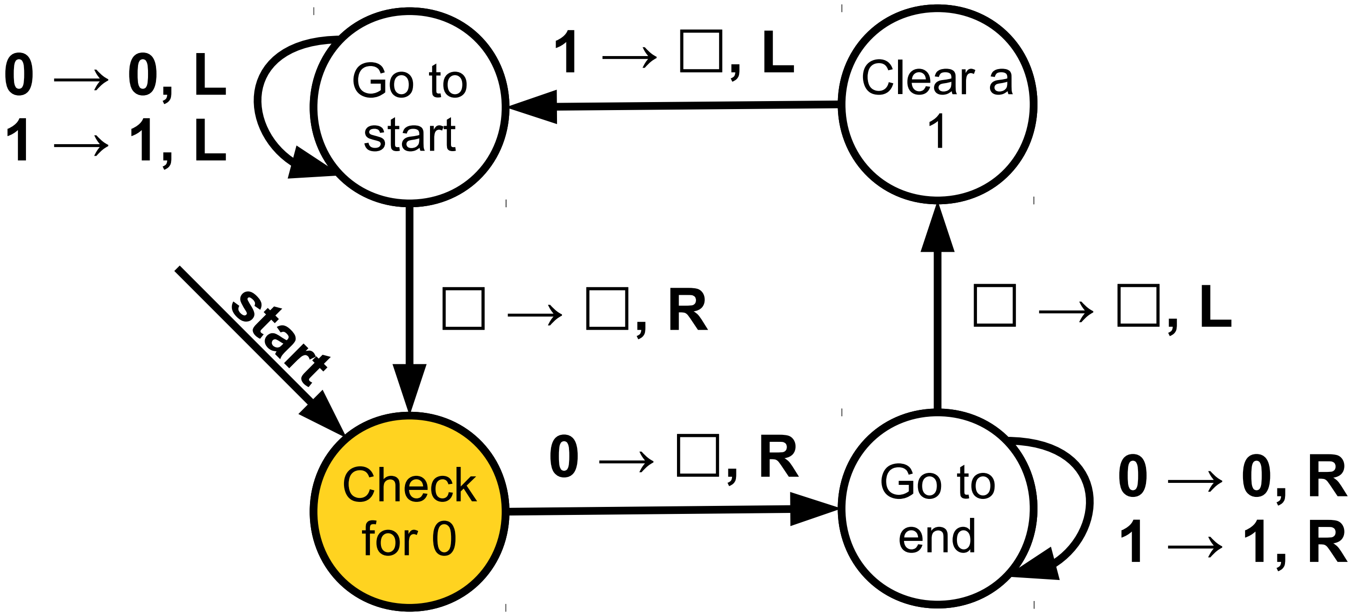
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Go to end
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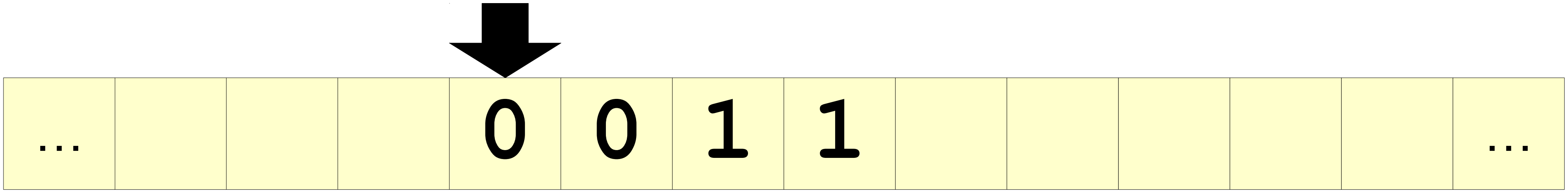
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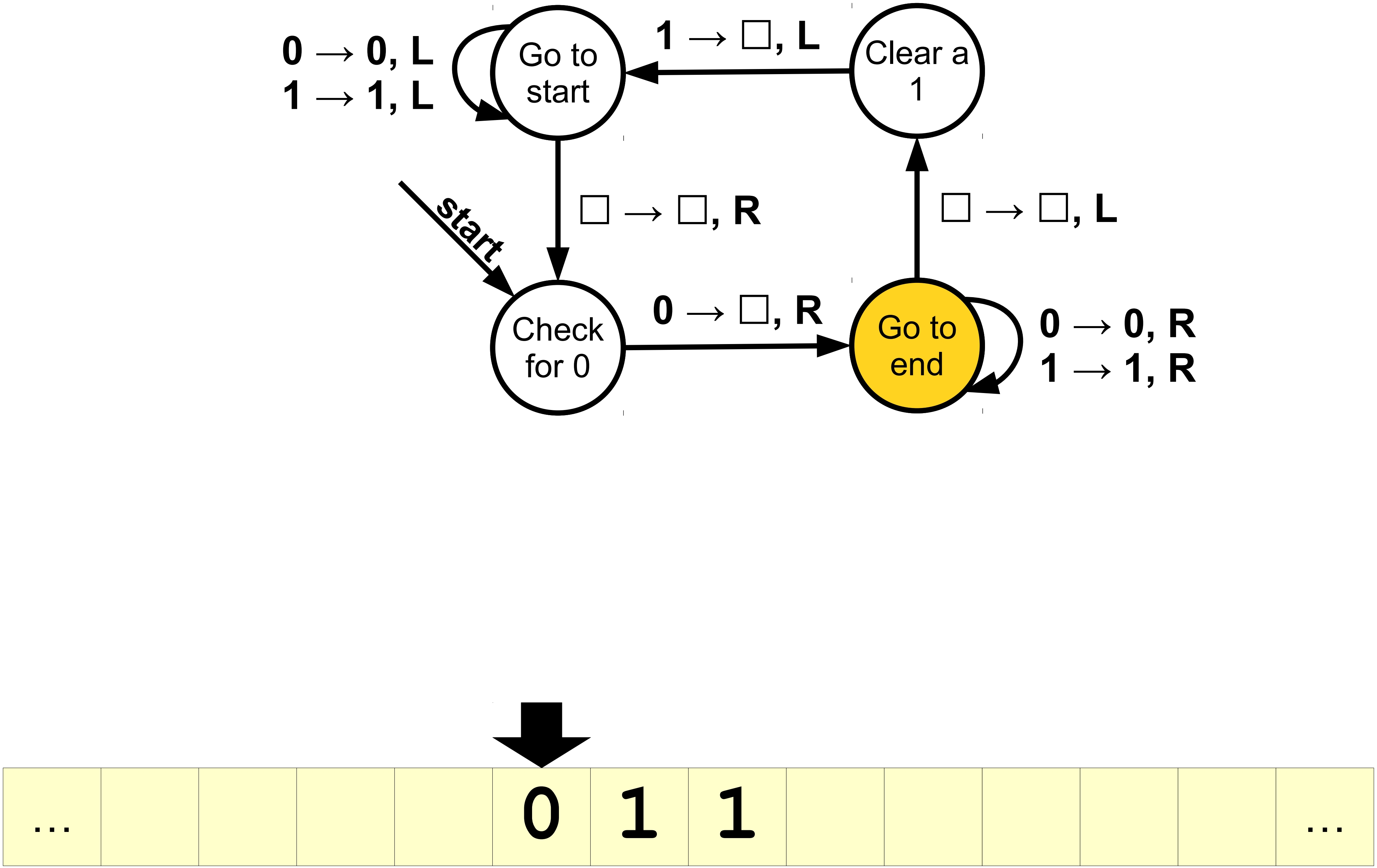

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start

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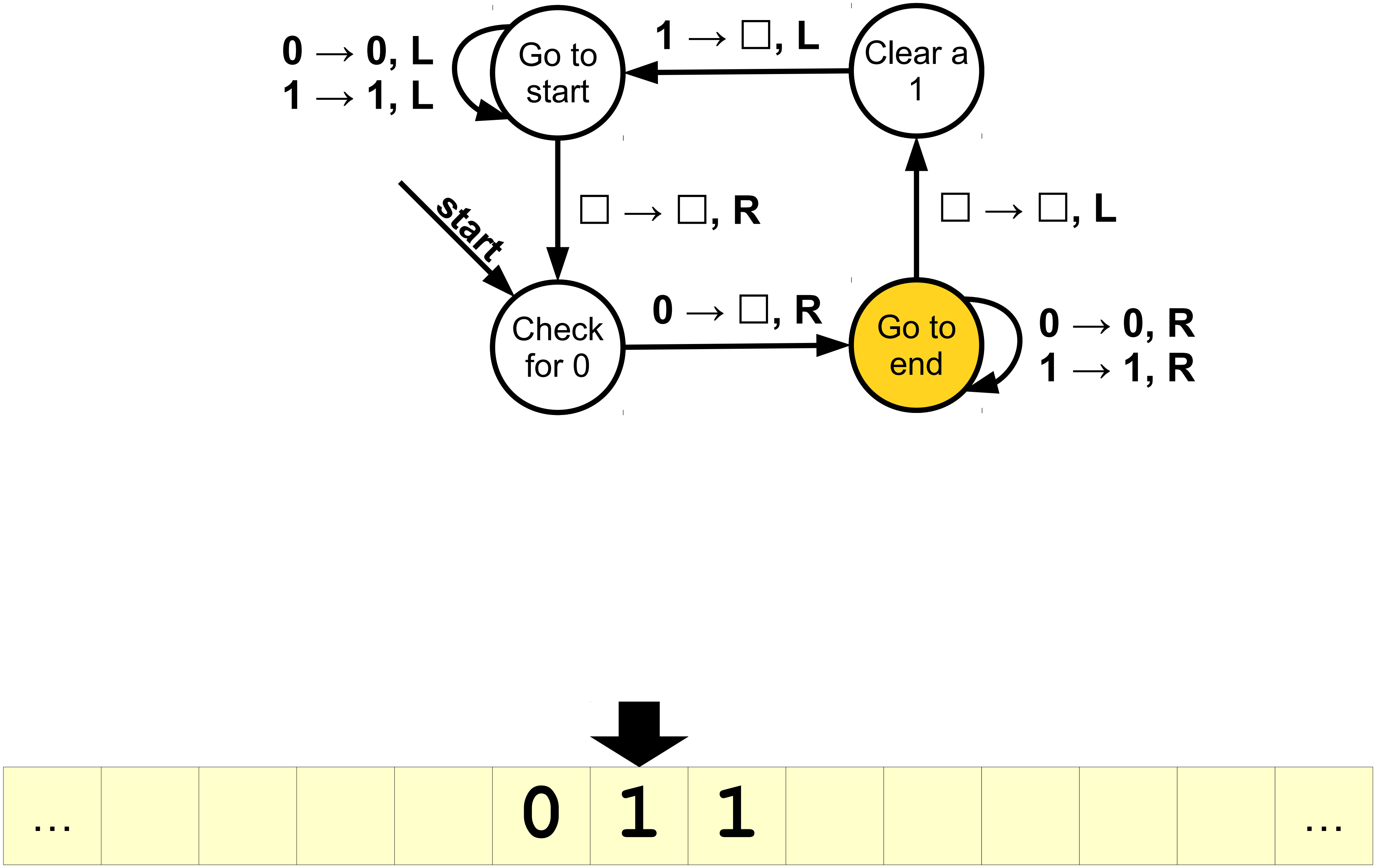
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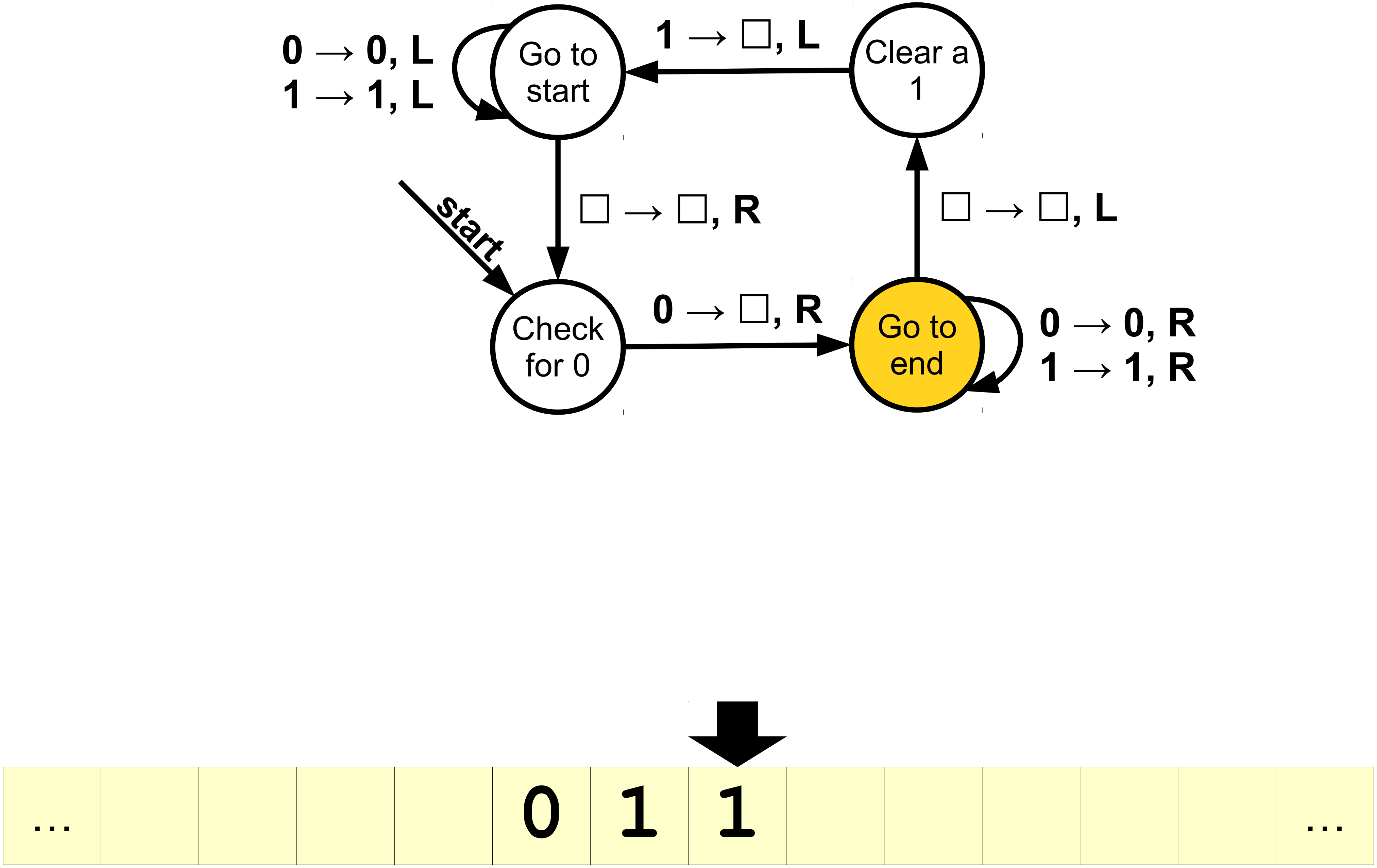
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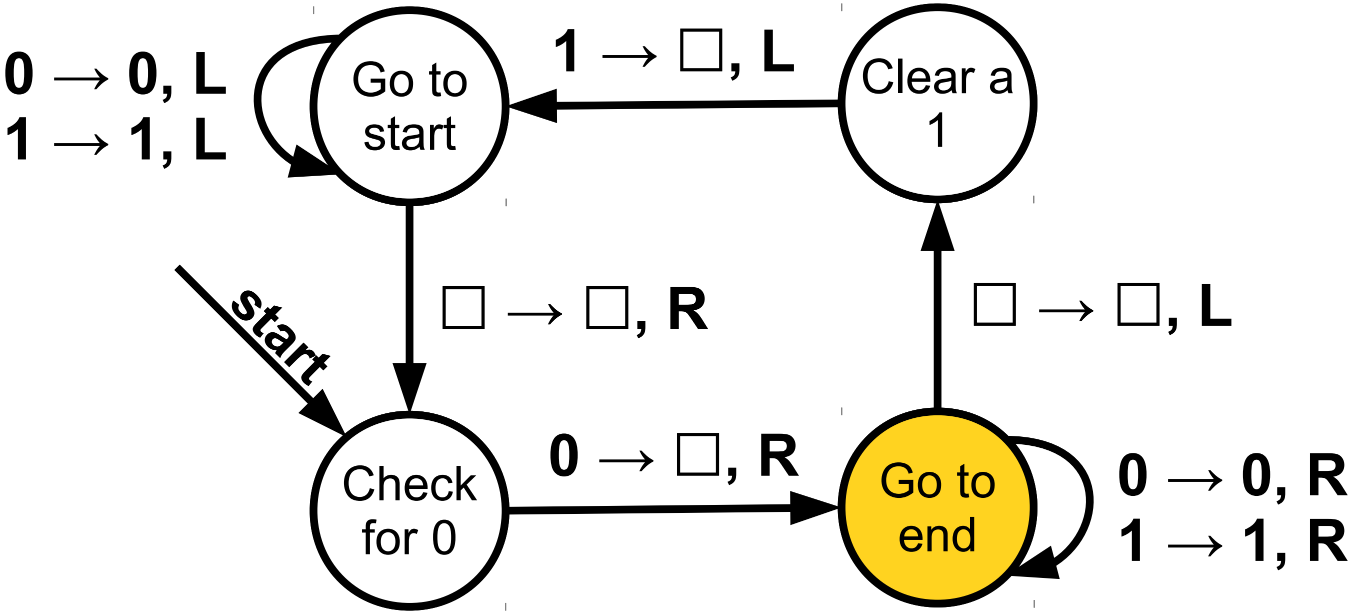
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Go to end
0 → 0, R
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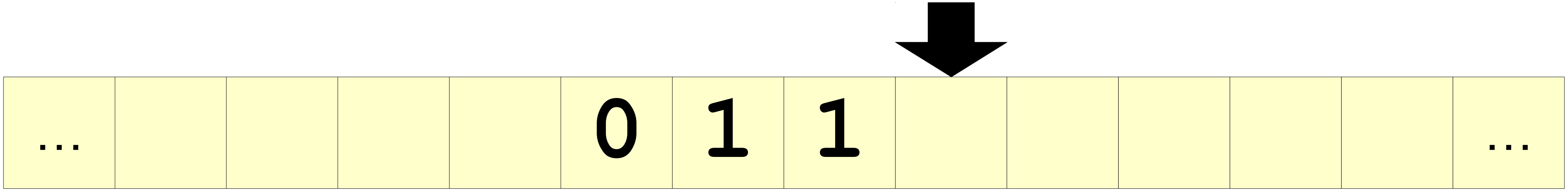
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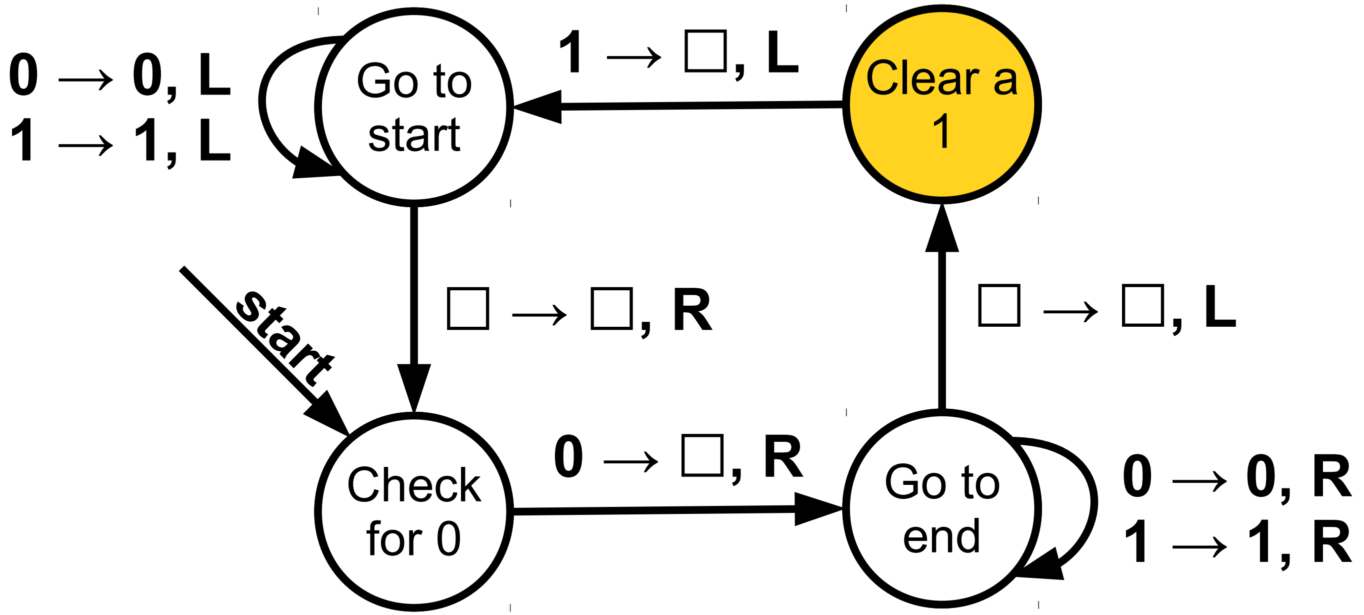
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1 → 1, L
Go to start
1 → □, L
Clear a 1
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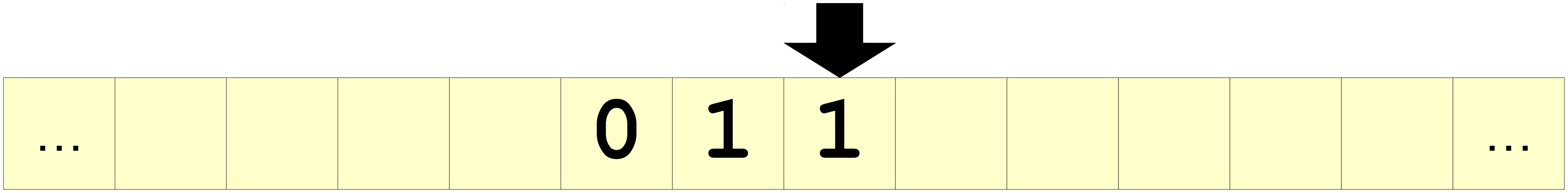
□ → □, R
□ → □, L
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R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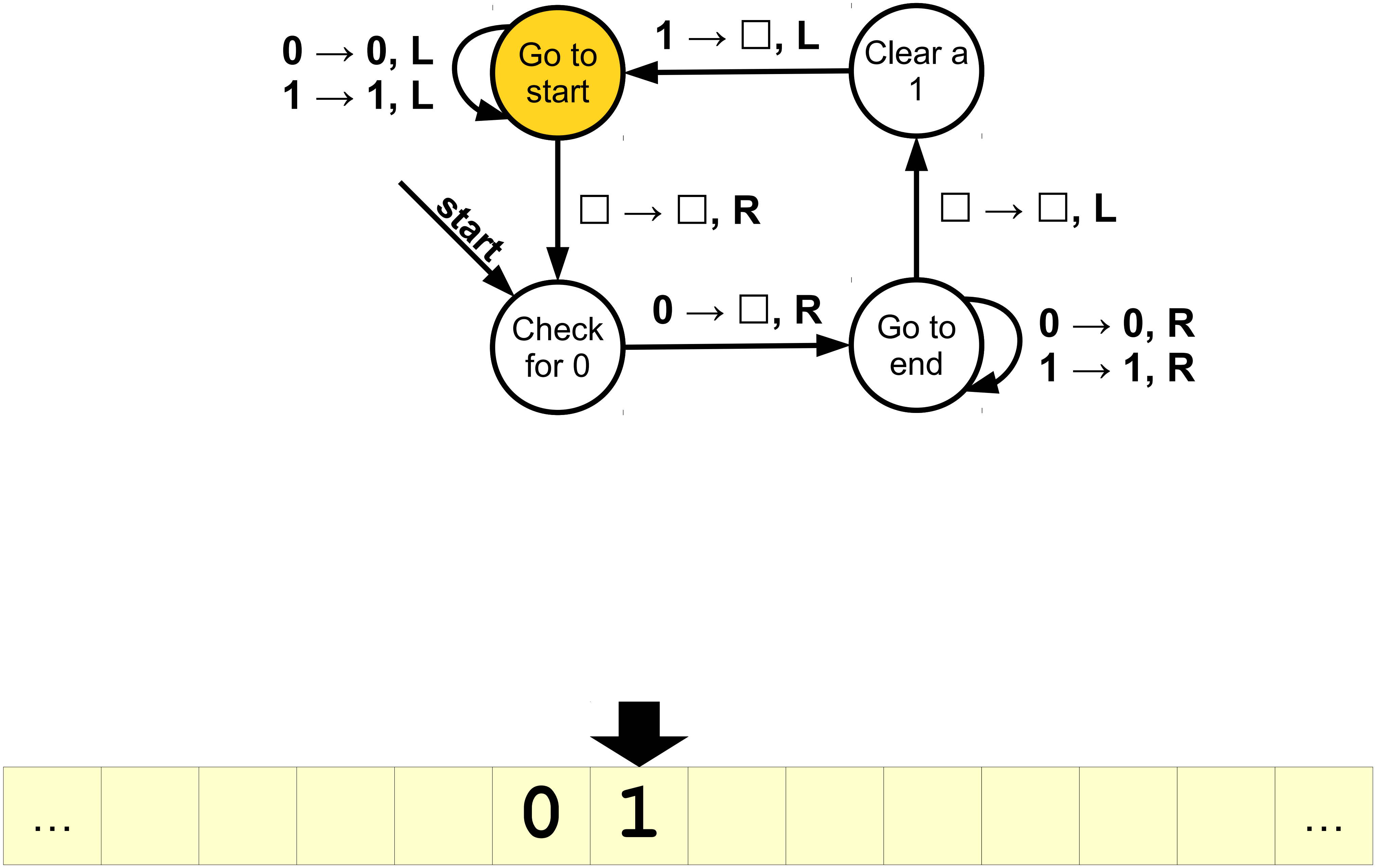
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□ → □, L
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Go to end
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1 → 1, R
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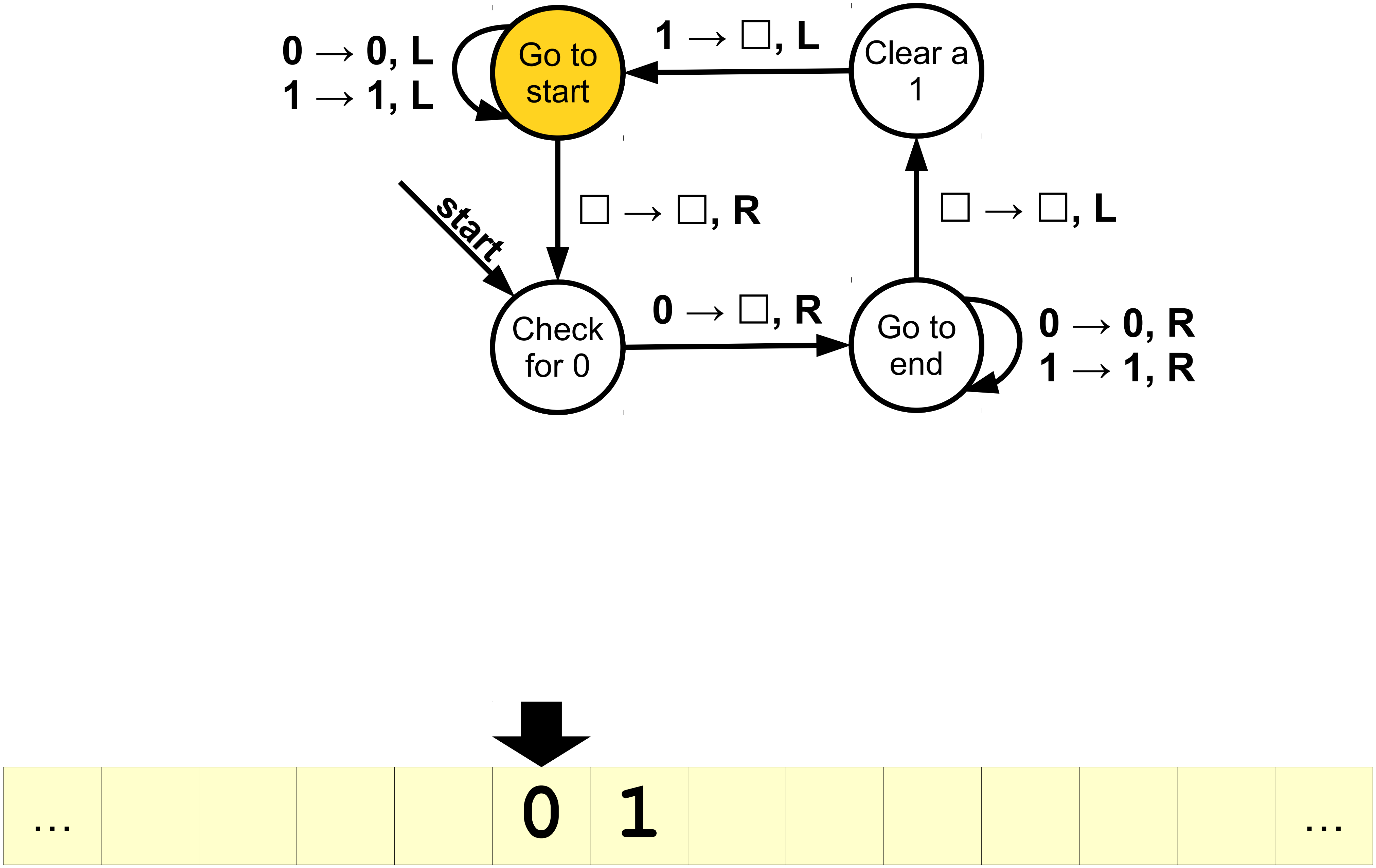
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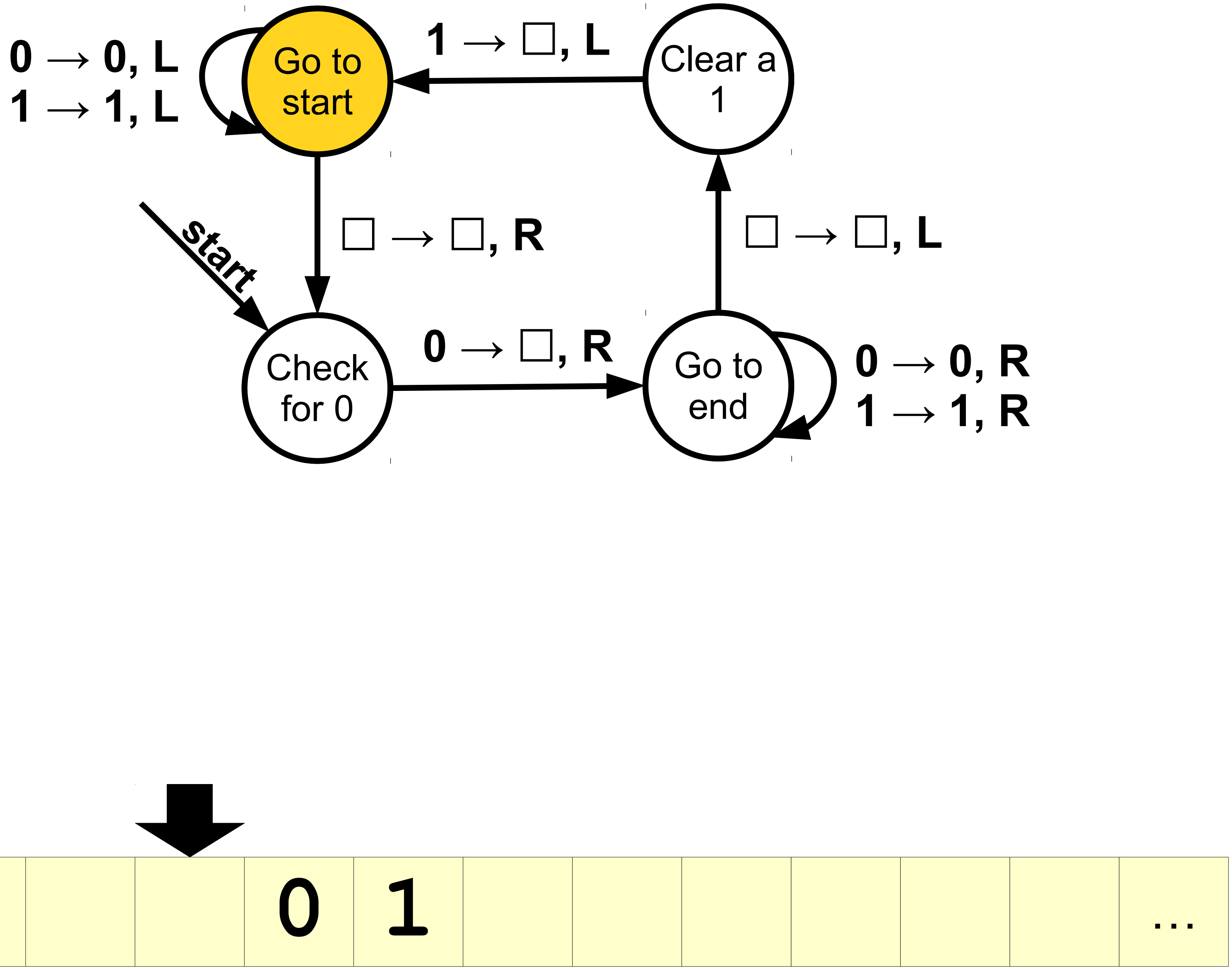
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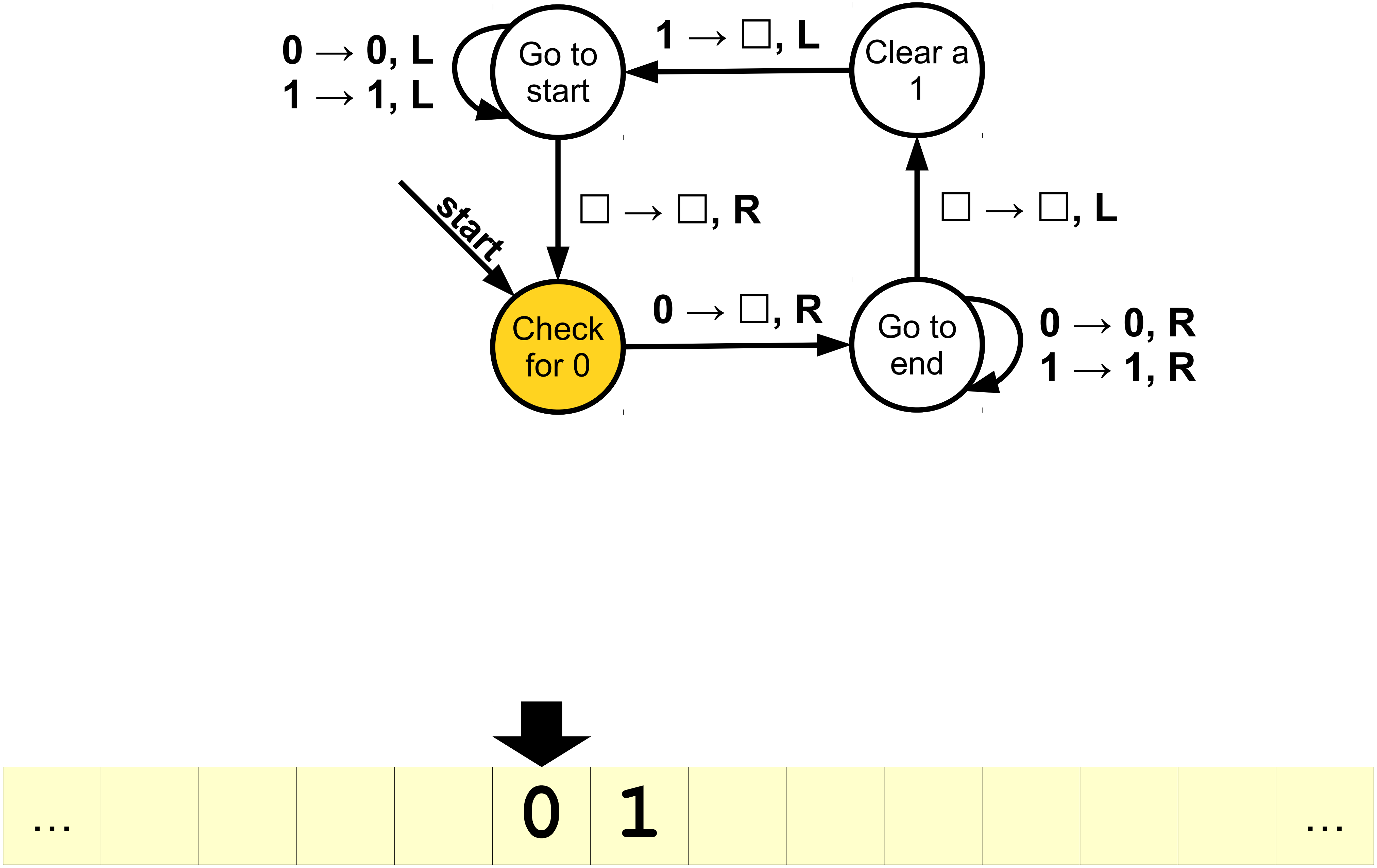
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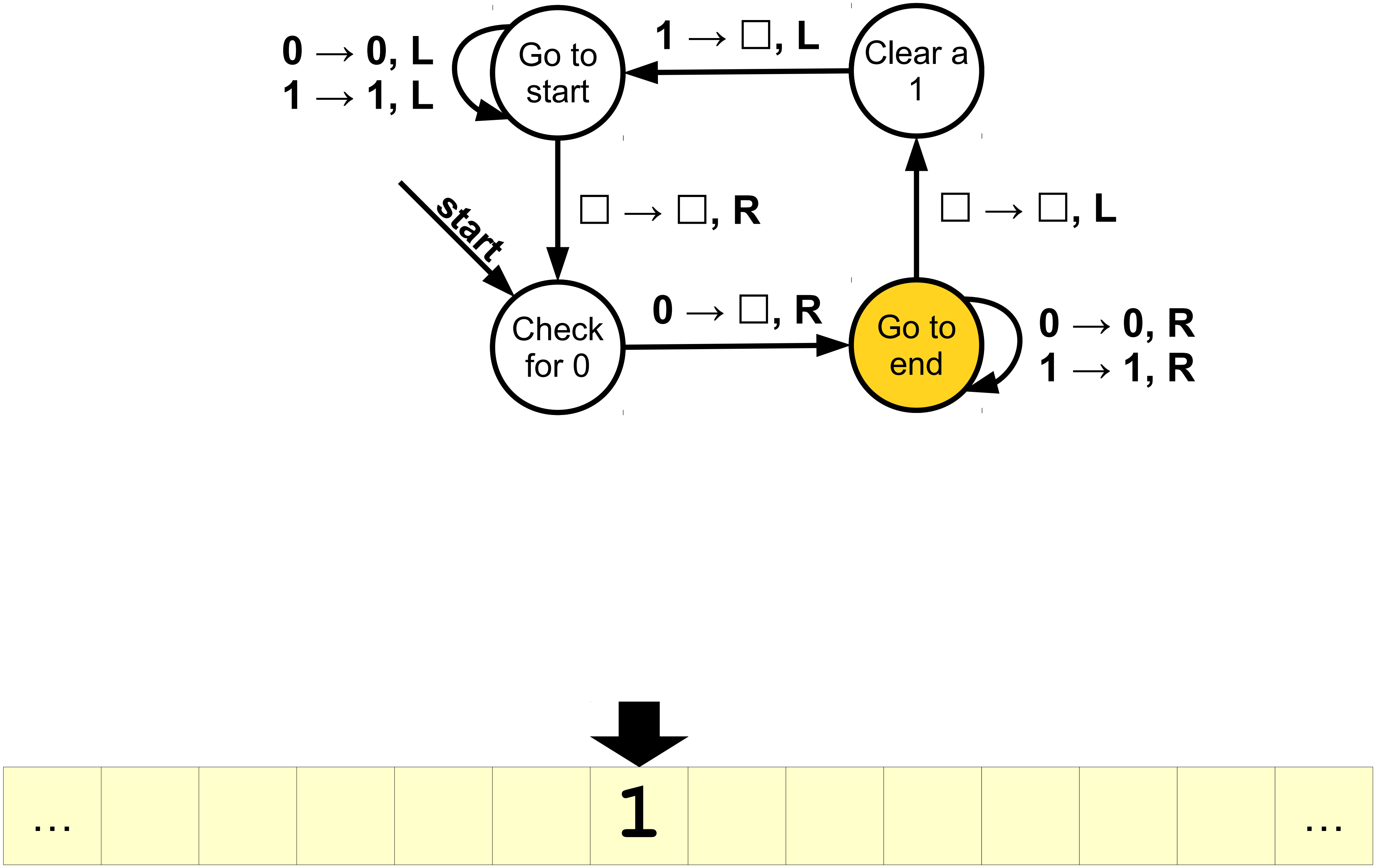
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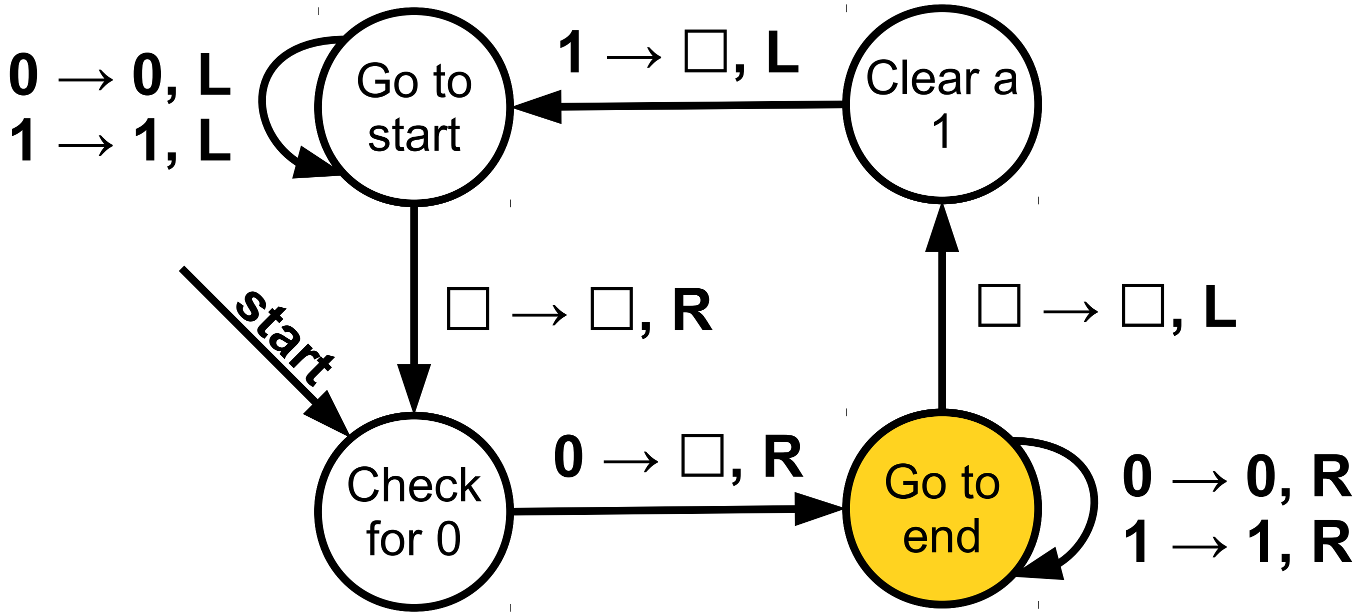
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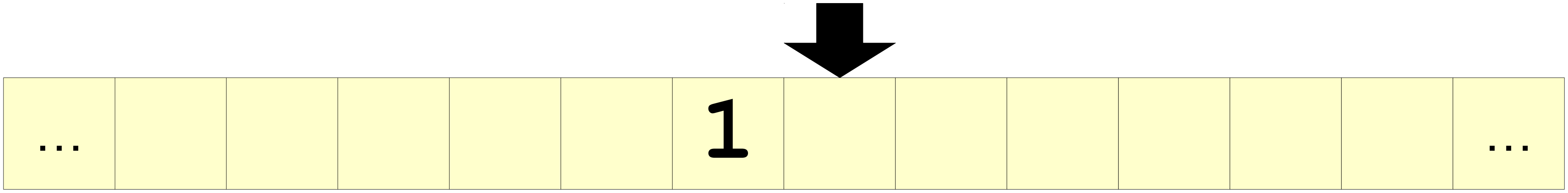
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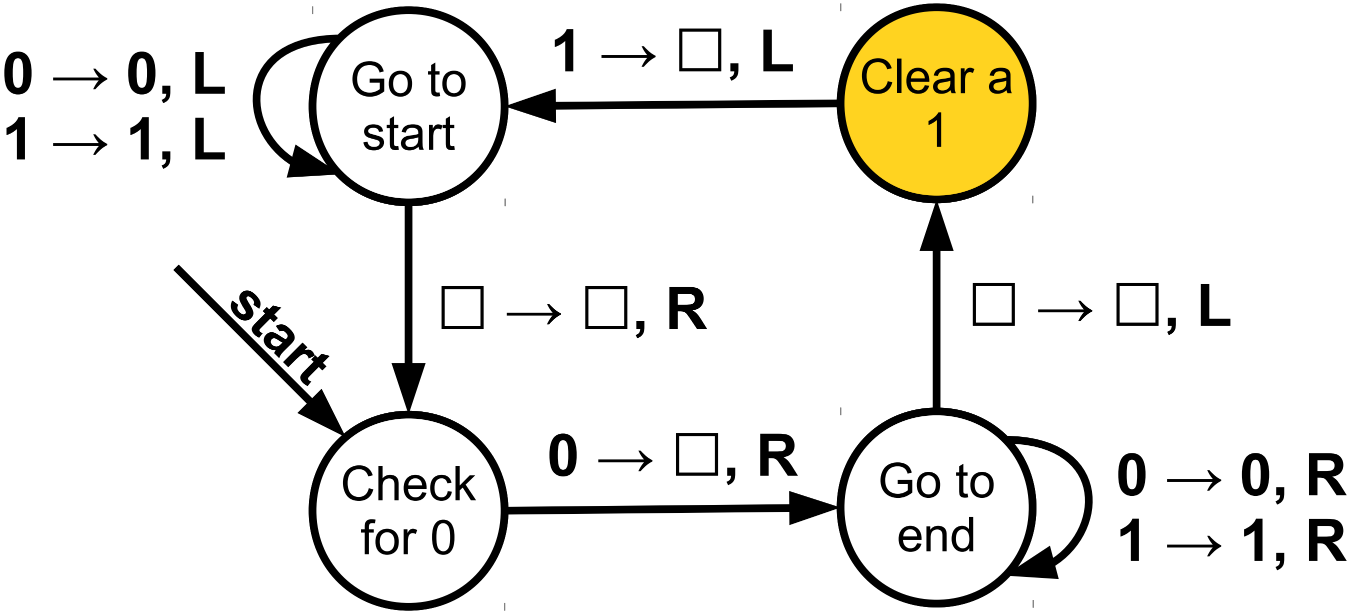
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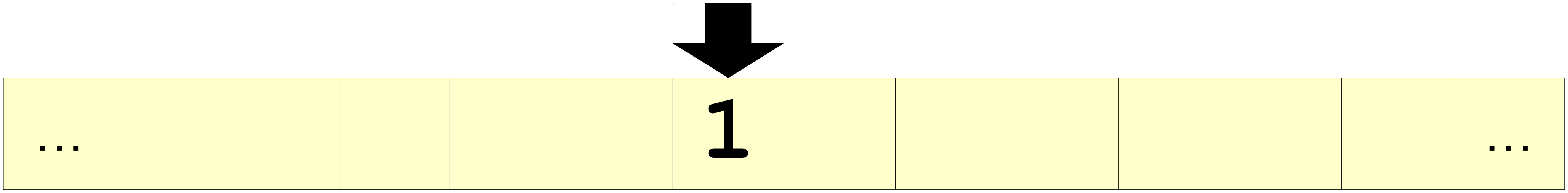
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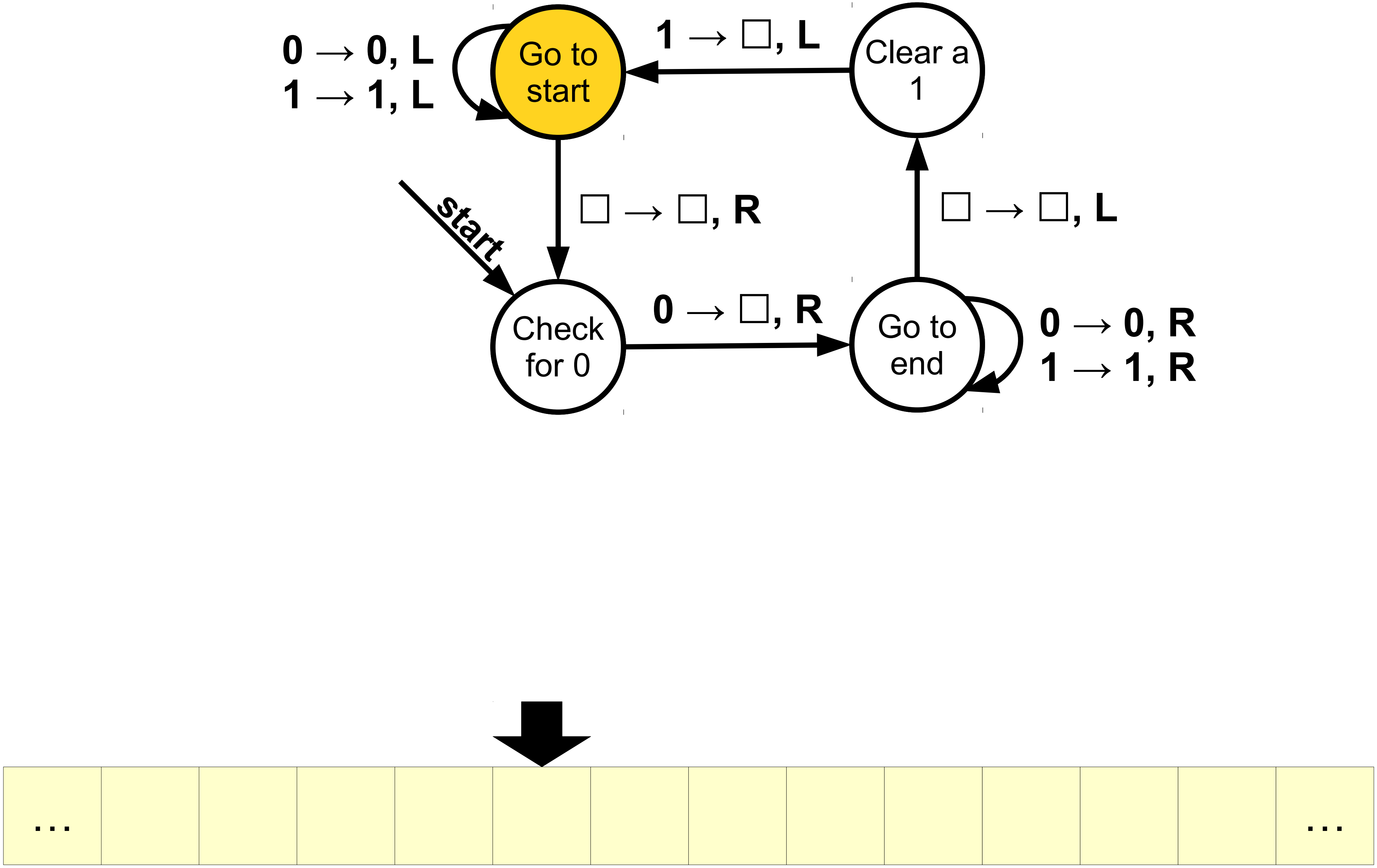
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Go to end
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1 → 1, R
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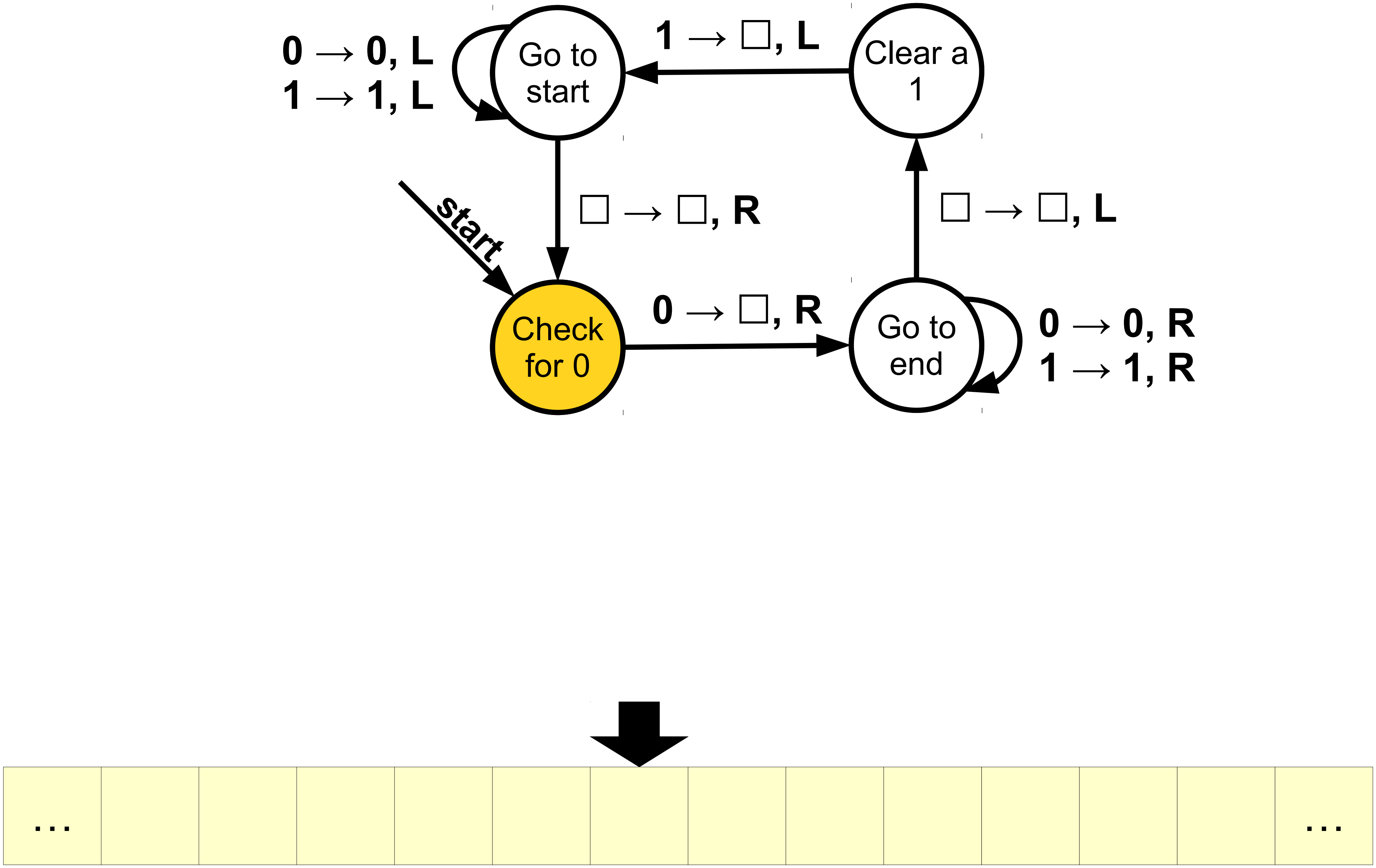
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Go to end
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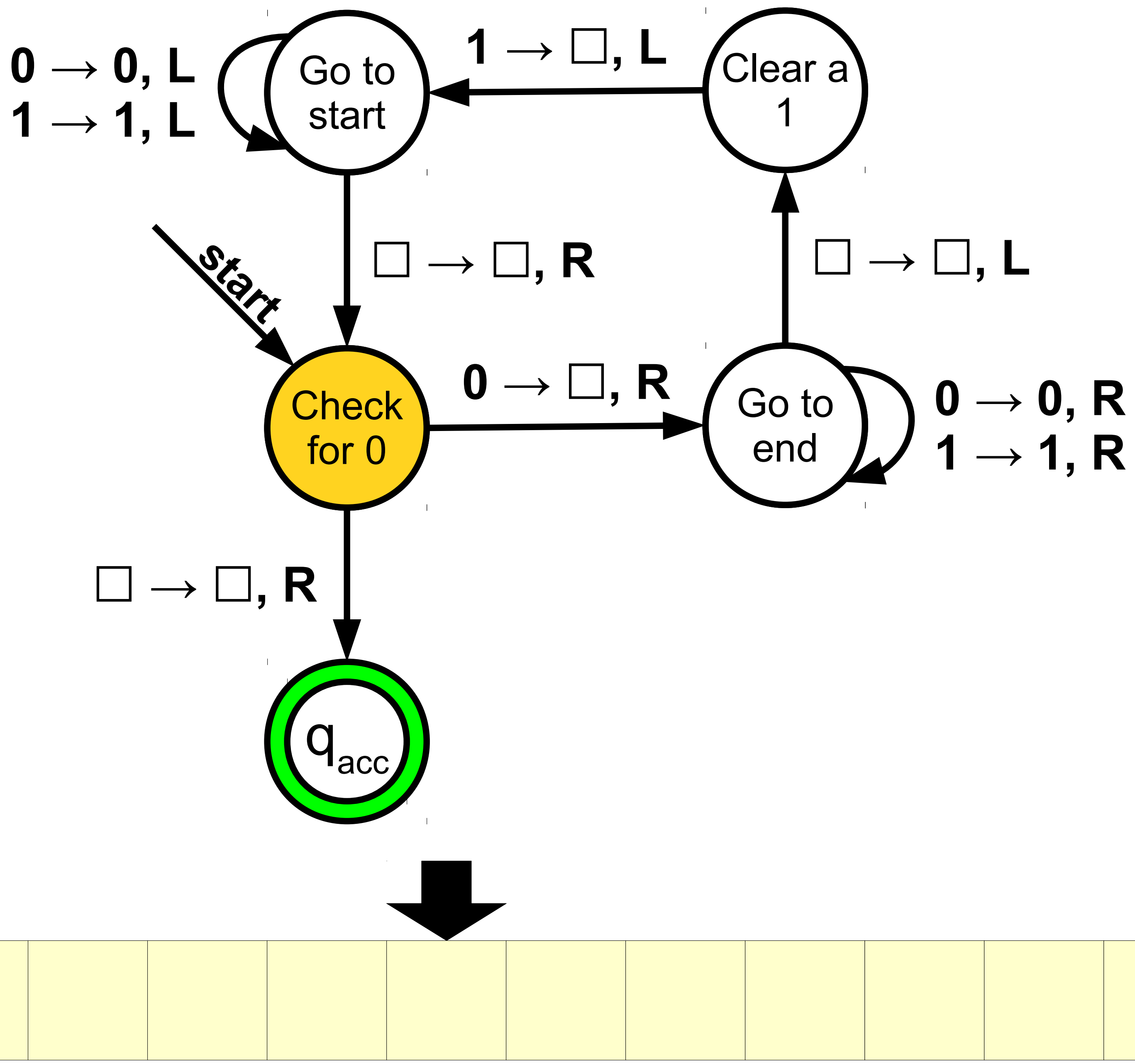
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Go to end
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□ → □, R
q_{acc}
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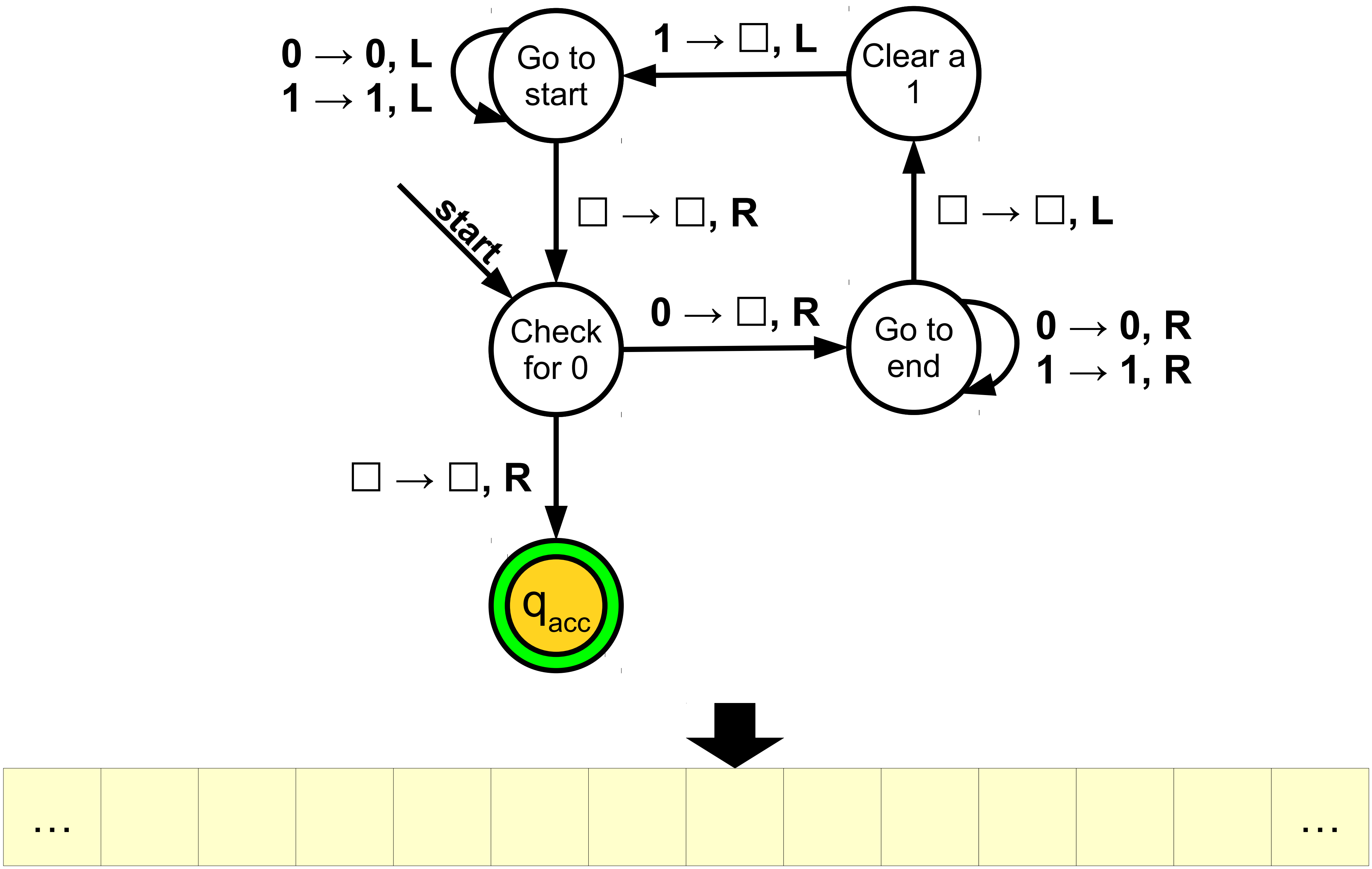
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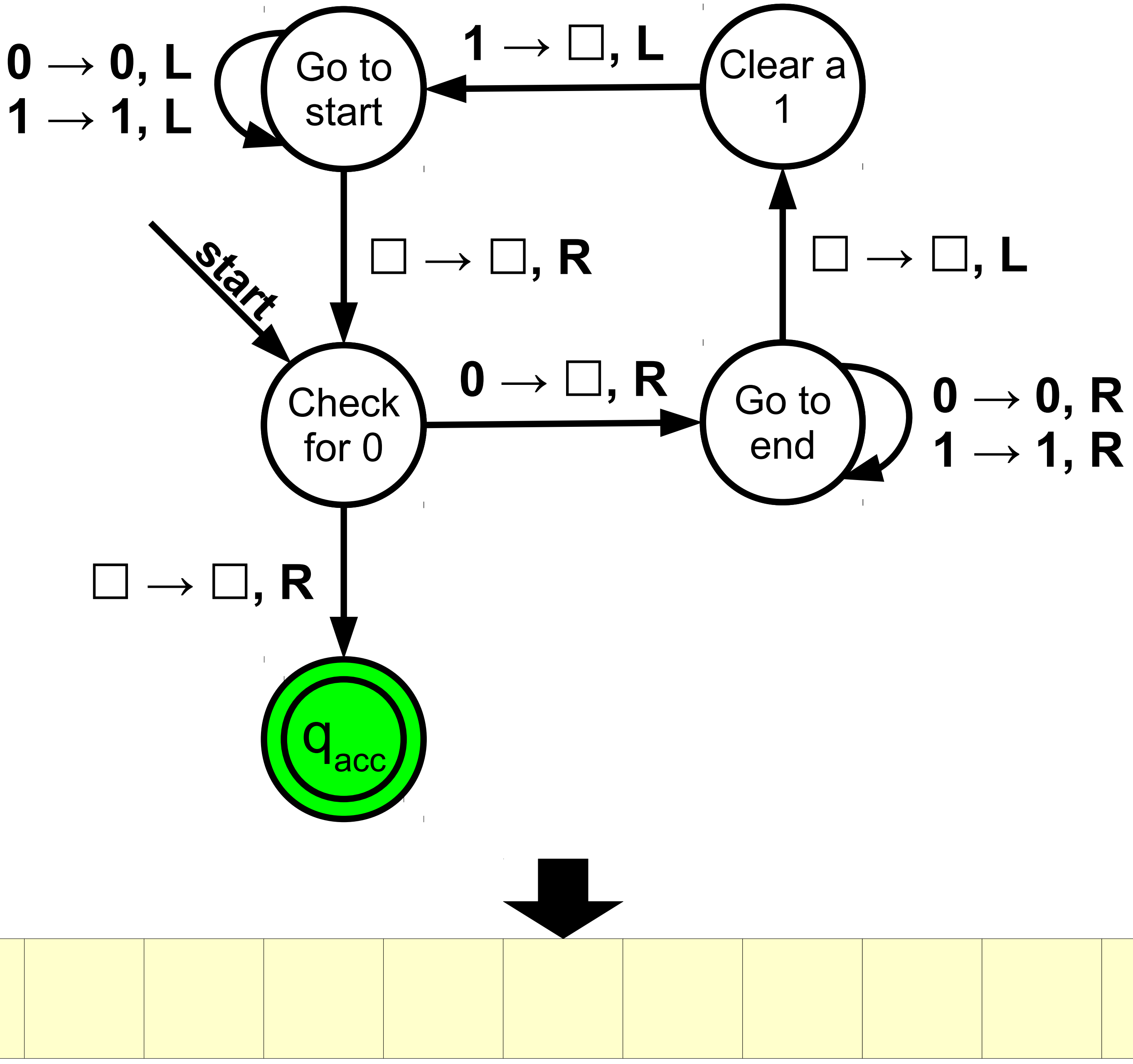
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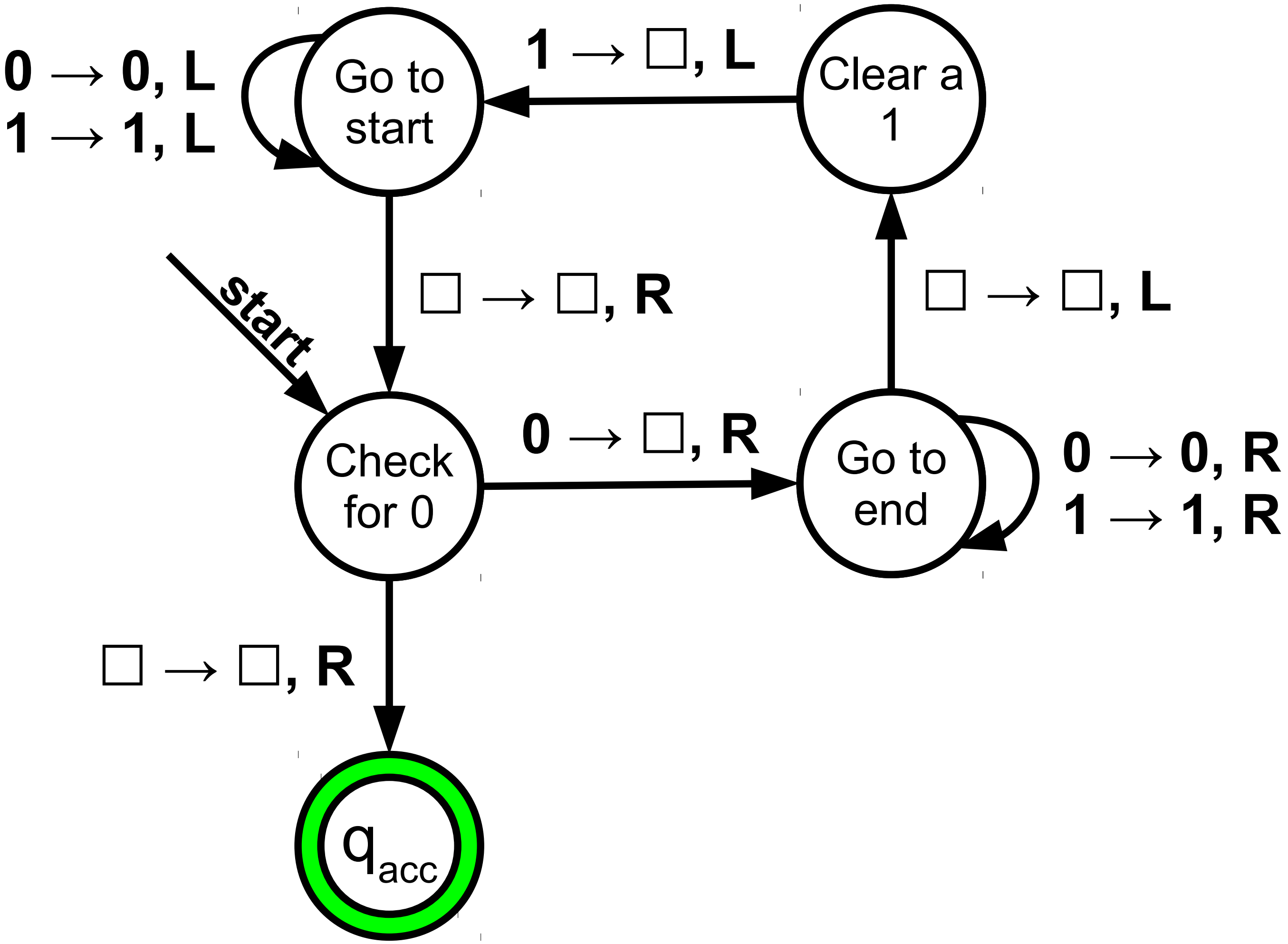
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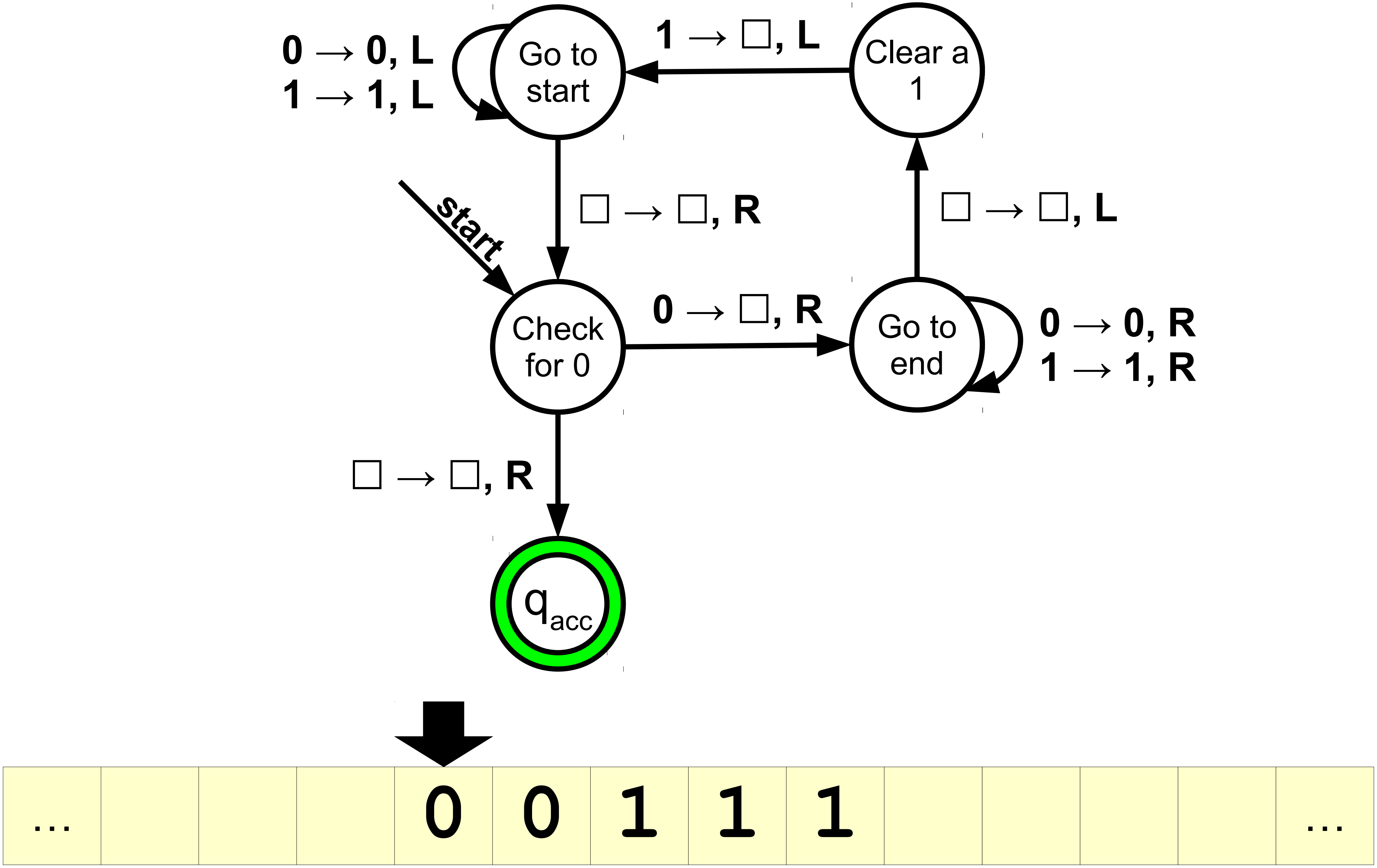
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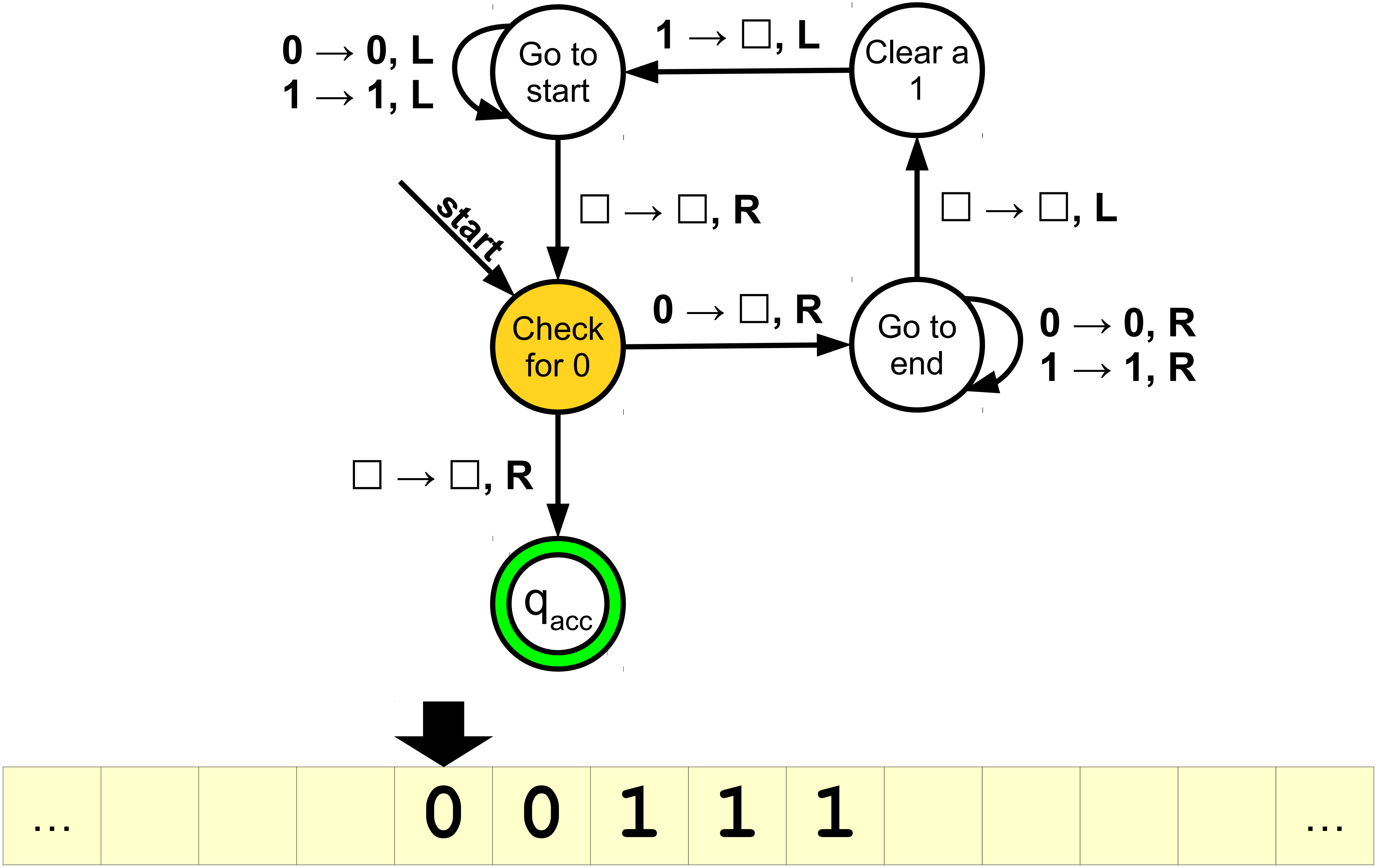
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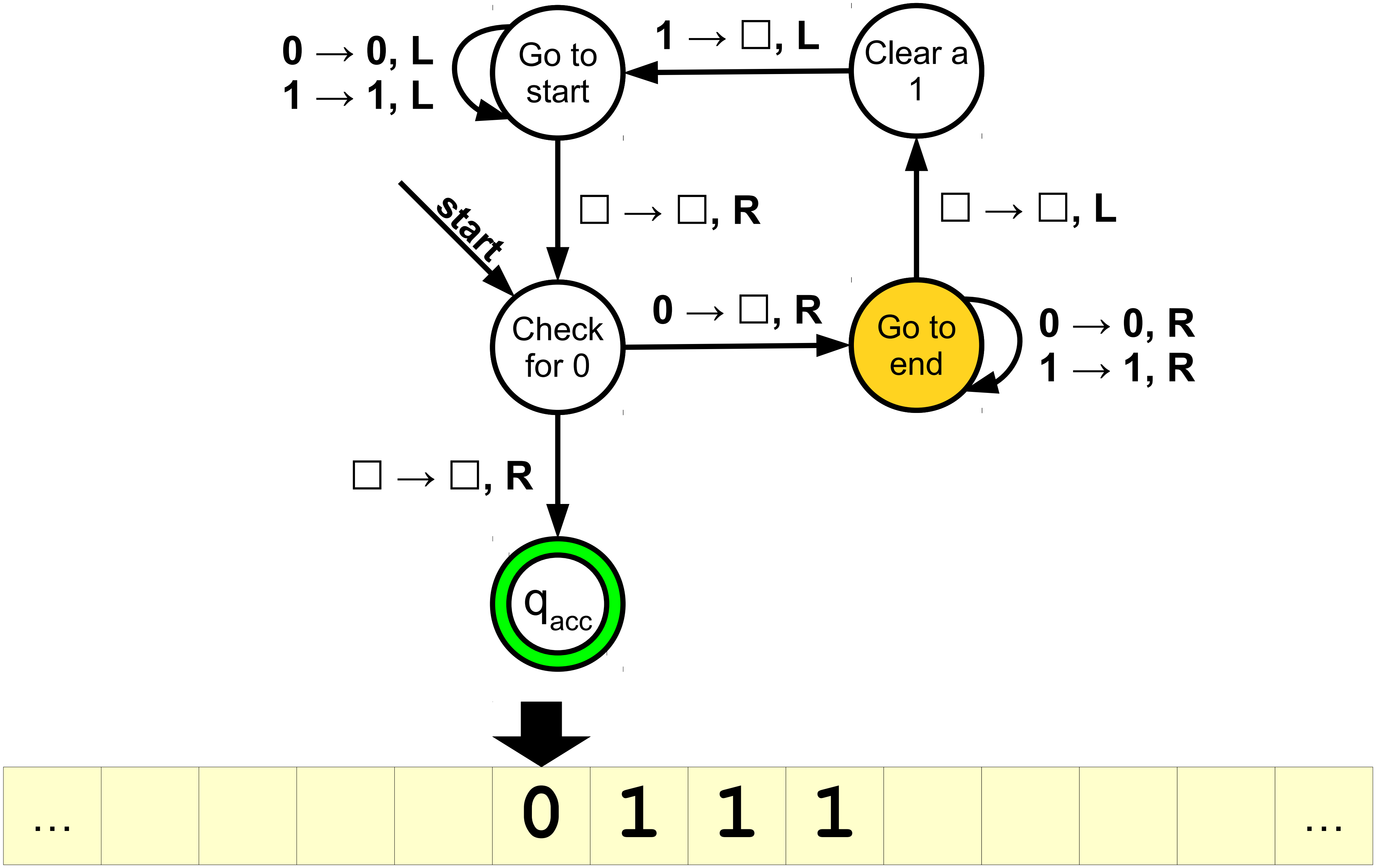
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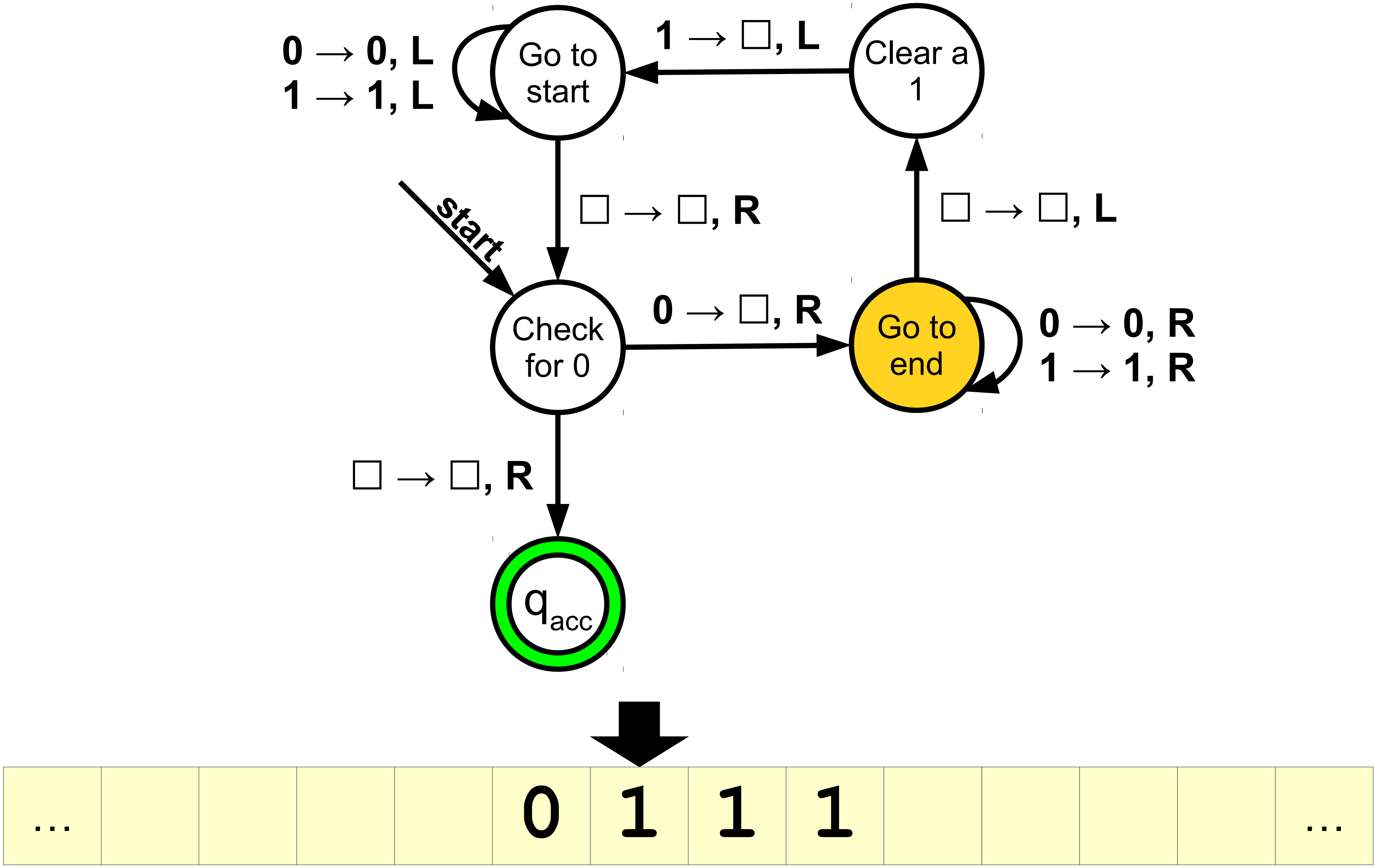
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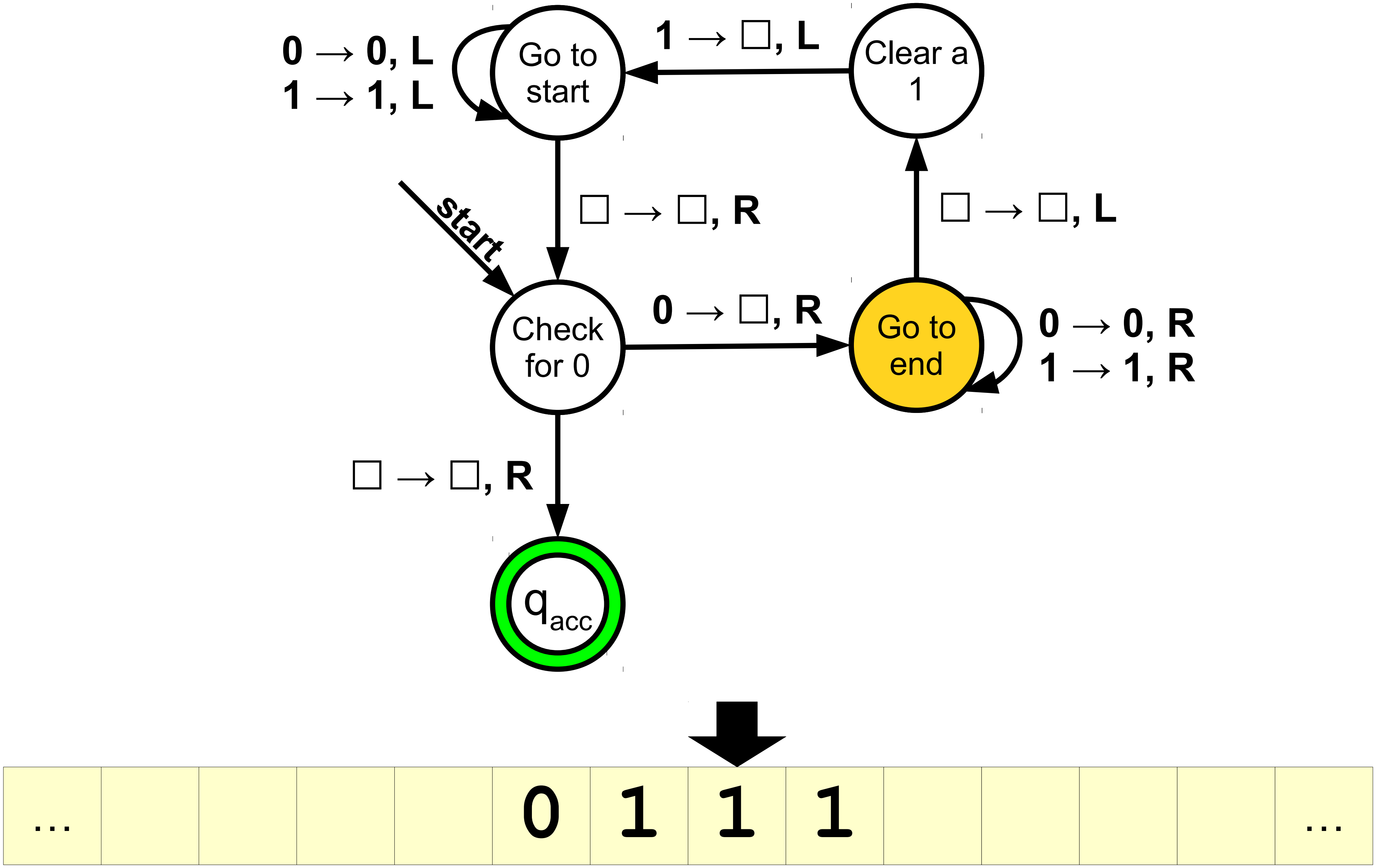
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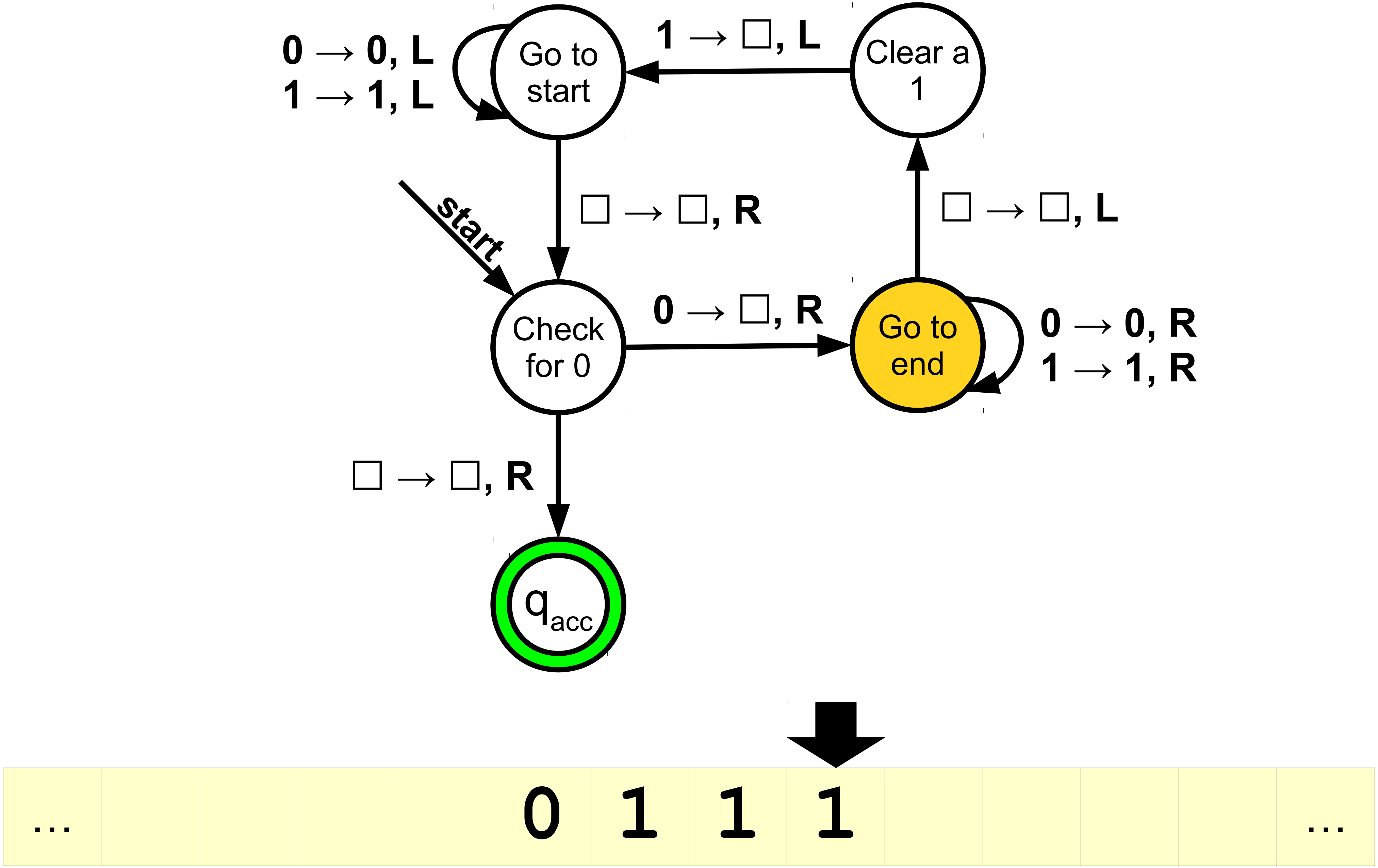
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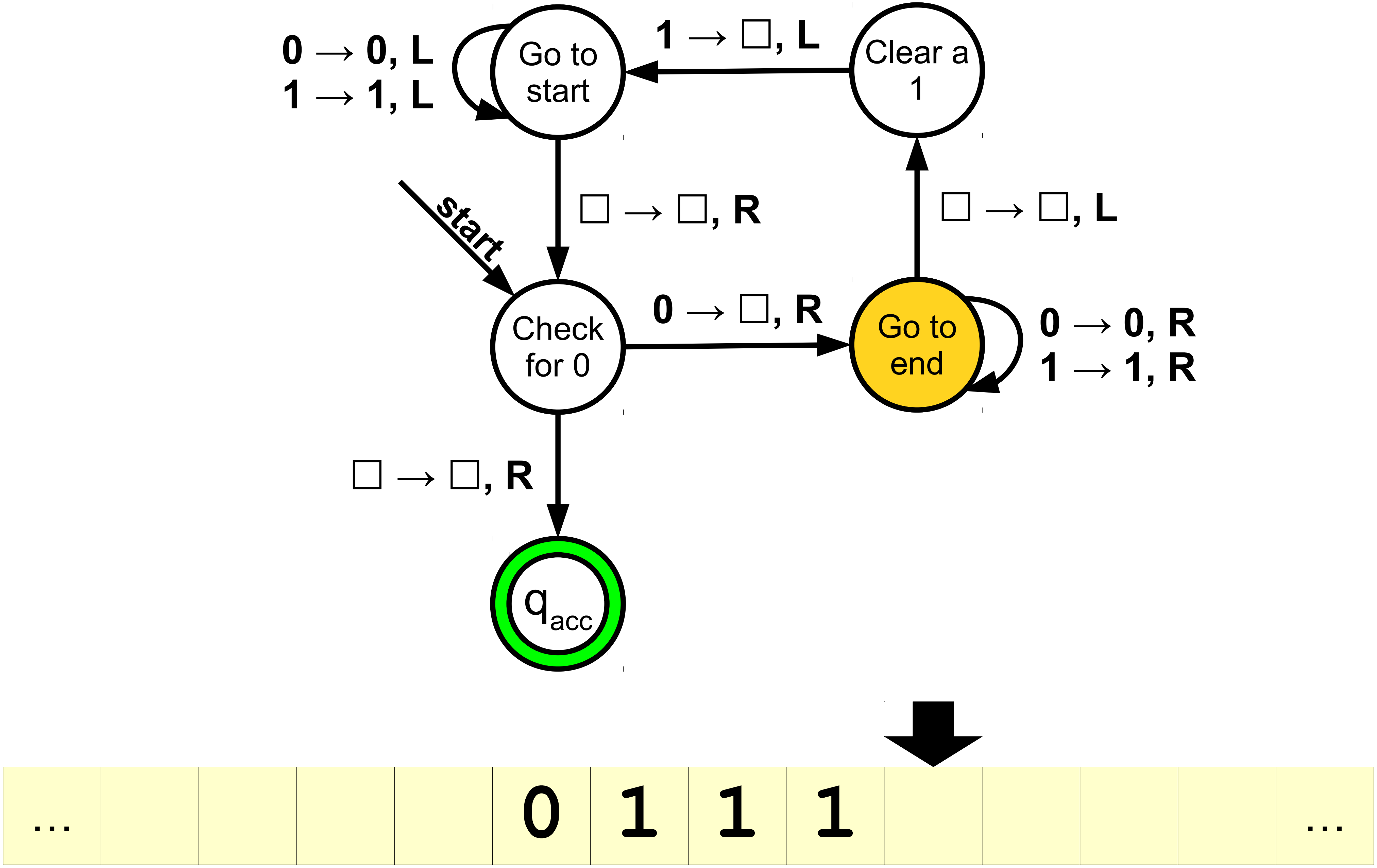
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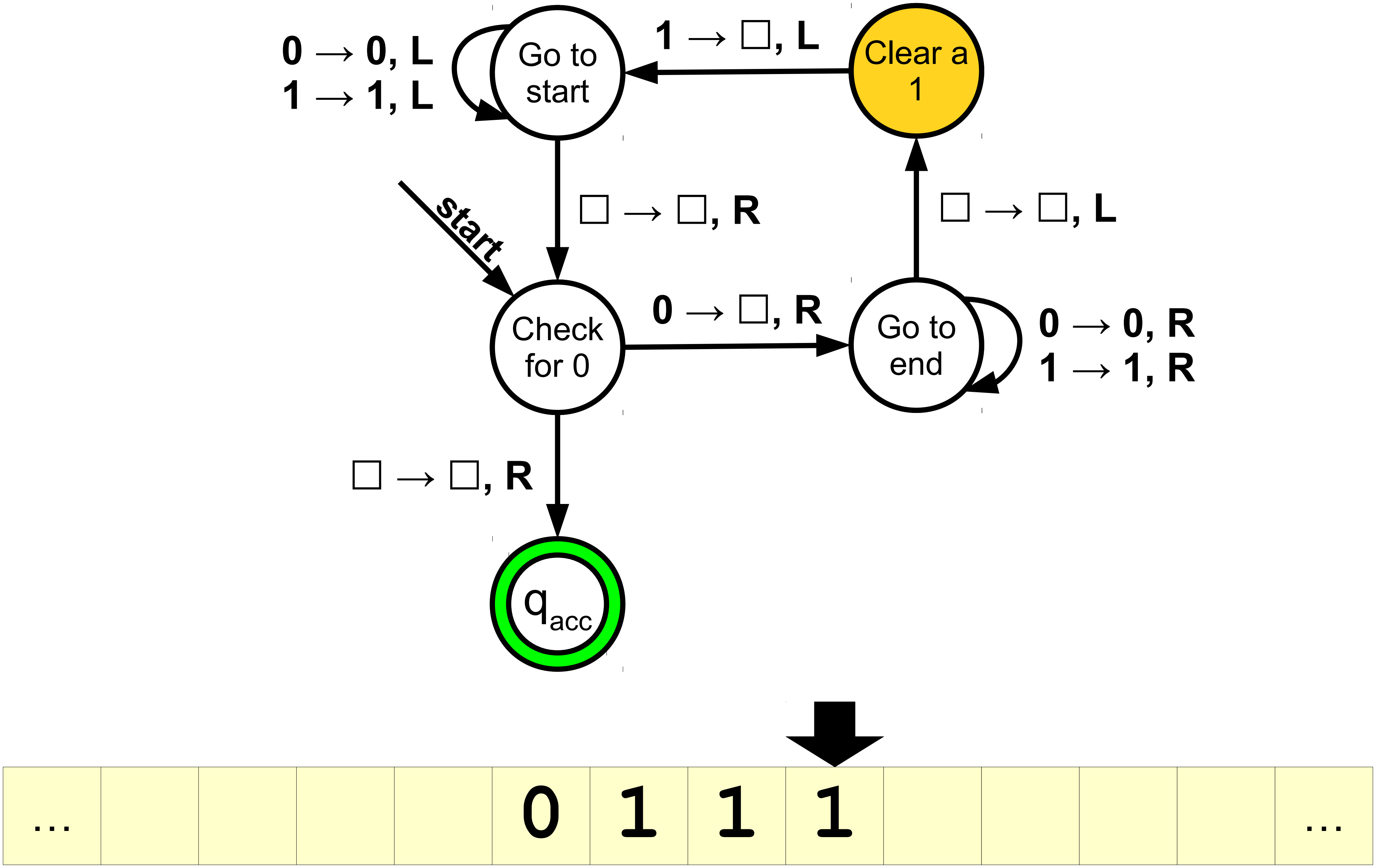
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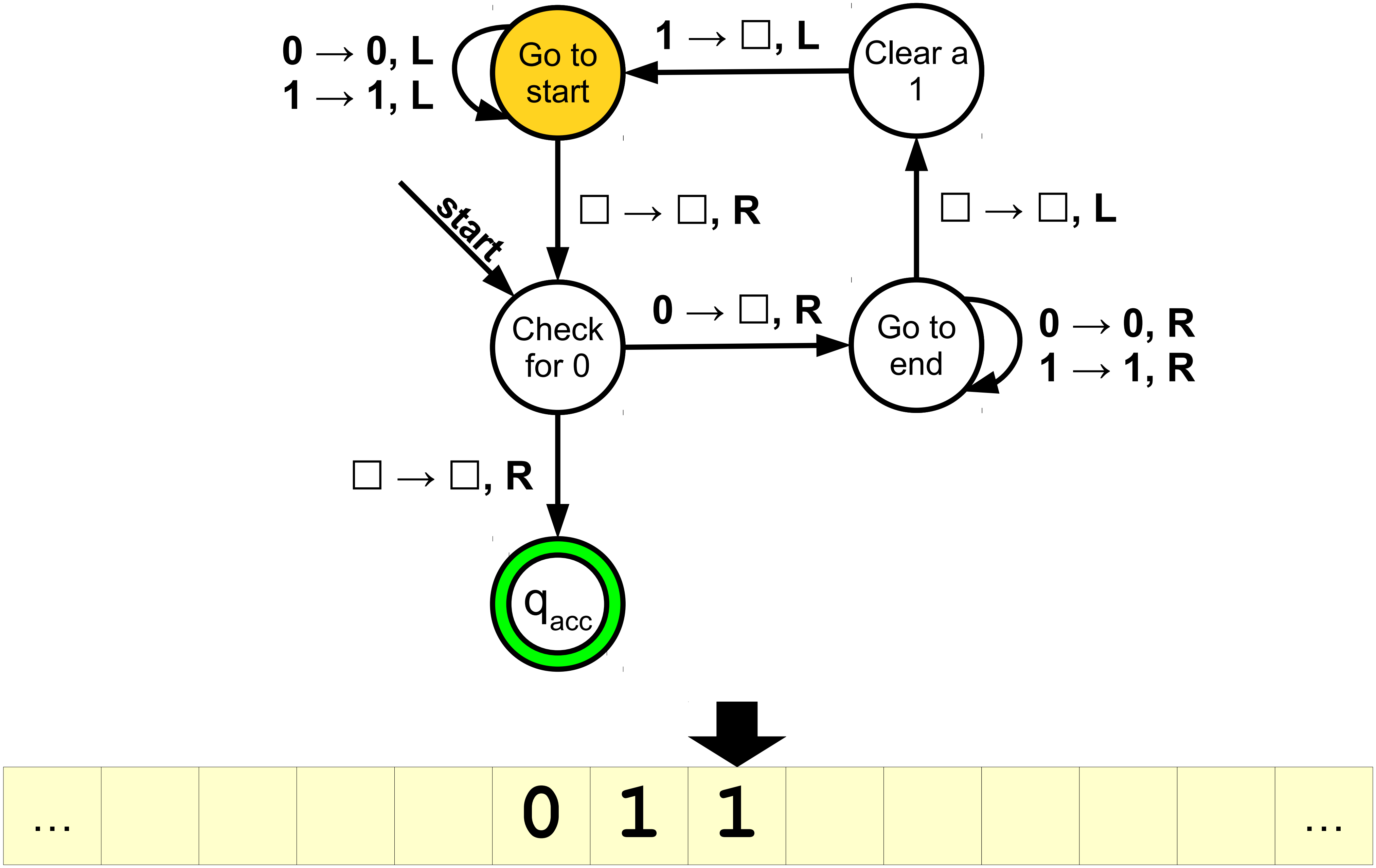
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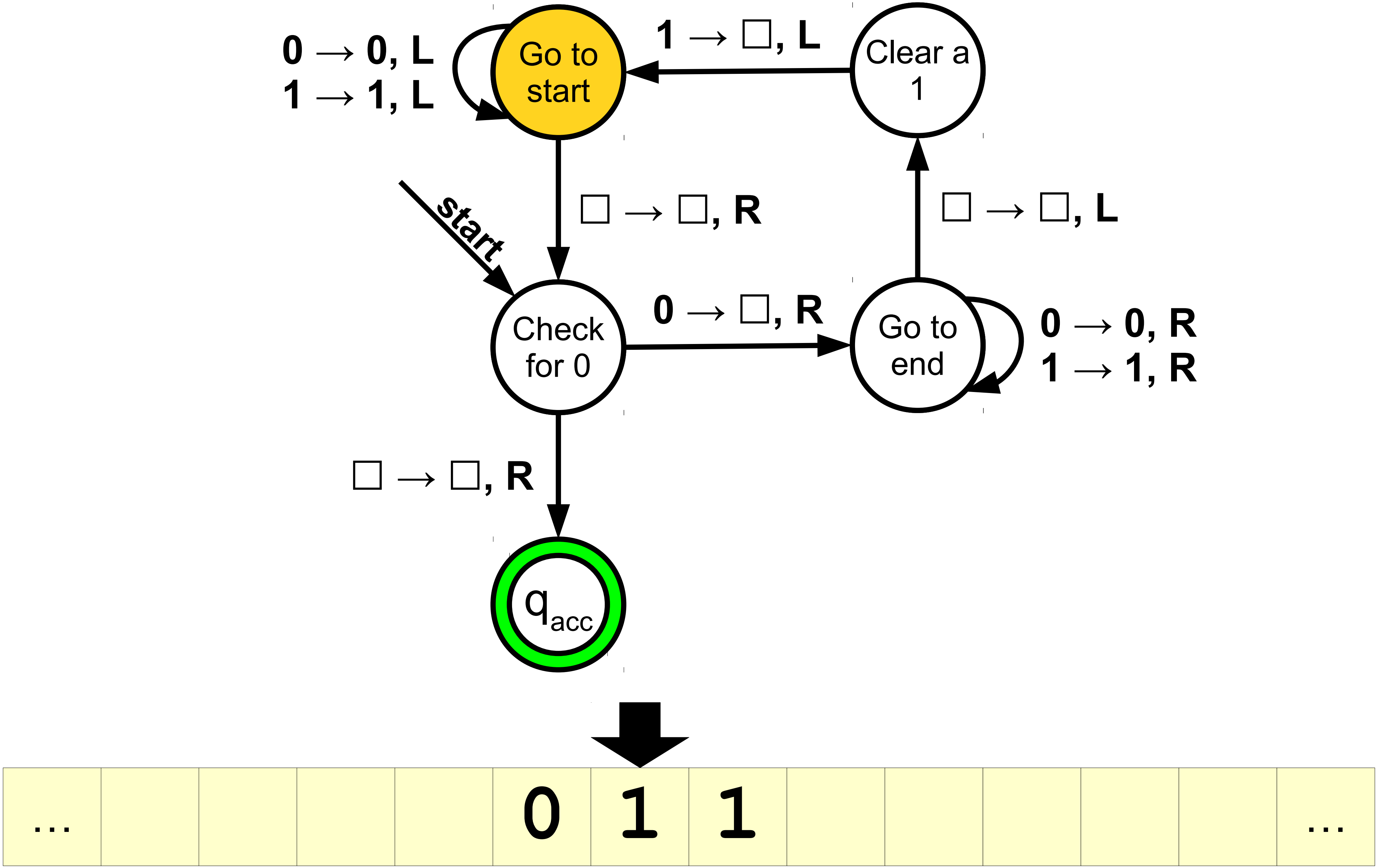
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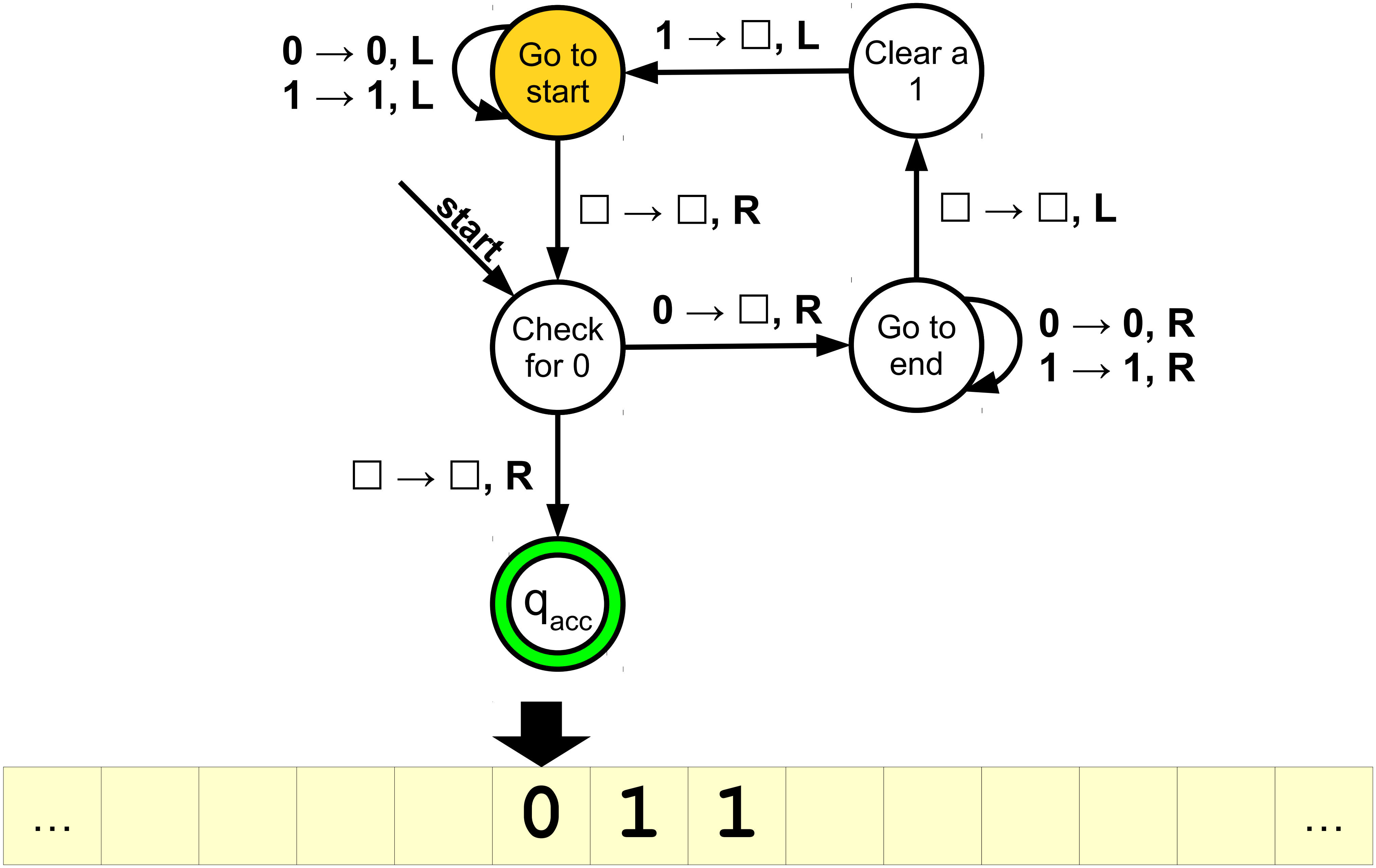
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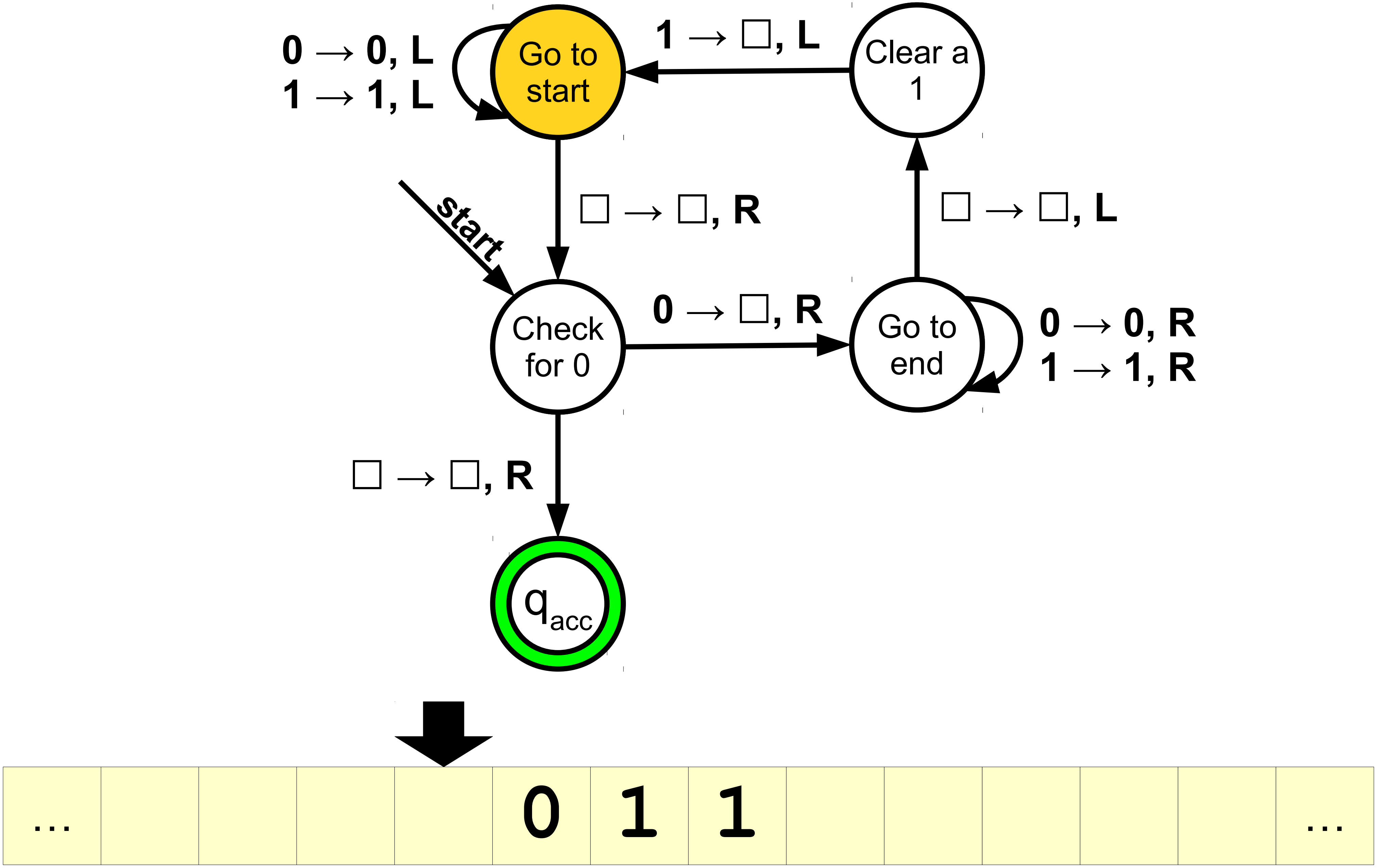
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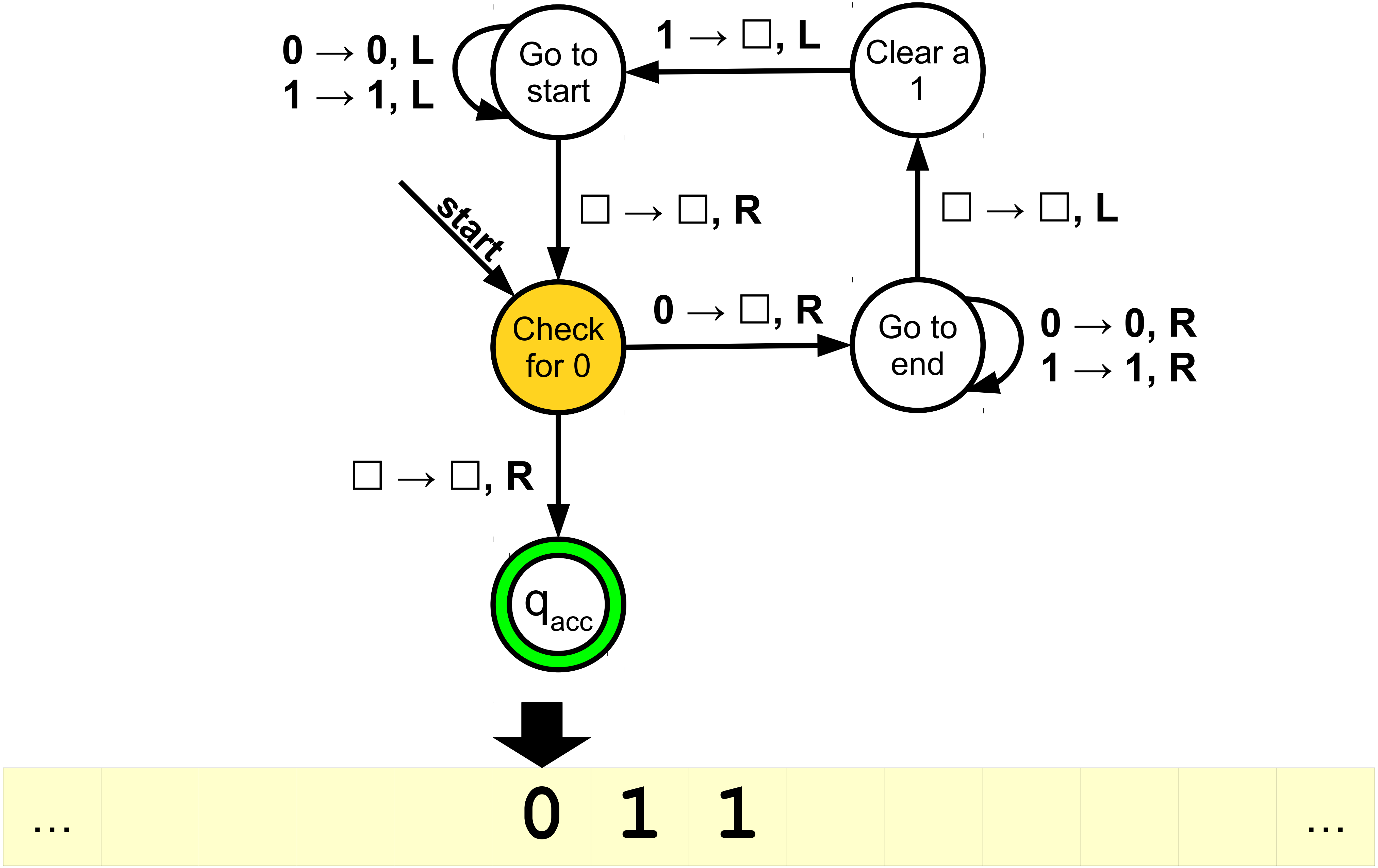
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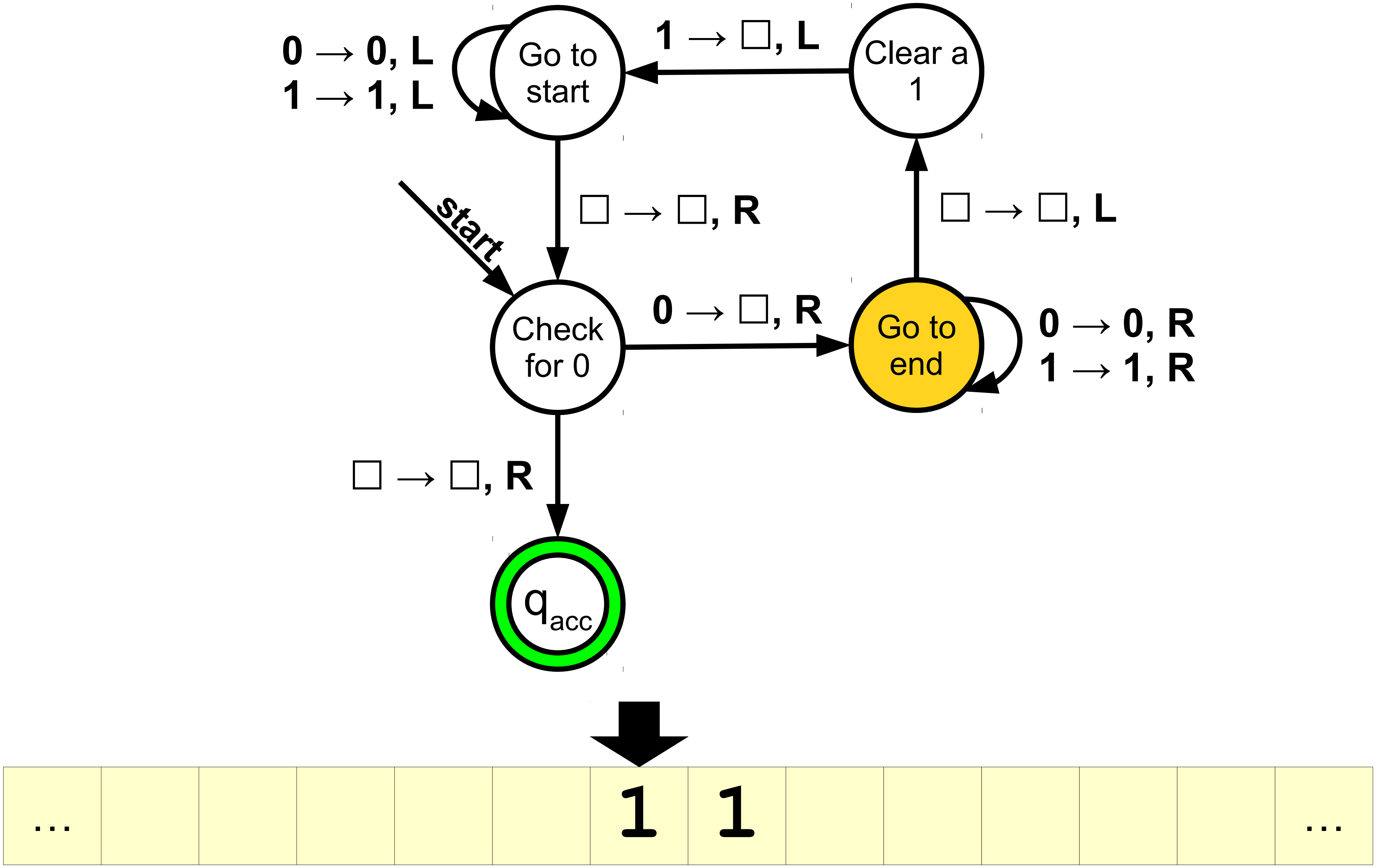
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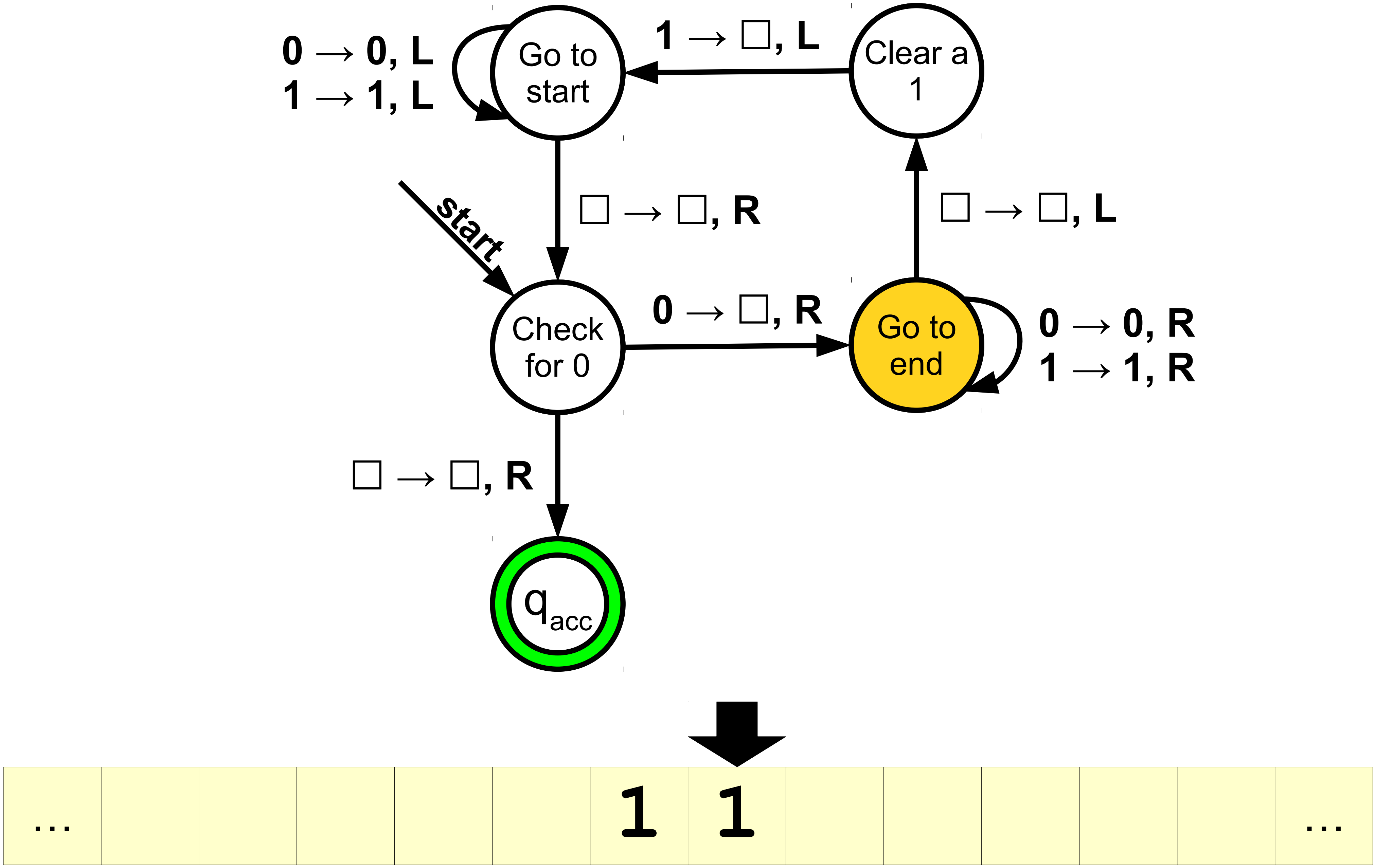
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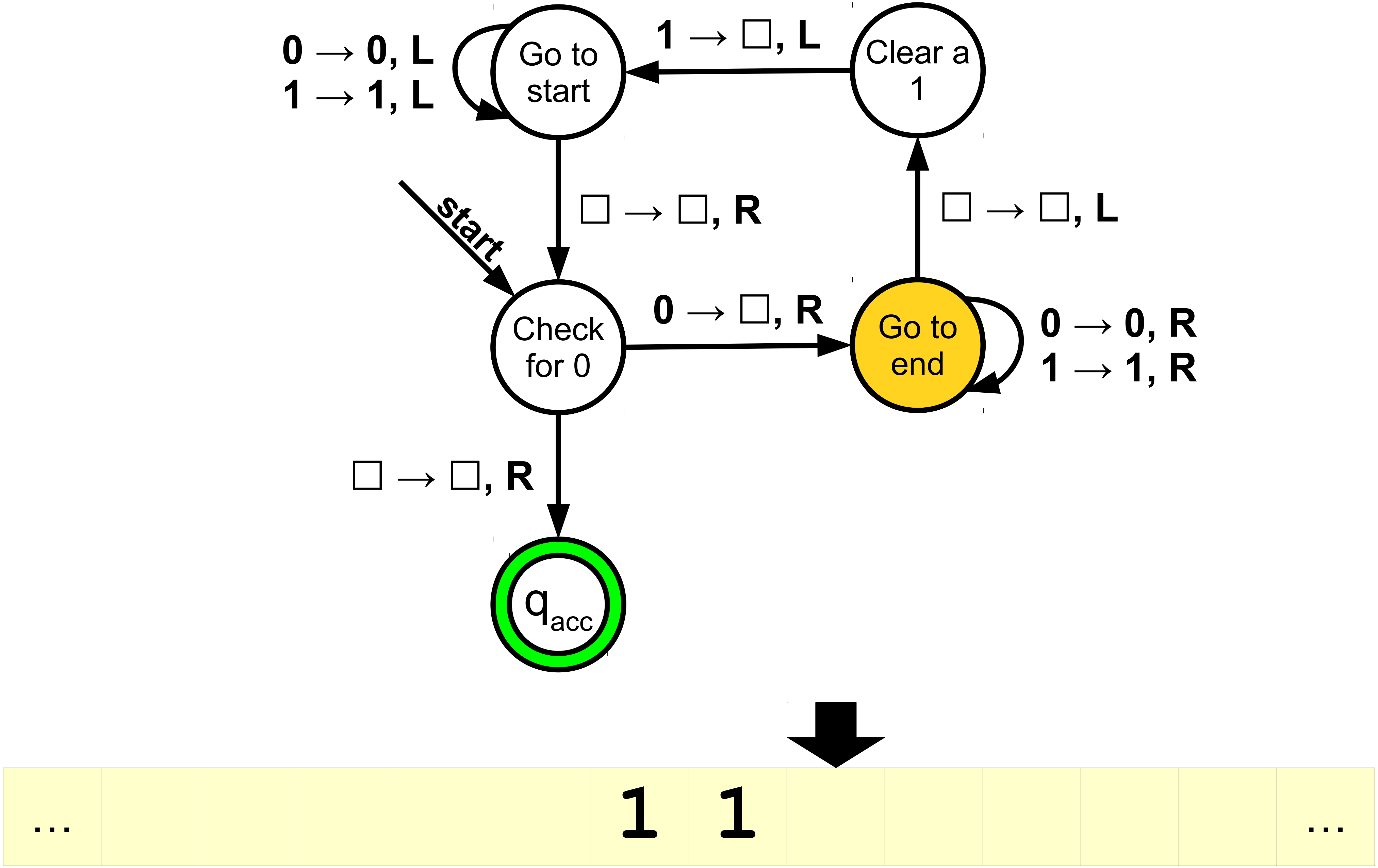
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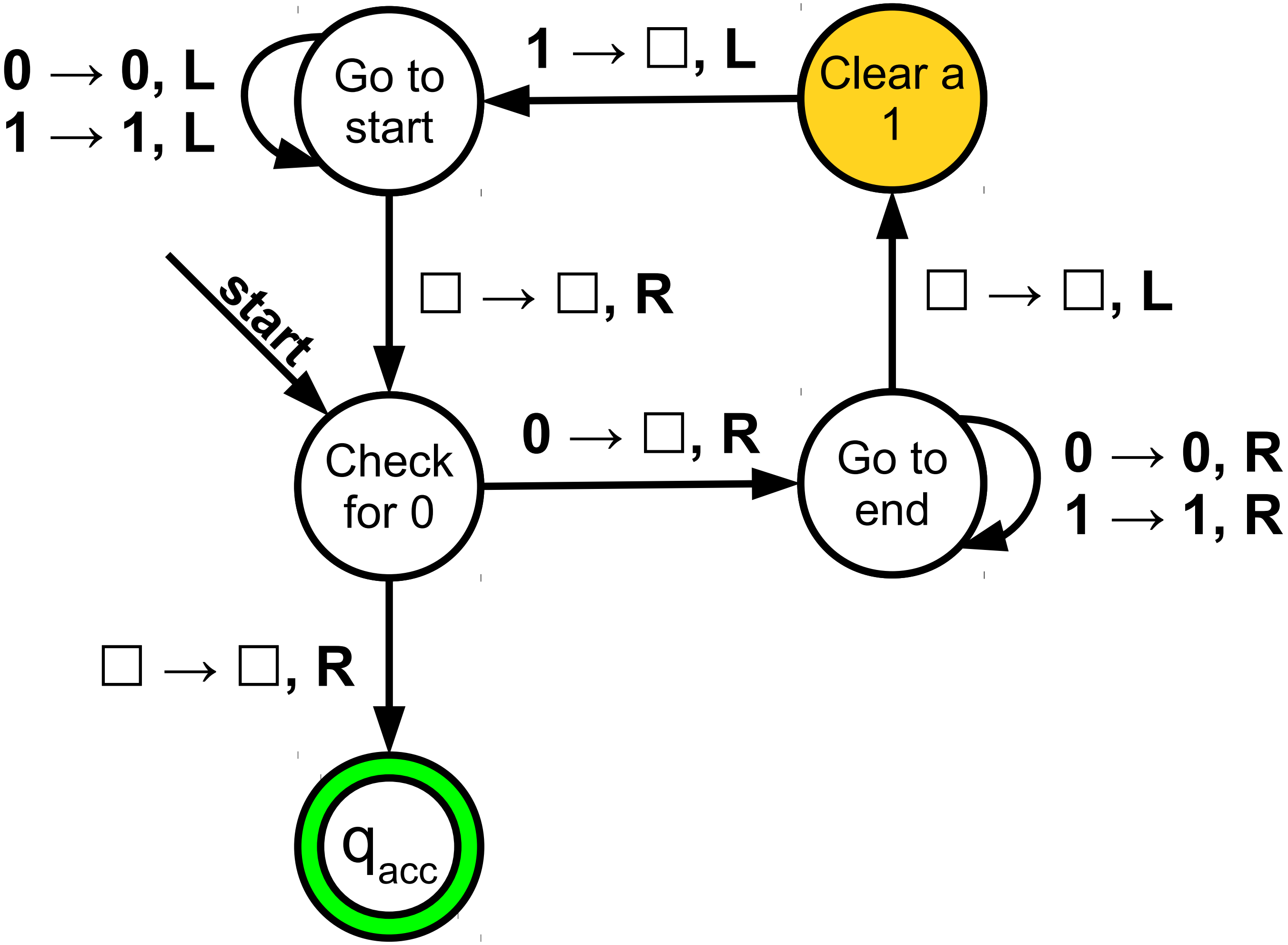
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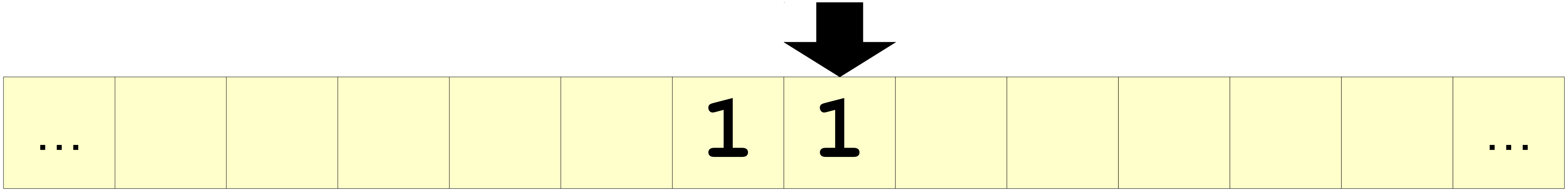
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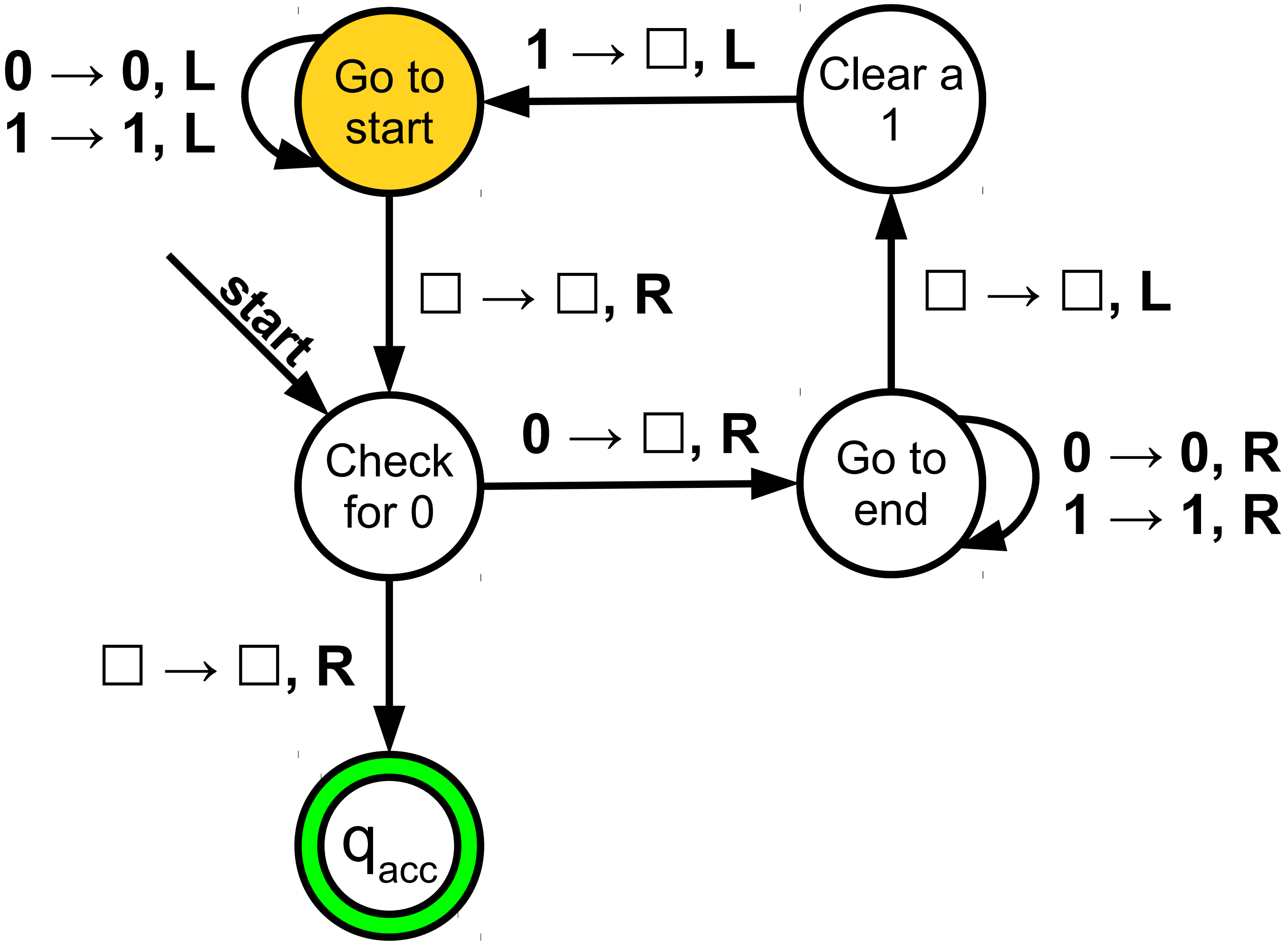
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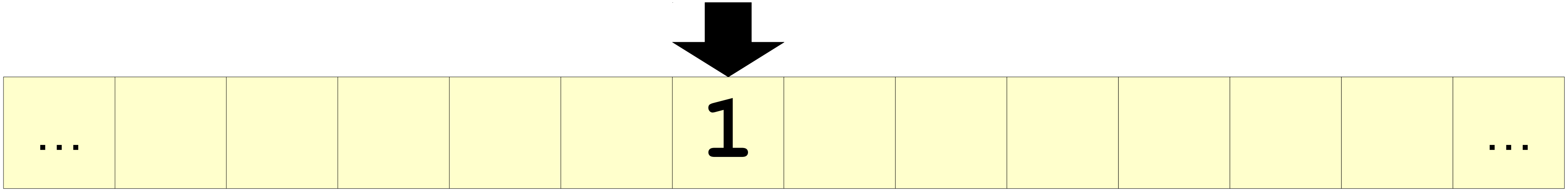
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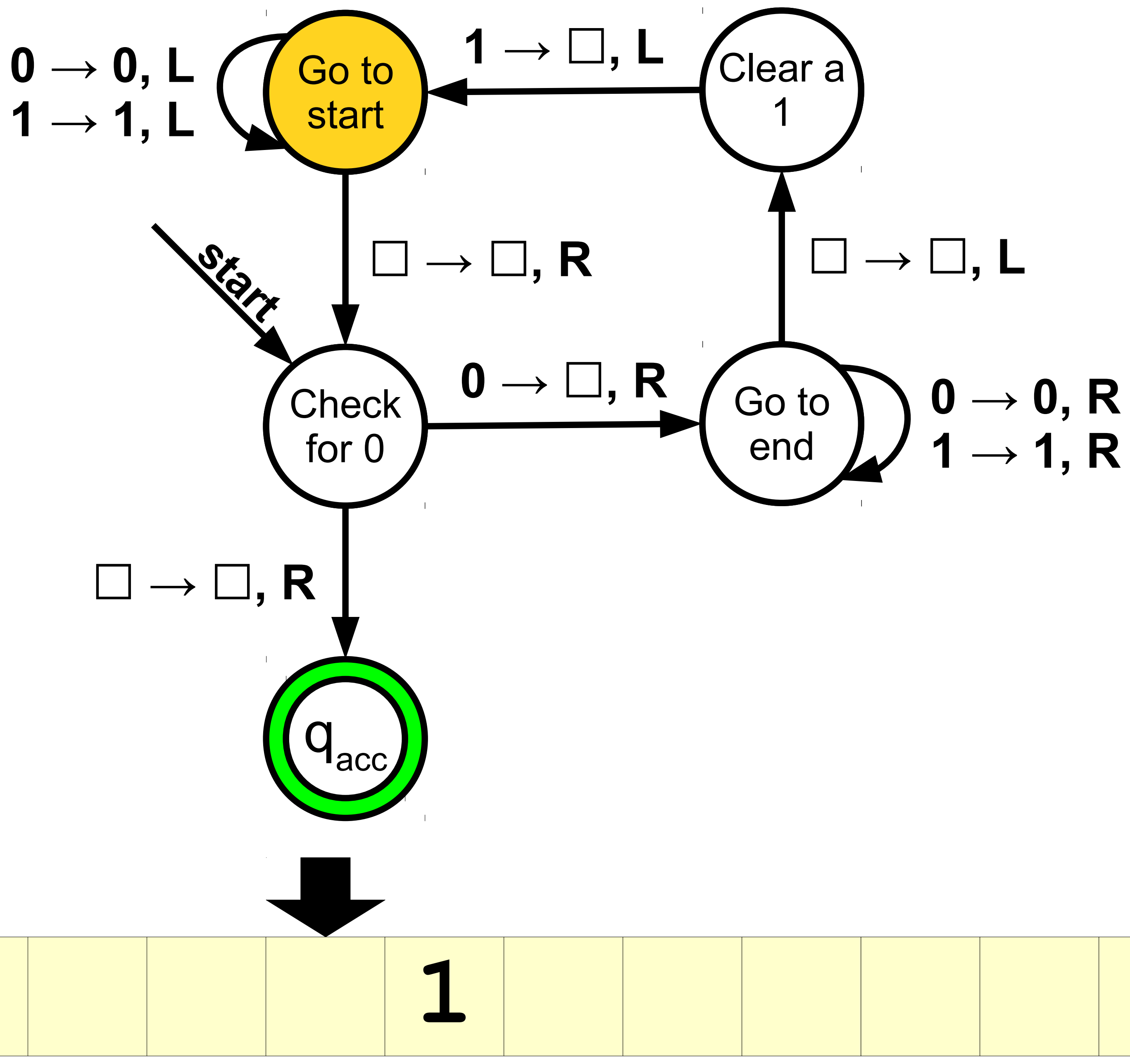
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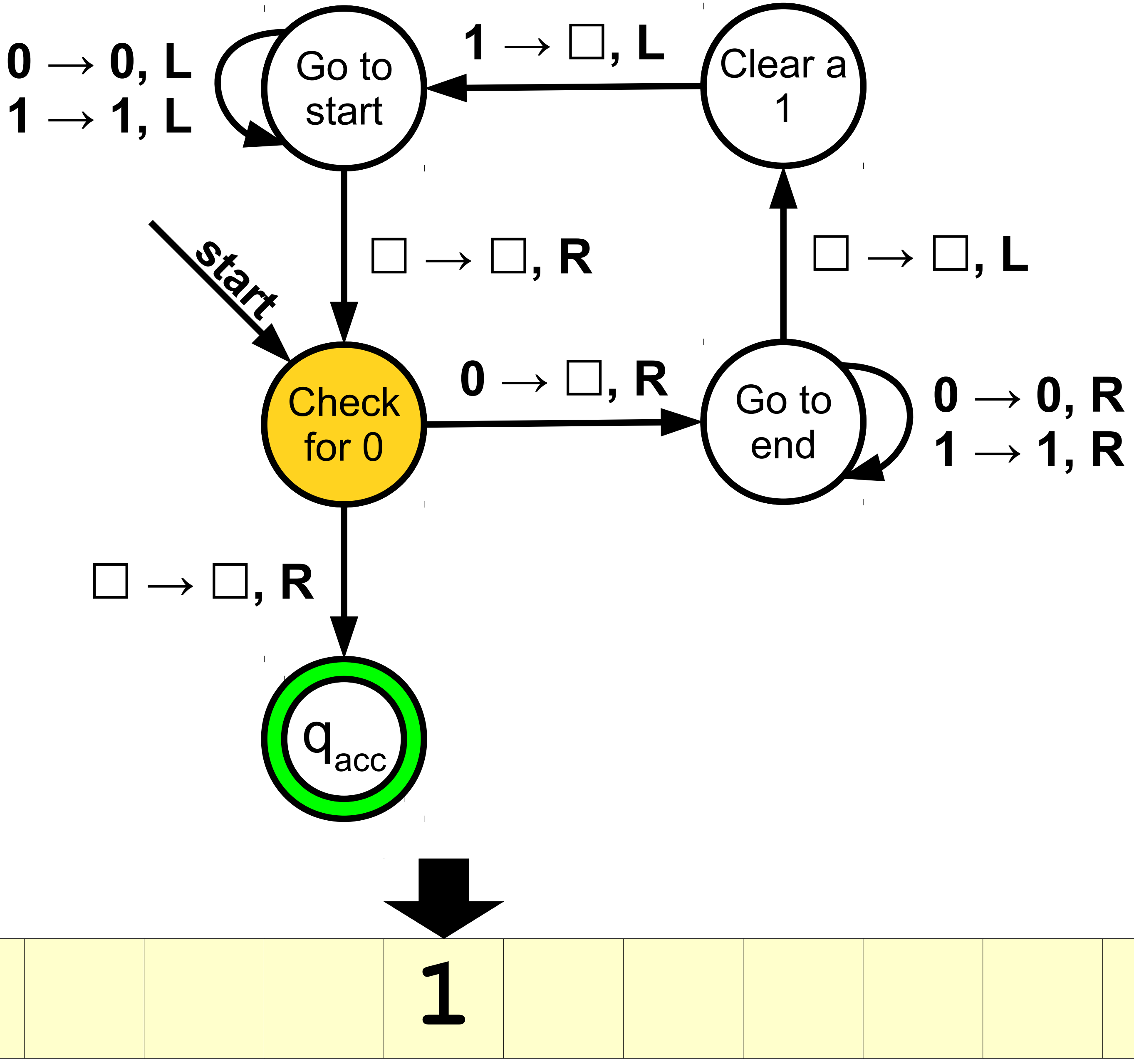
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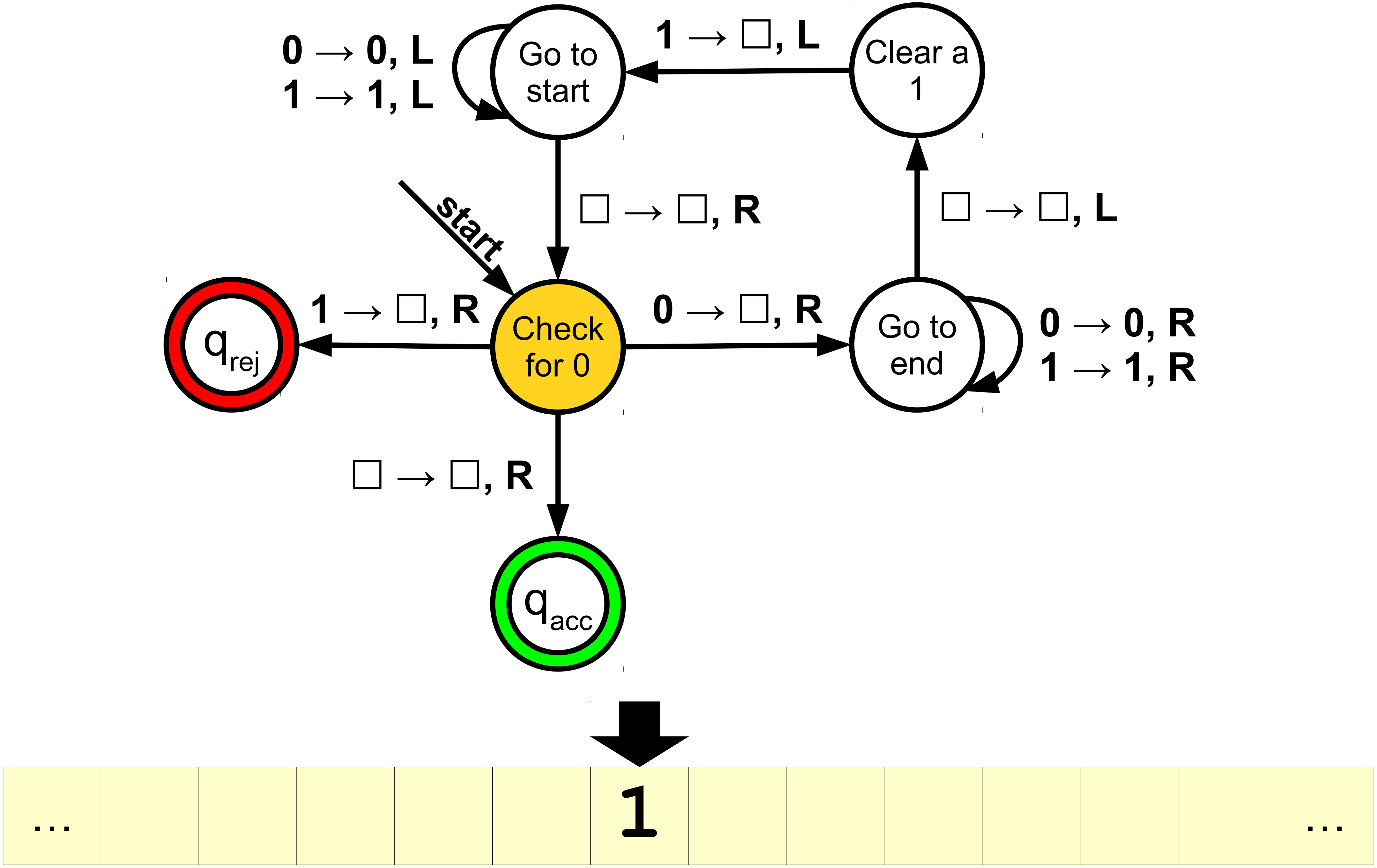
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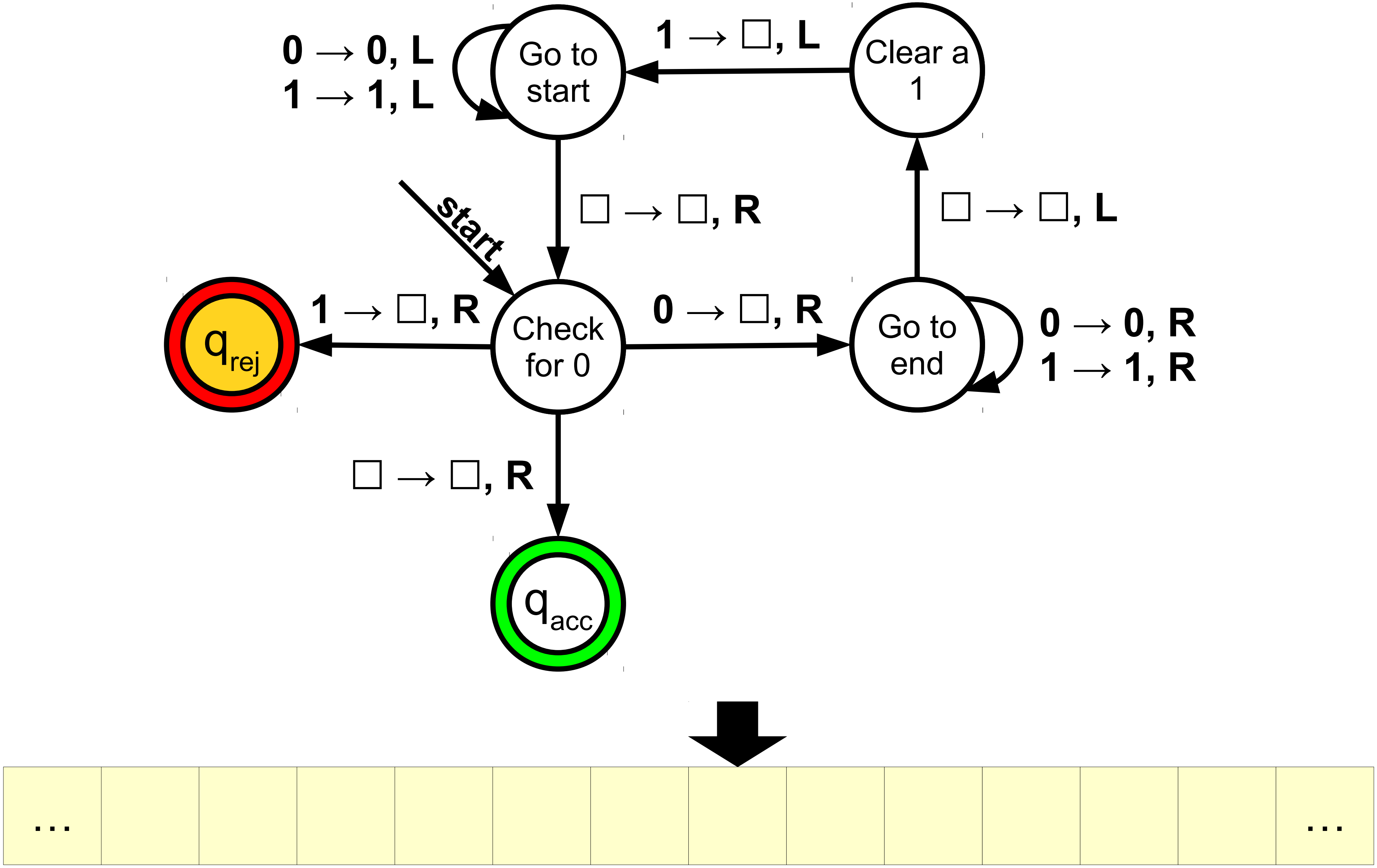
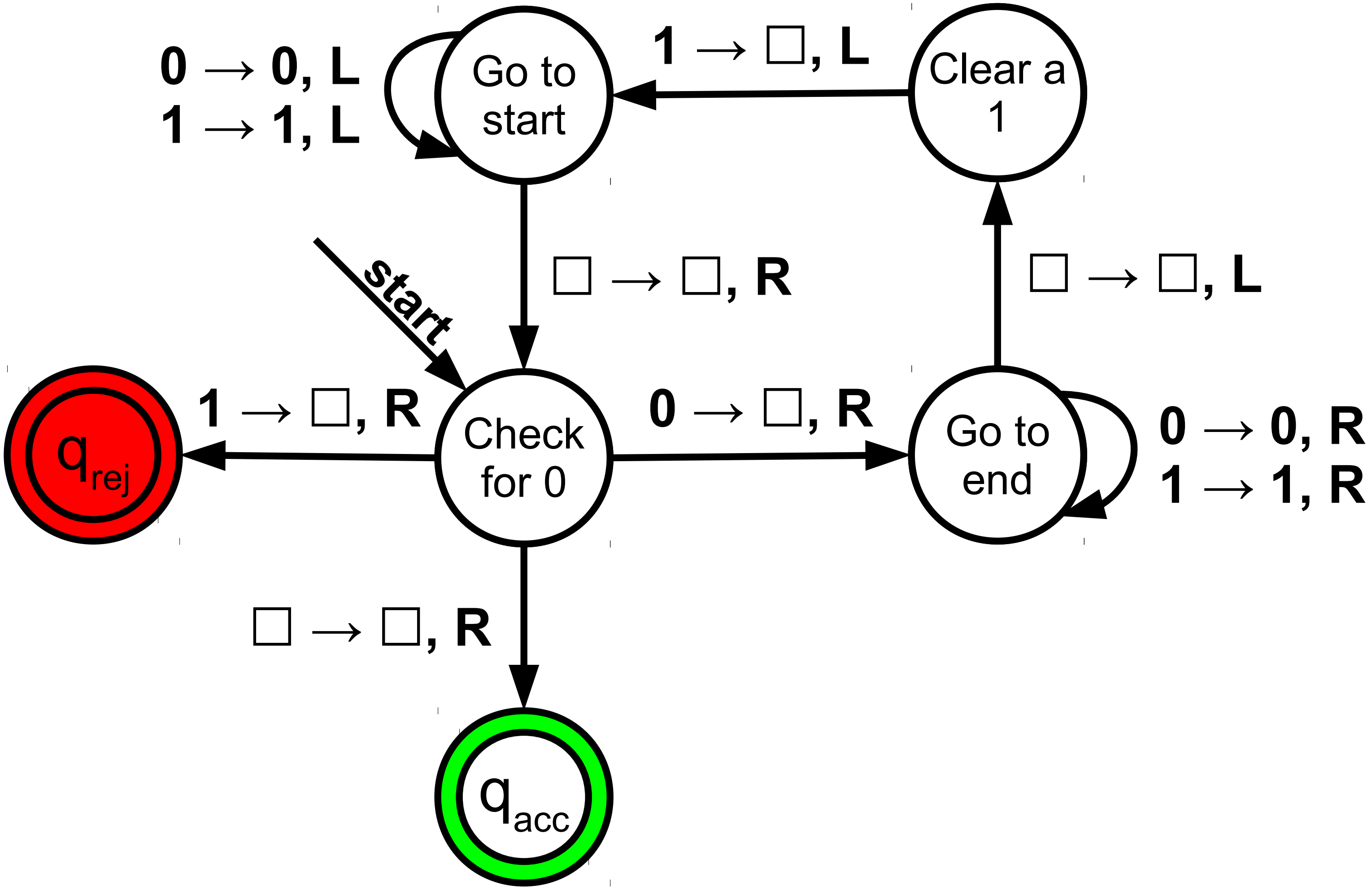
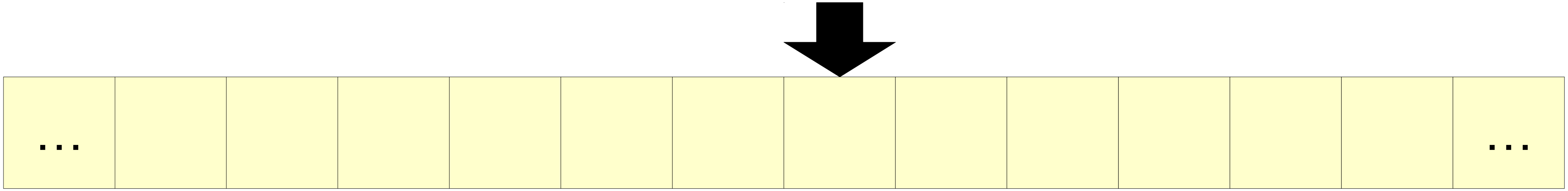
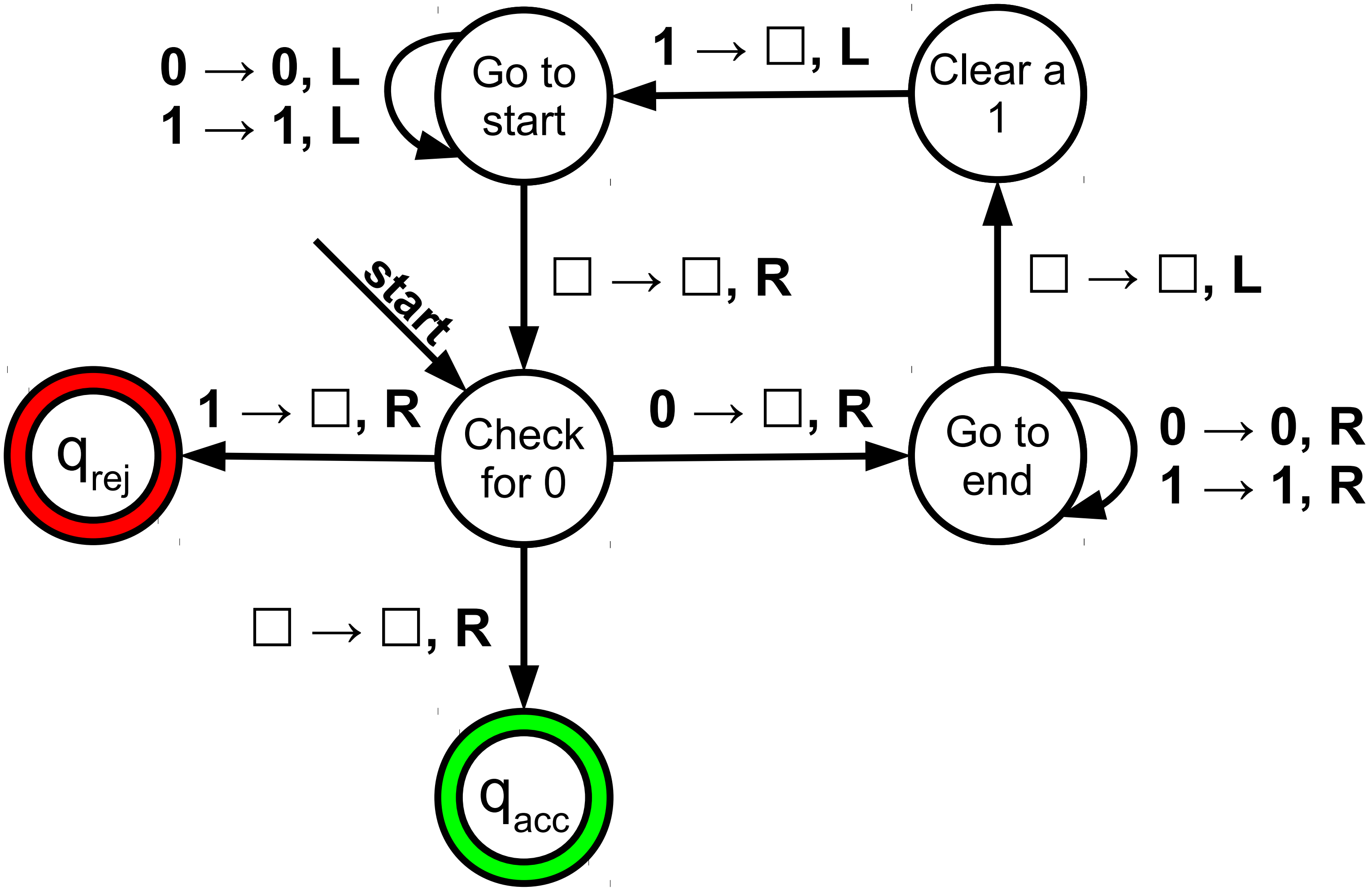
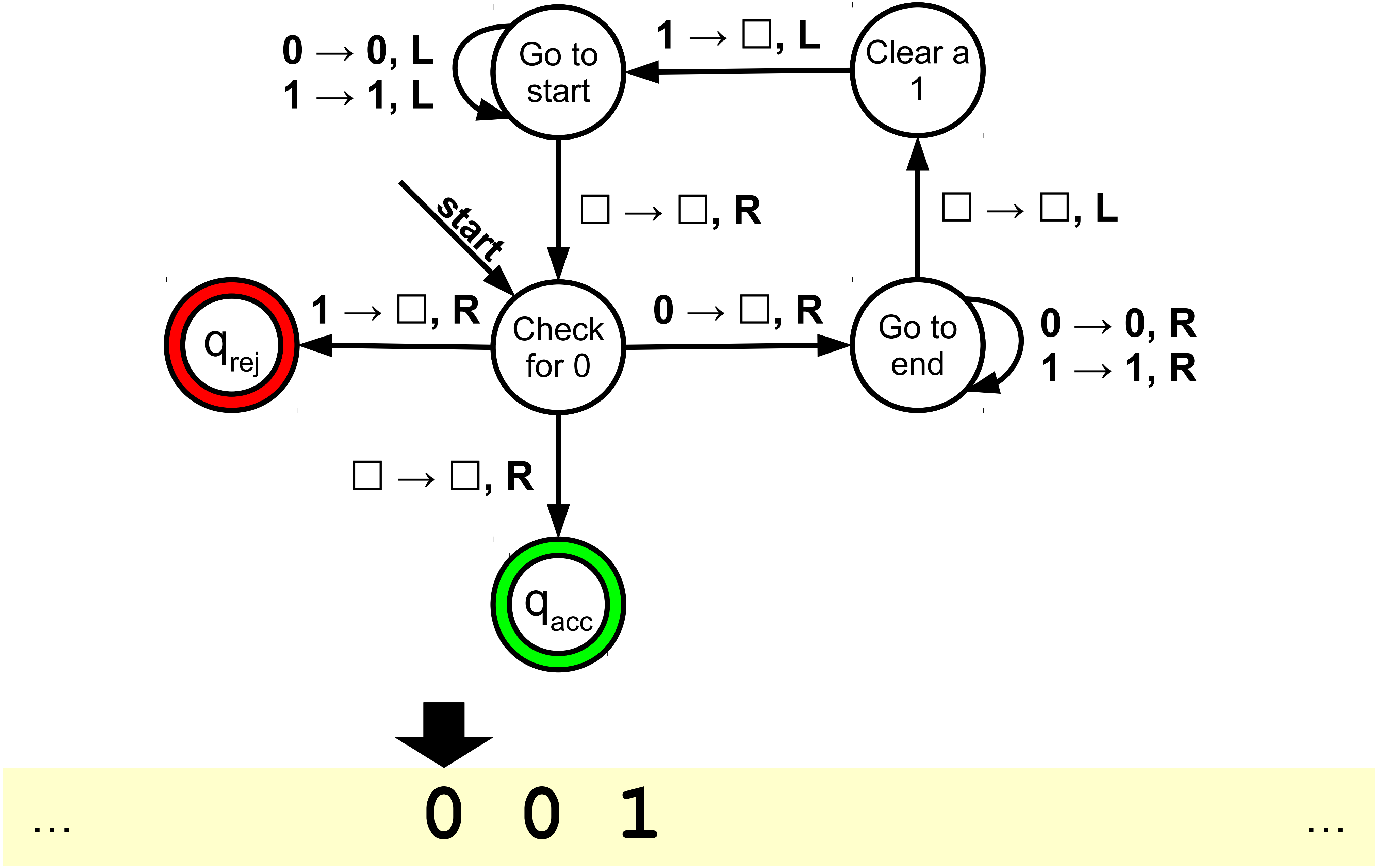
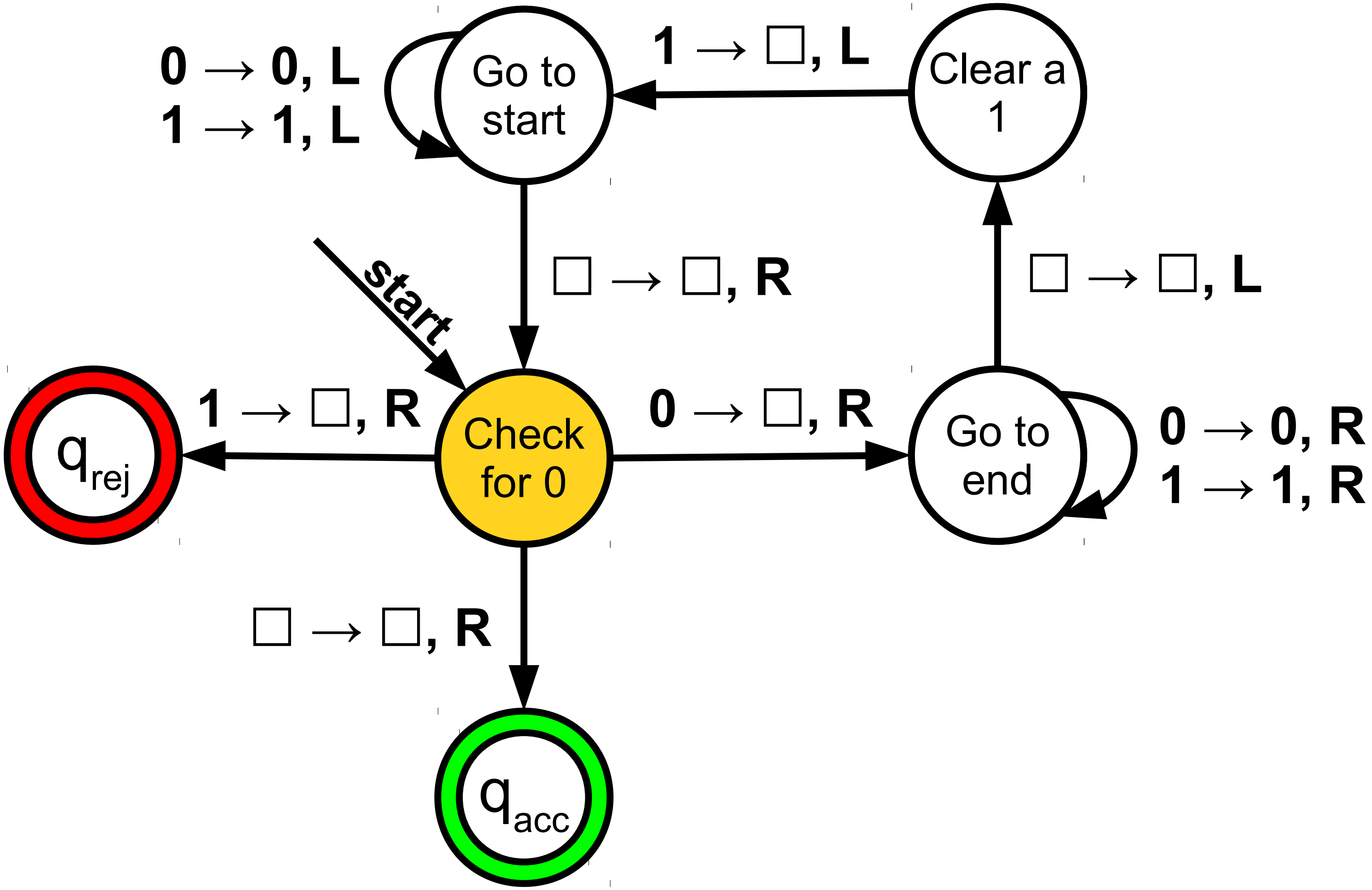

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
□ → □, L
start
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
q_rej
□ → □, R
q_acc
…
…

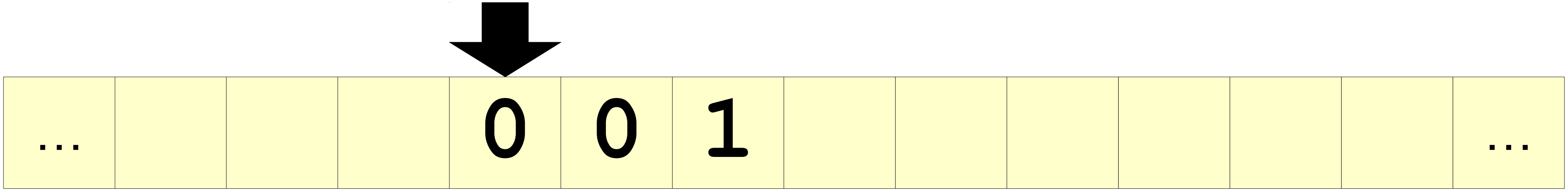

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
1 → □, R
q_rej
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc

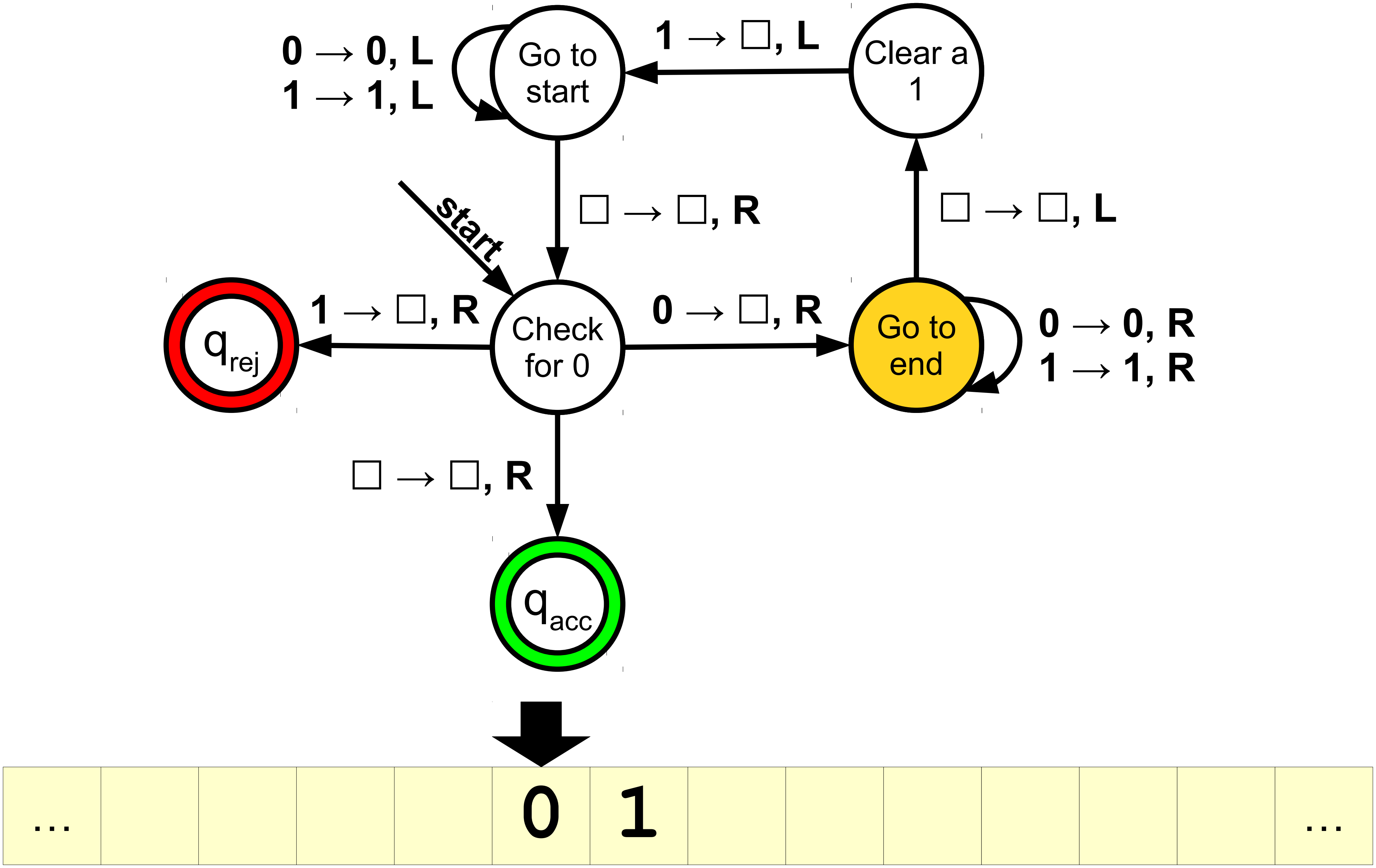

…
…

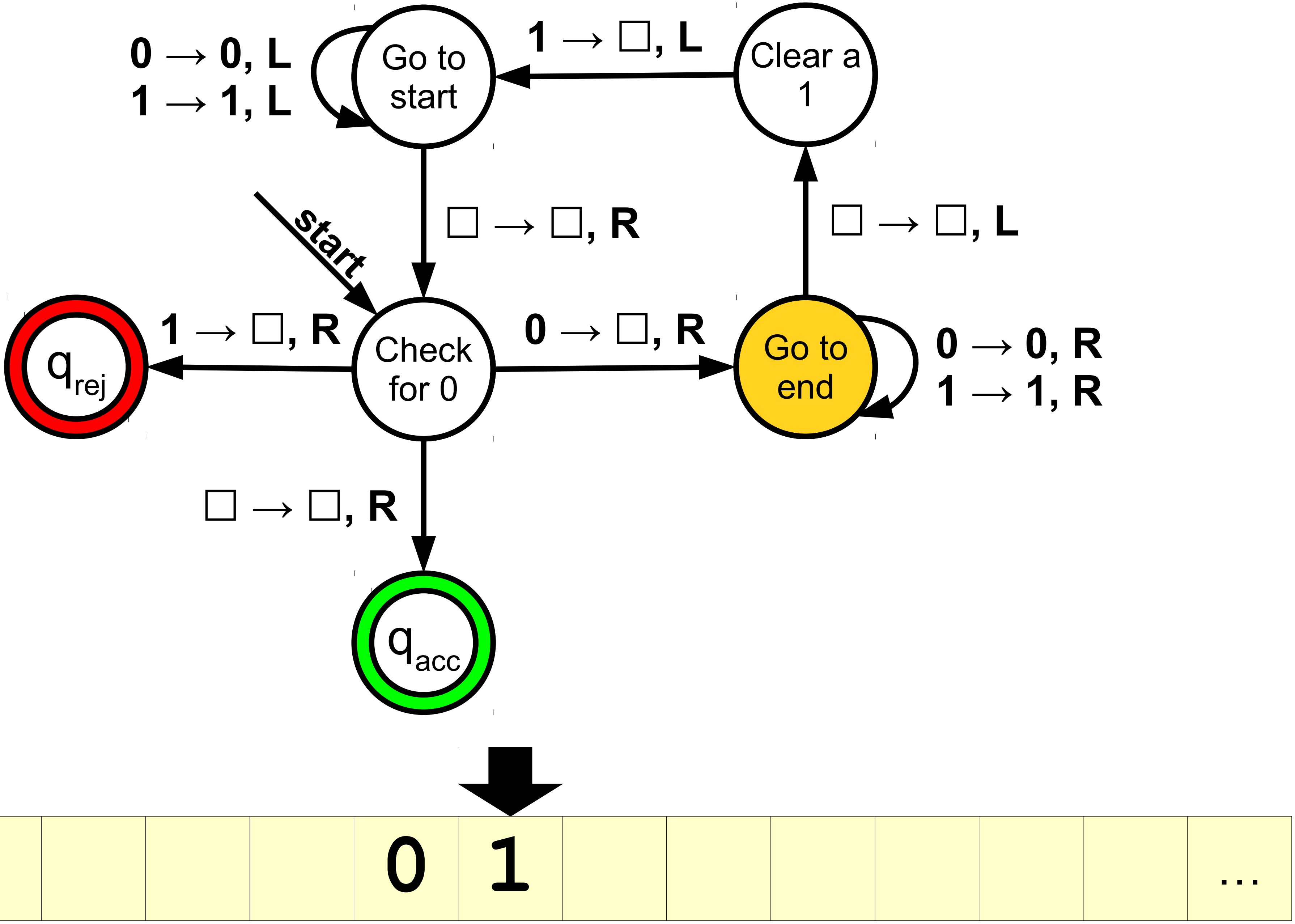

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
start
□ → □, L
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
q_{rej}
□ → □, R
q_{acc}

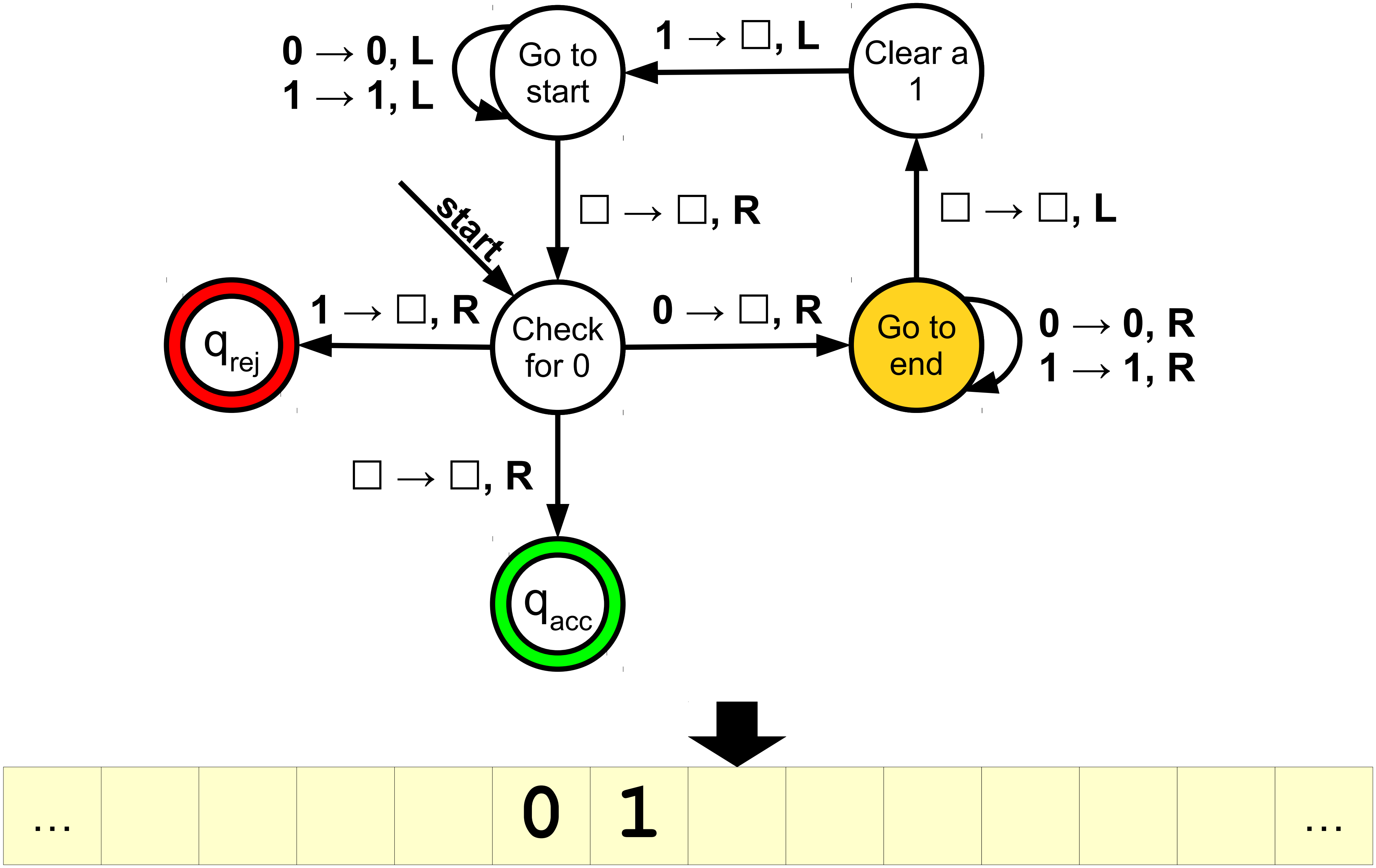

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
□ → □, L
start
1 → □, R
q_rej
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
0
0
1
…

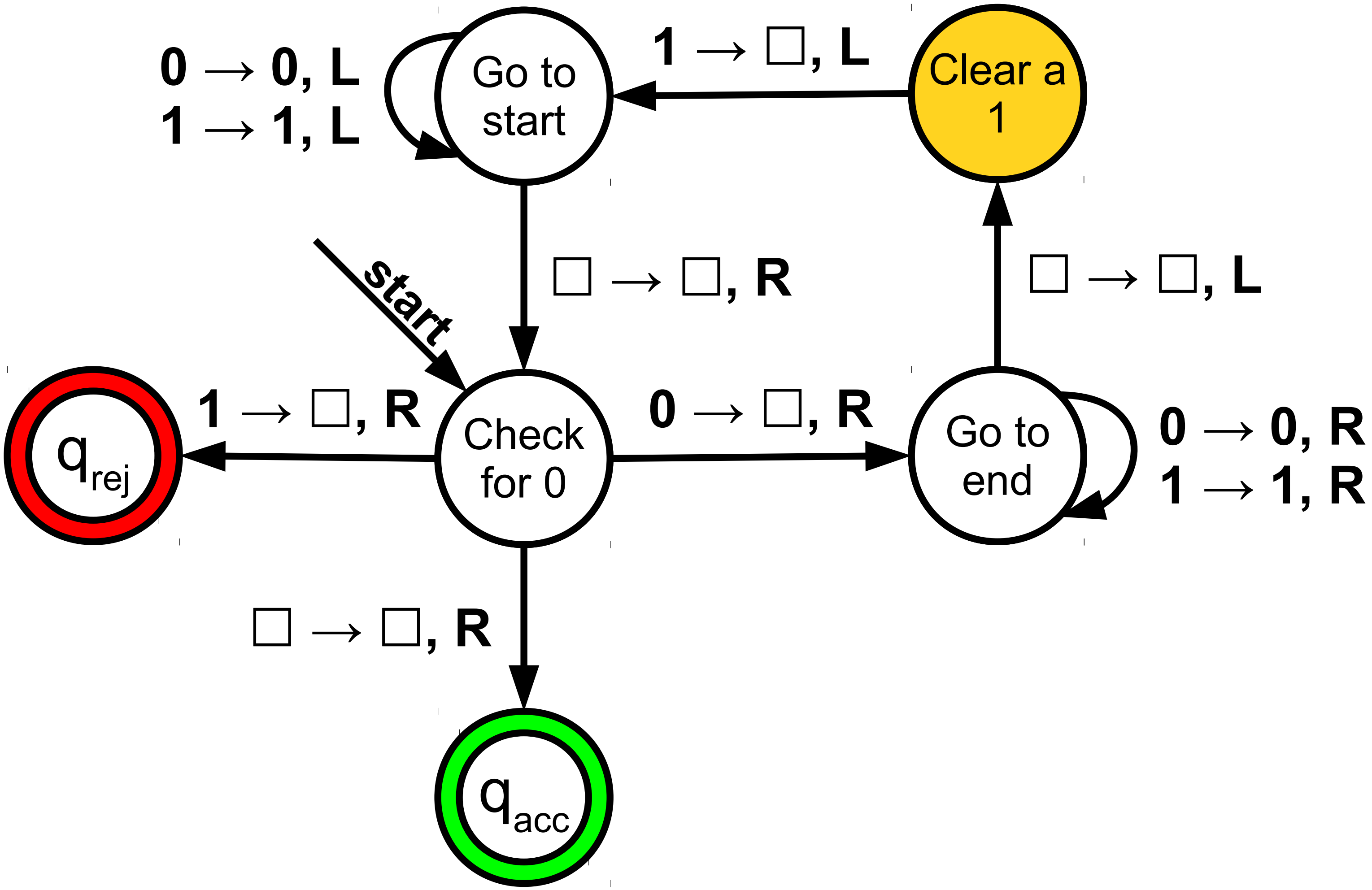

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
start
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc

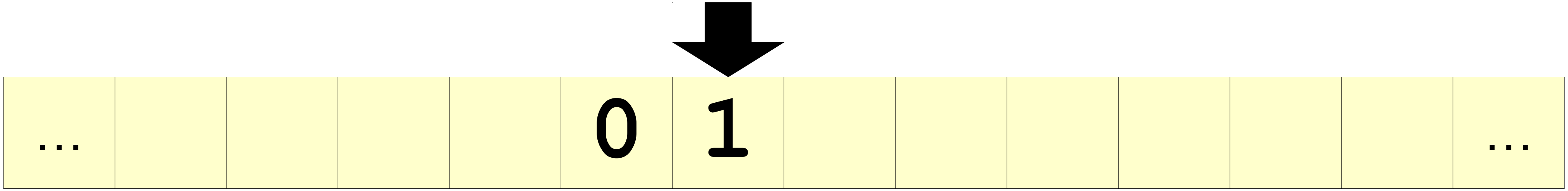

…
0
0
1
…

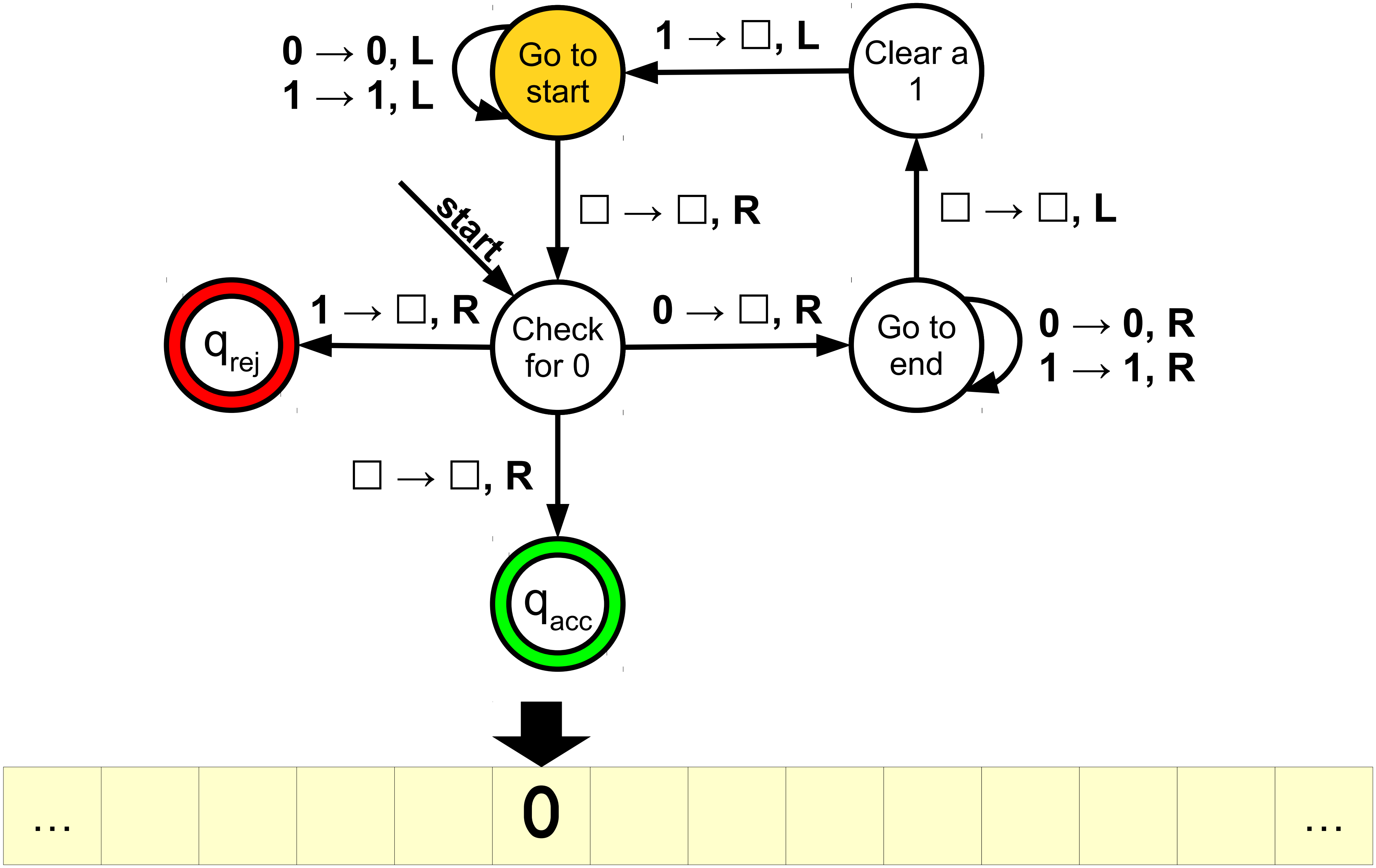

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
start
□ → □, L
q_{rej}
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_{acc}
…
0
1
…

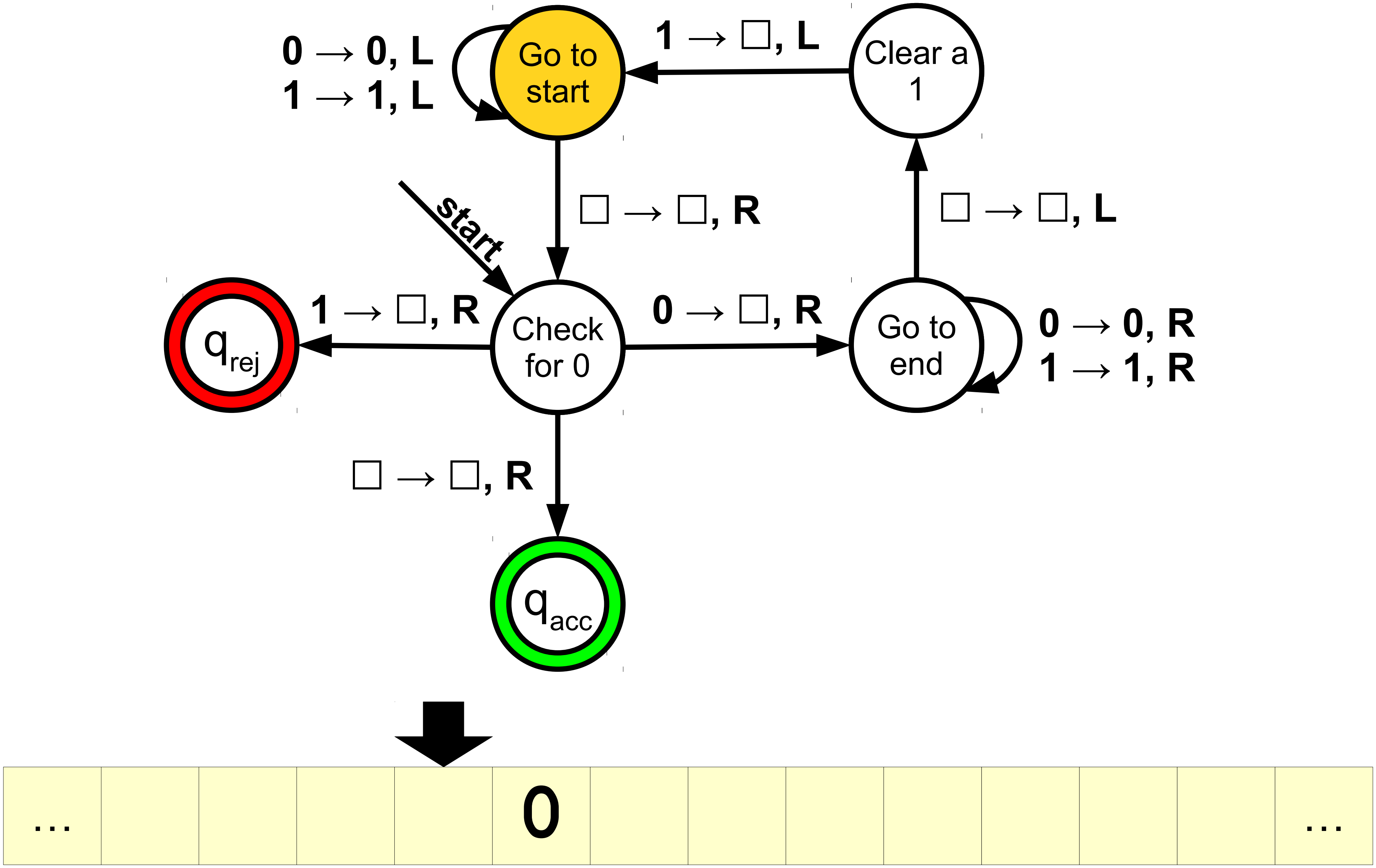

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
start
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
0
1
…

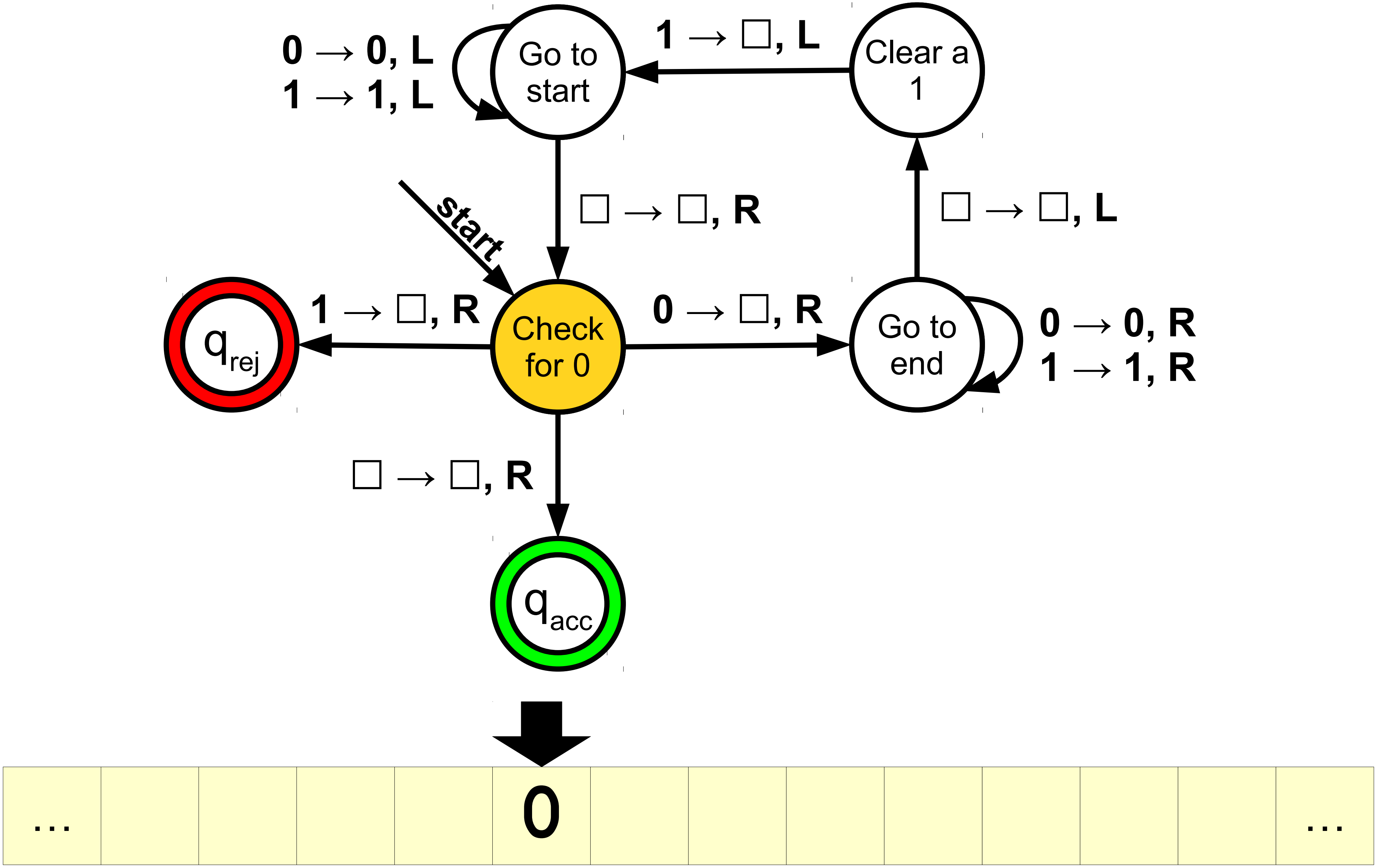

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
□ → □, L
start
1 → □, R
q_rej
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
0
1
…

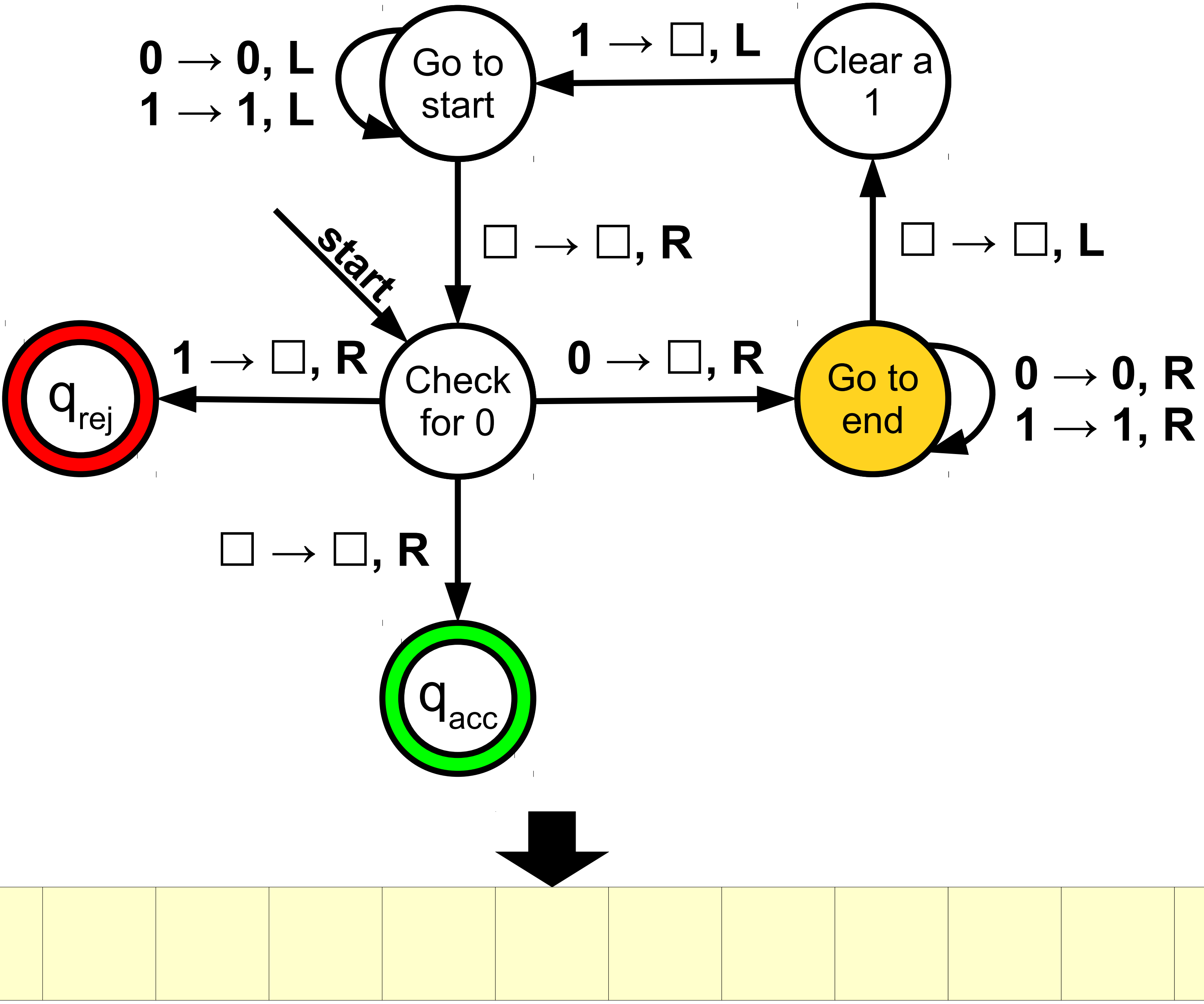

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
□ → □, L
start
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc

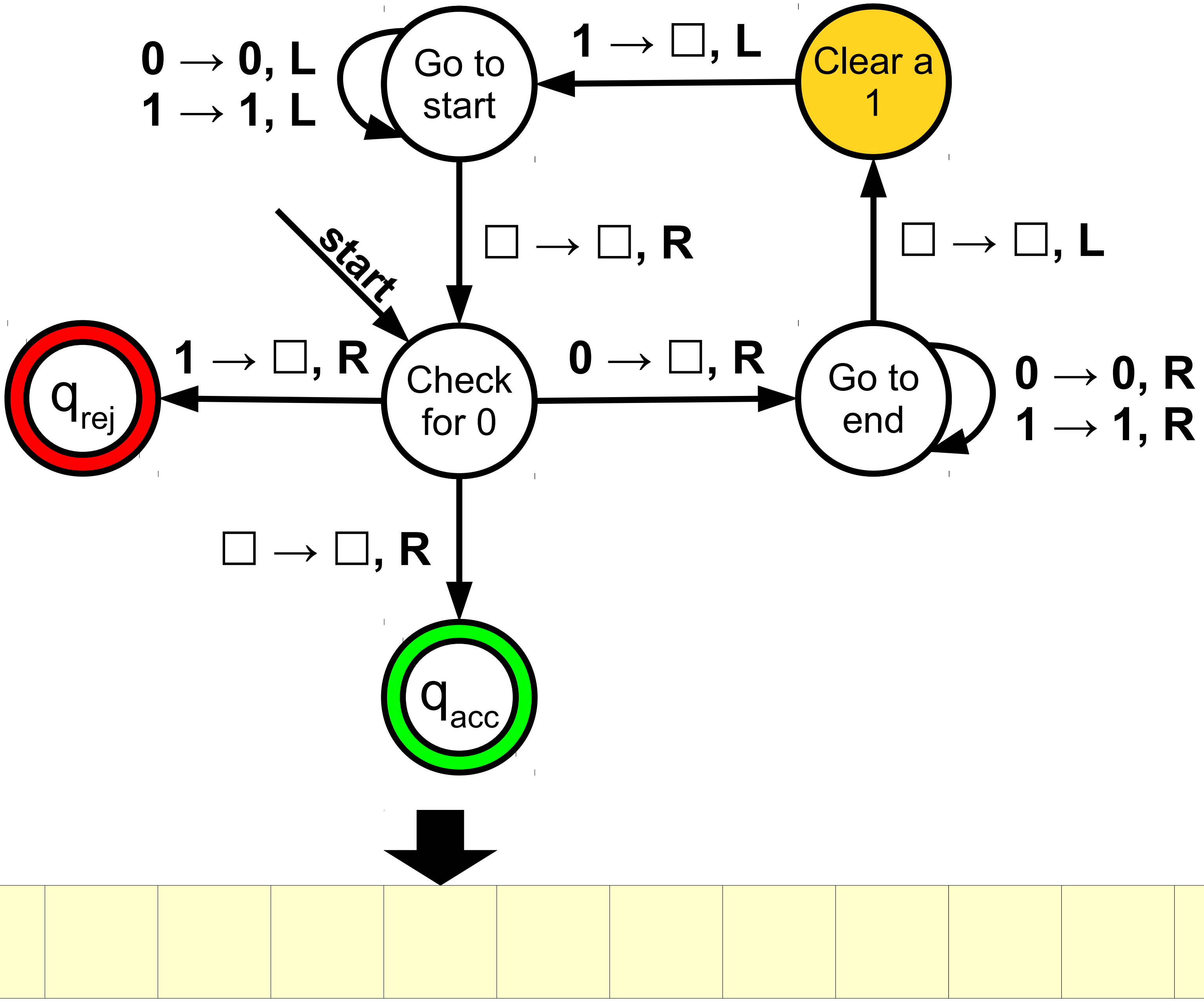

…
0
1
…

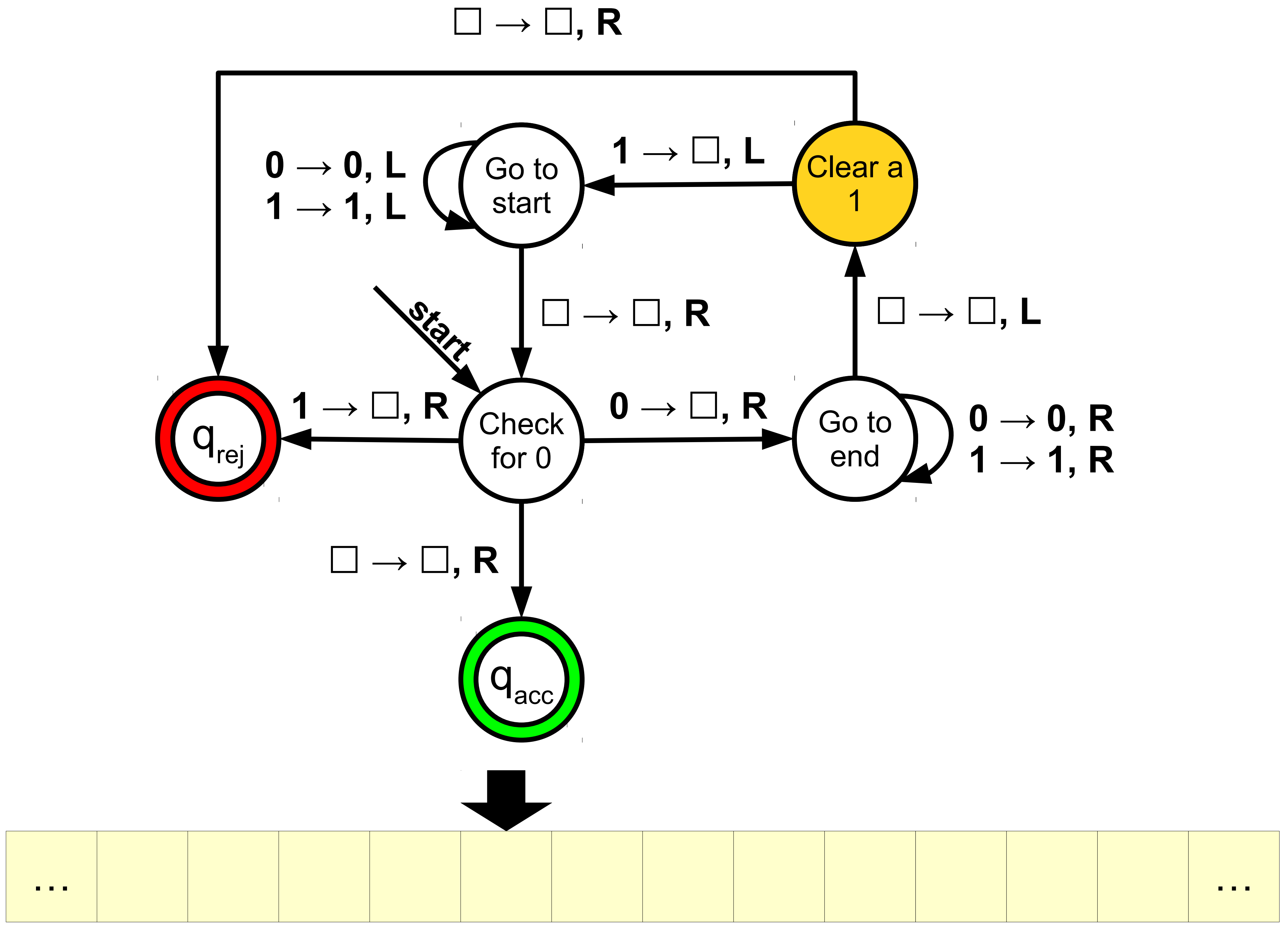

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q$_{rej}$
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q$_{acc}$
…
0
…

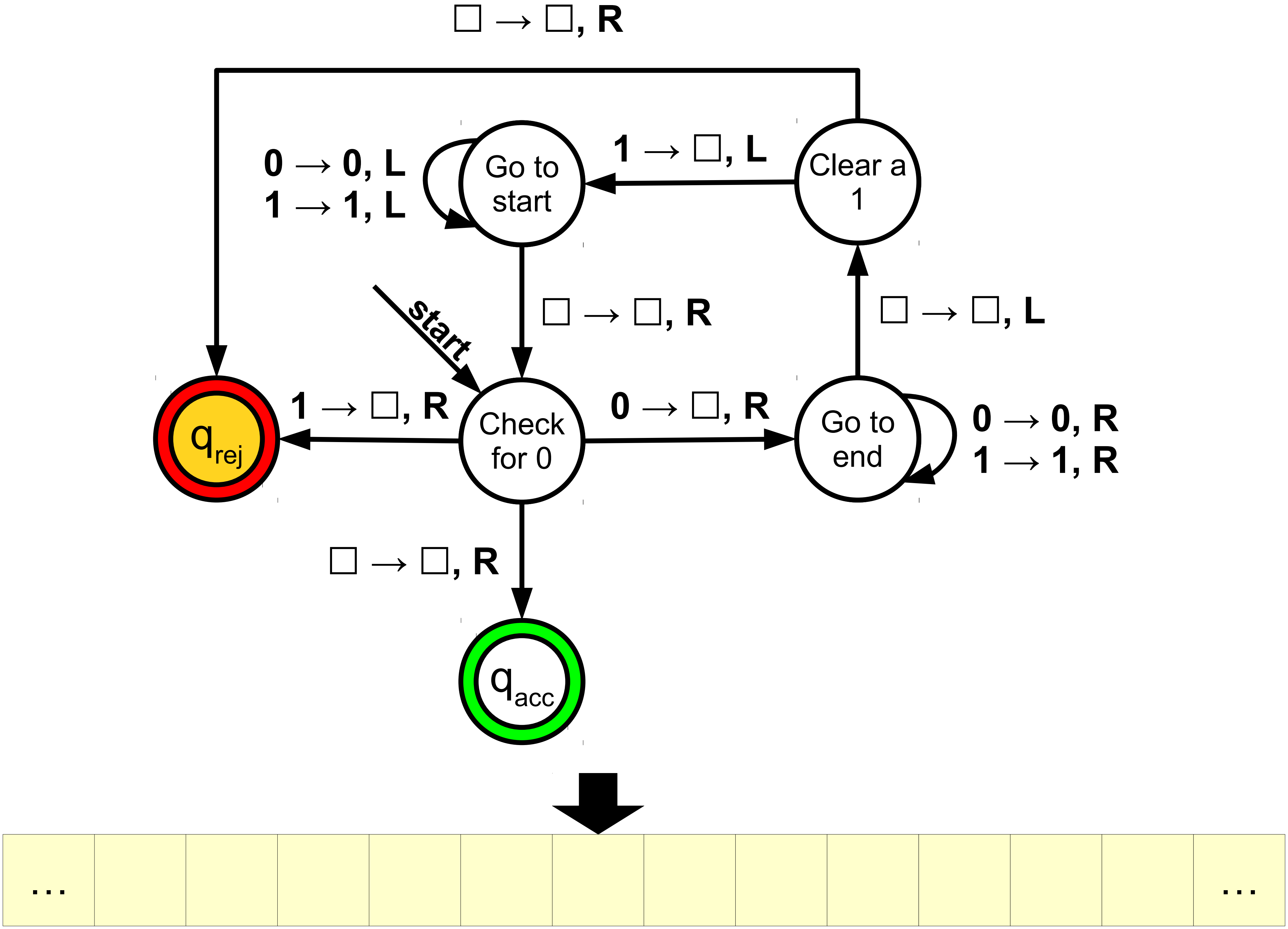

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
□ → □, L
start
1 → □, R
q_rej
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
0
…

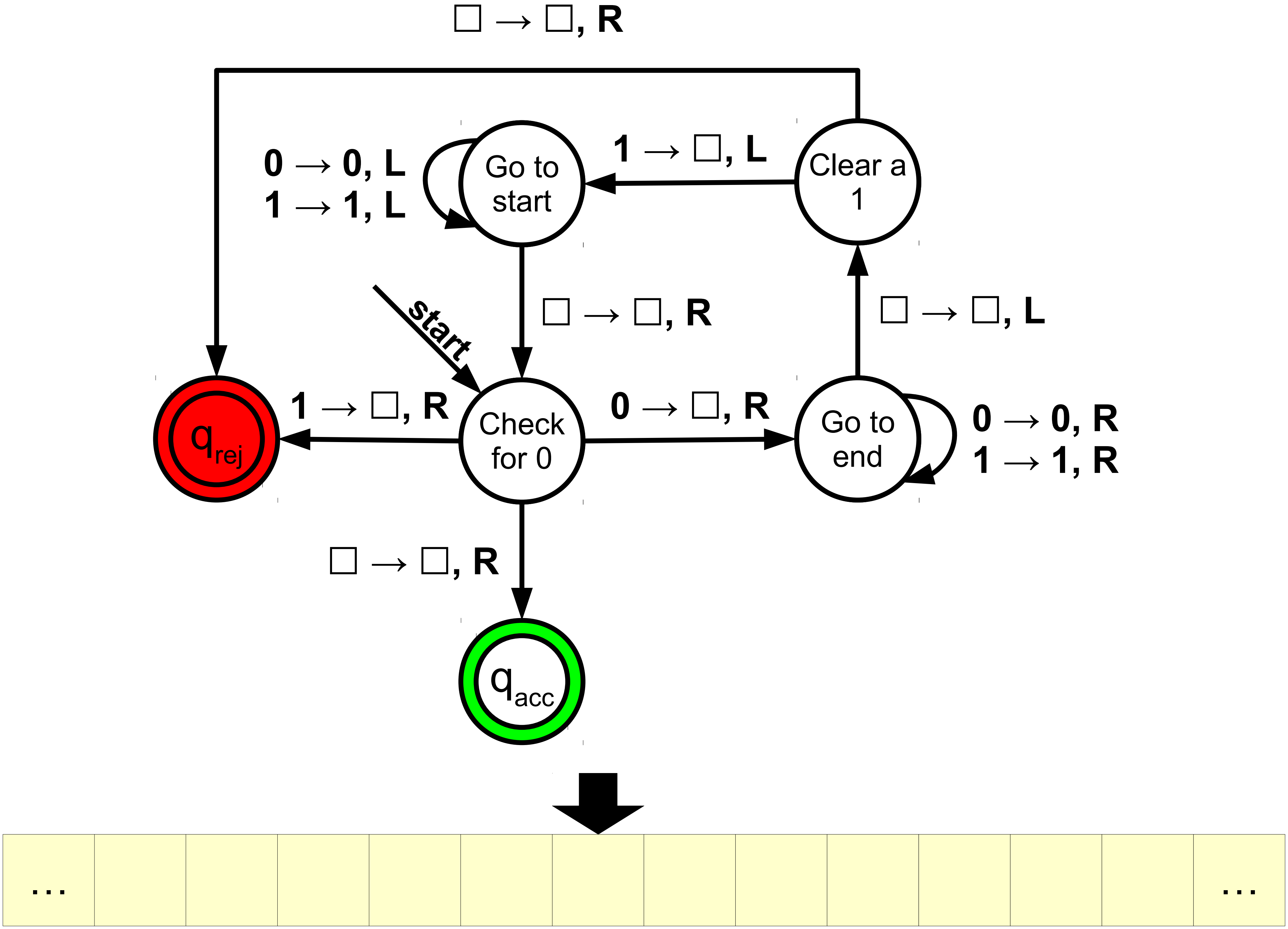

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
q_rej
□ → □, R
q_acc
…
0
…

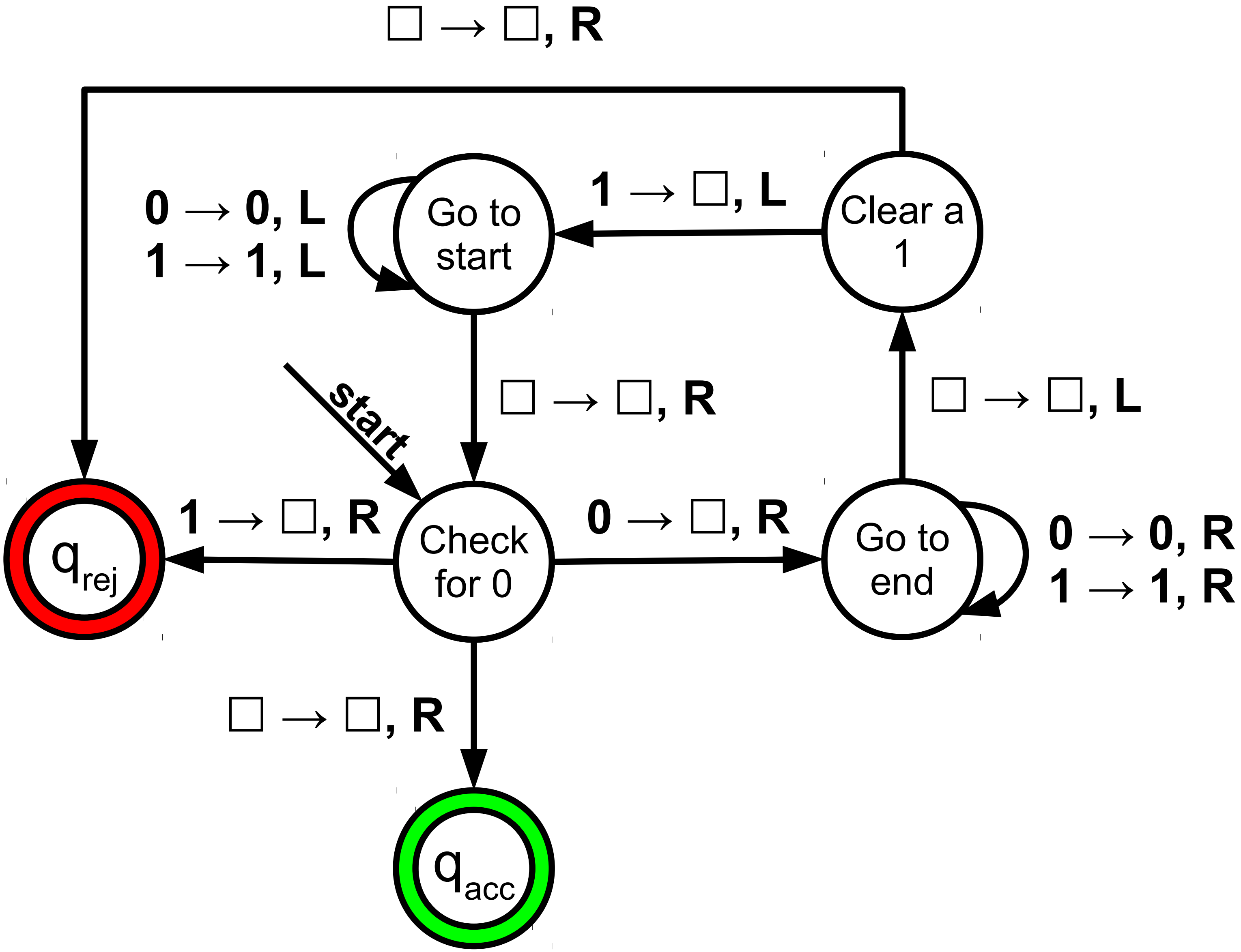

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
…

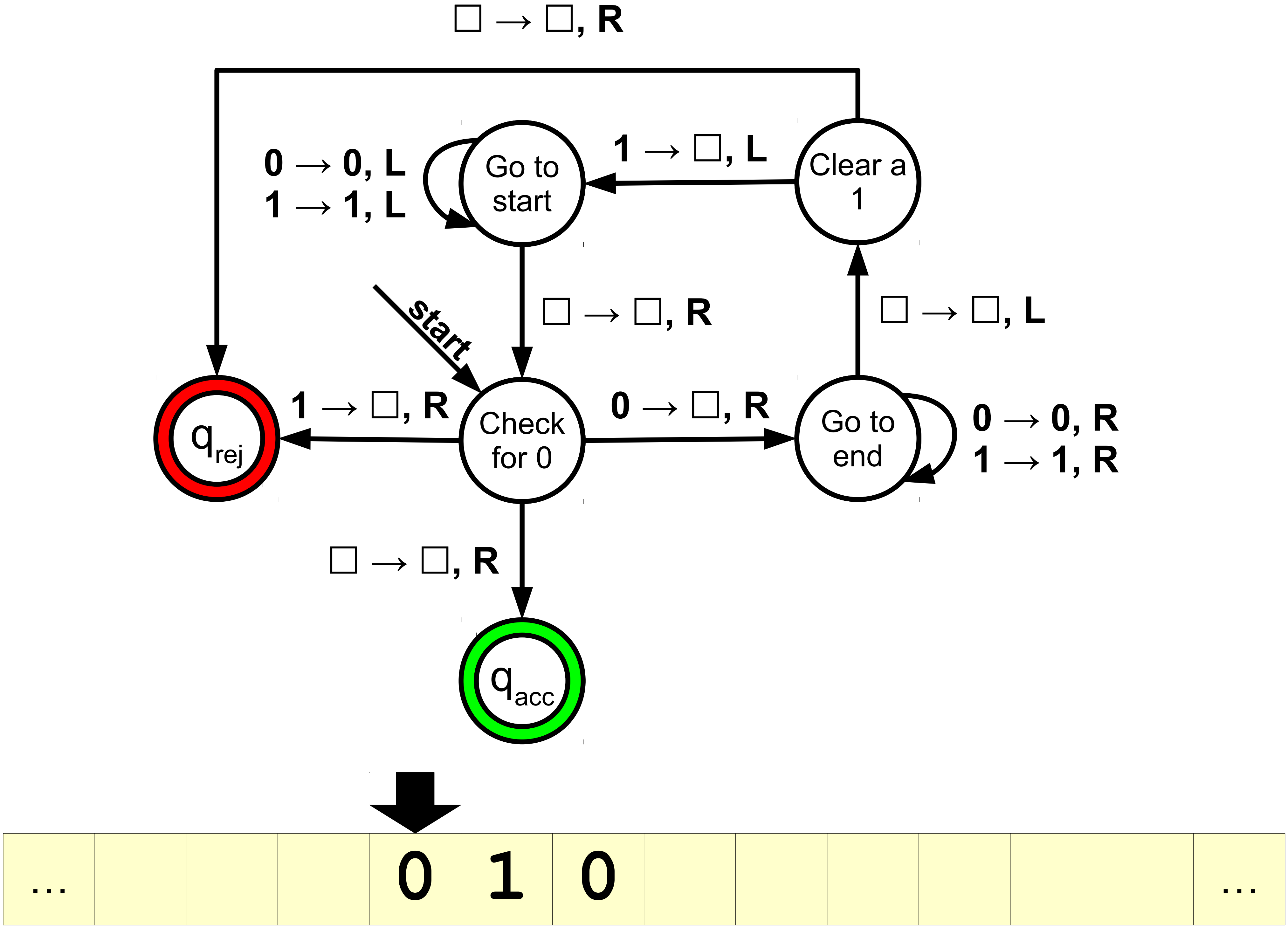

0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
…

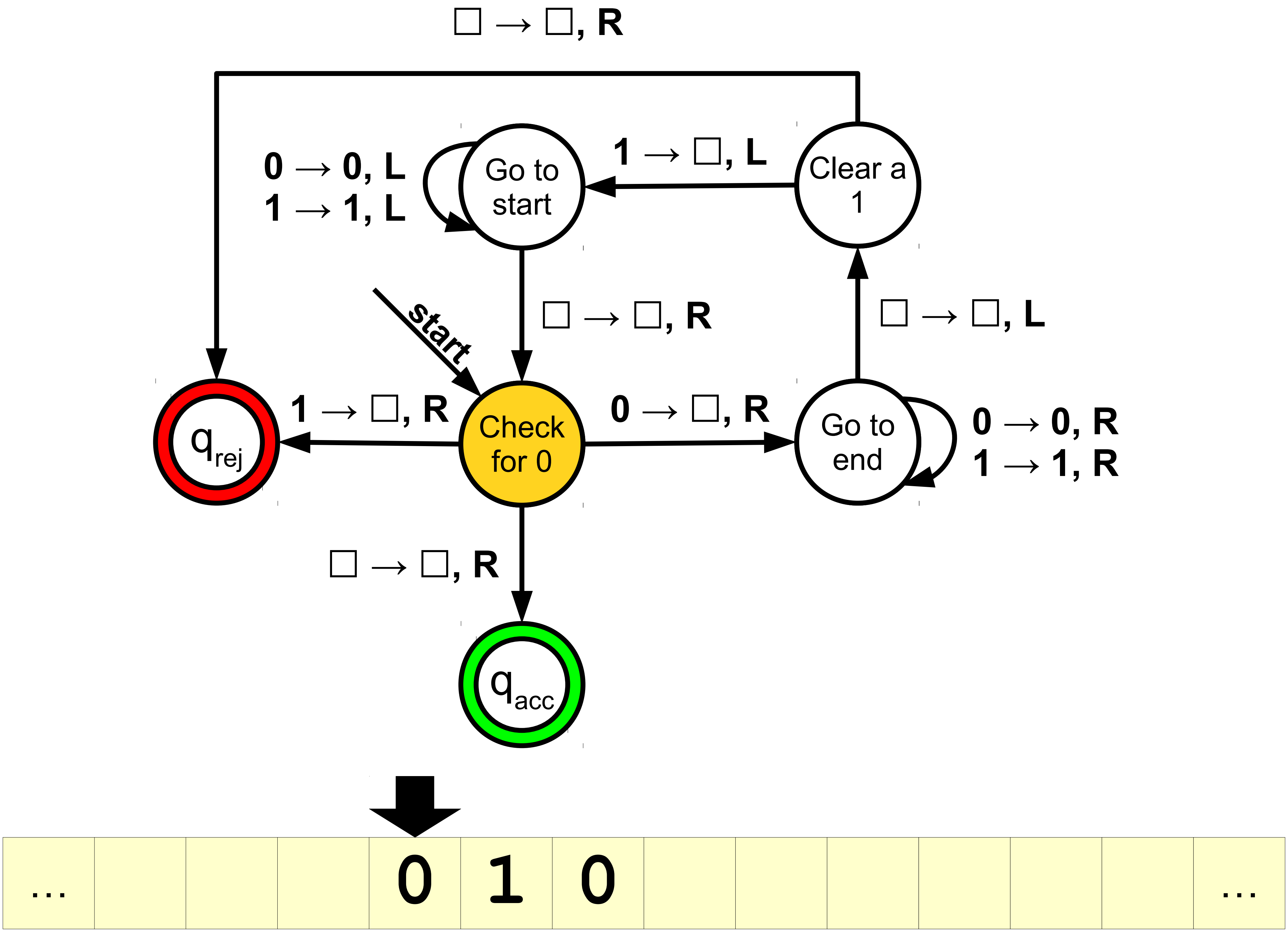

□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
…

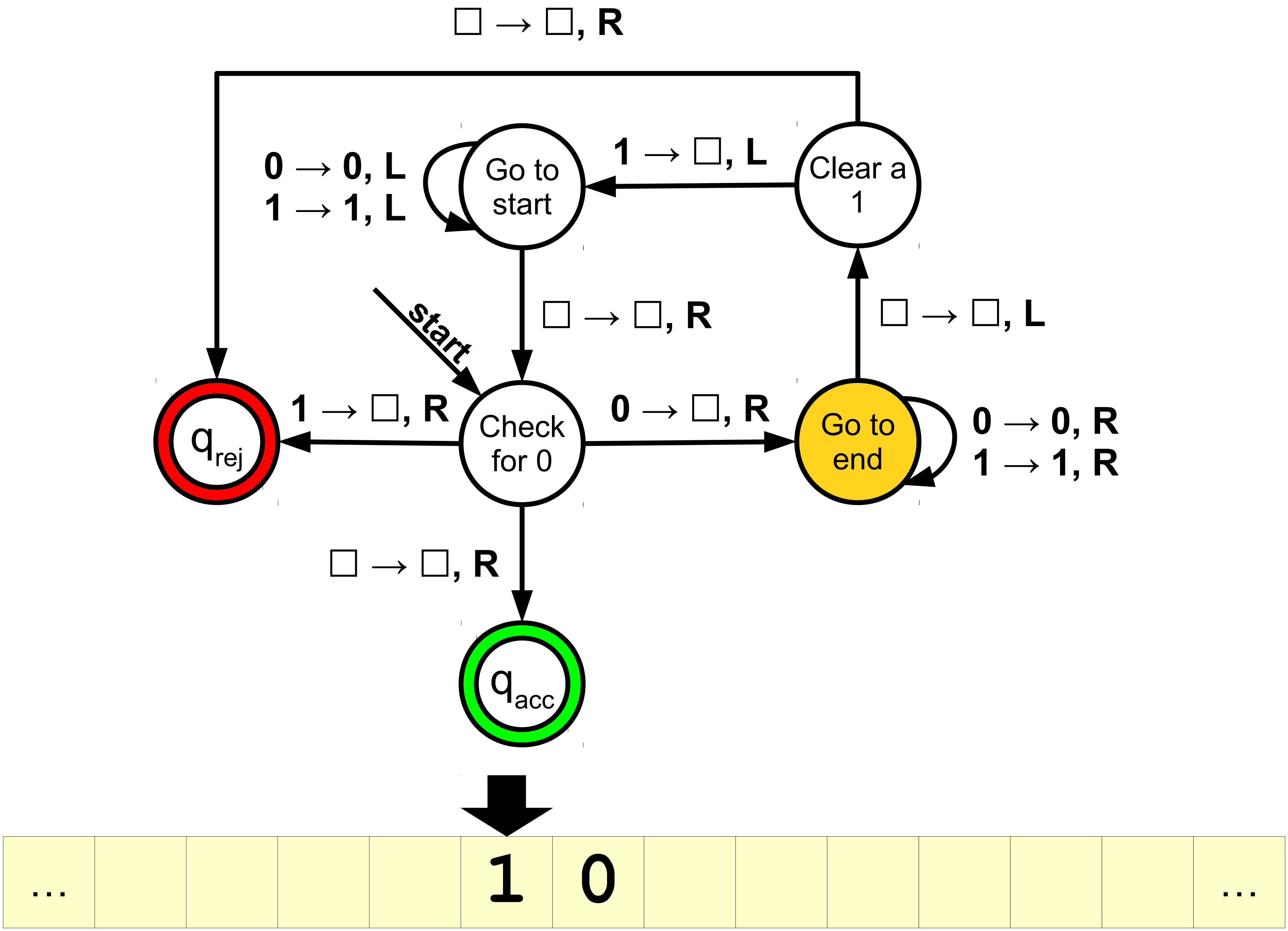

□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
…

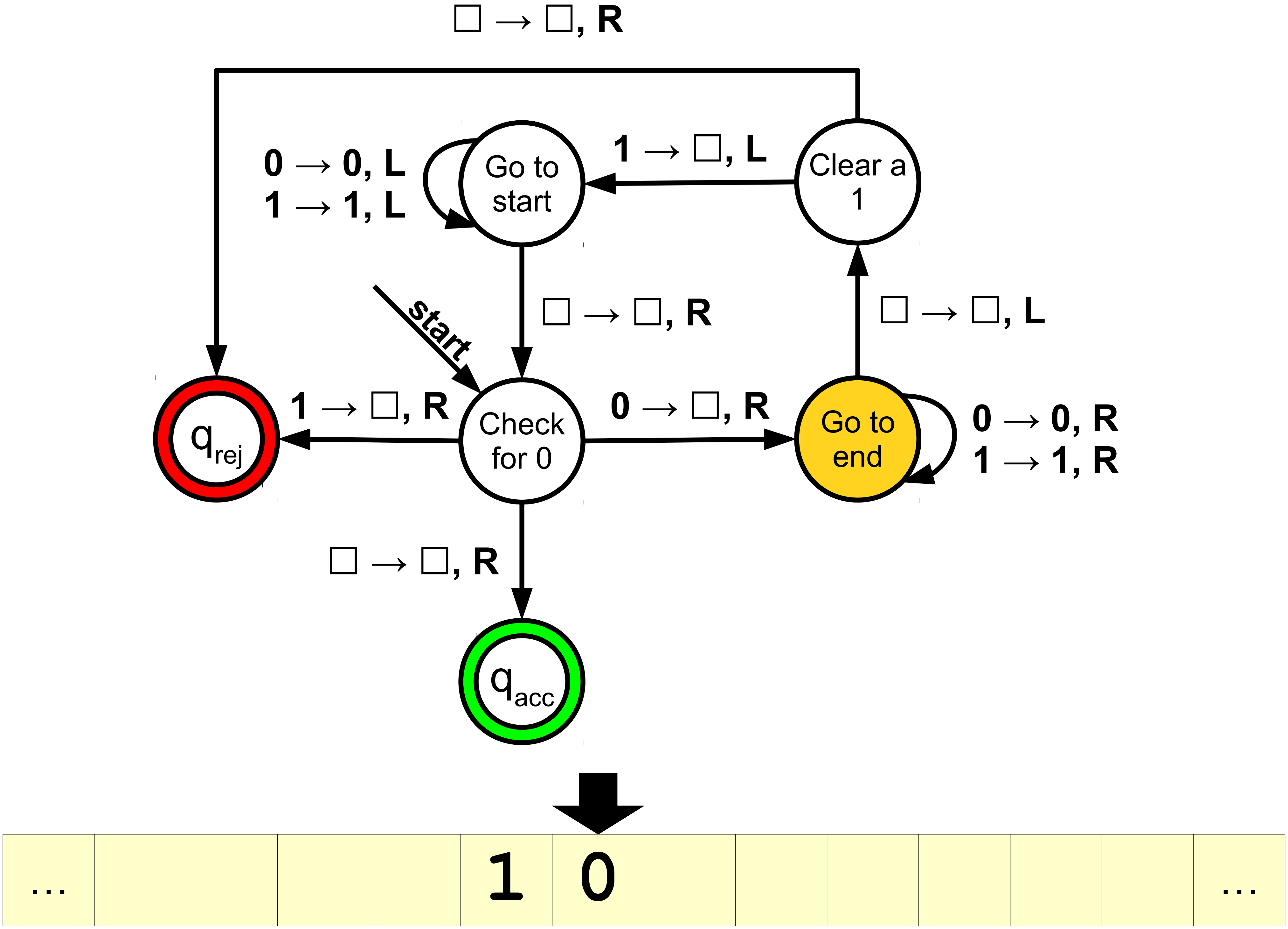

□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
□ → □, L
start
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
…

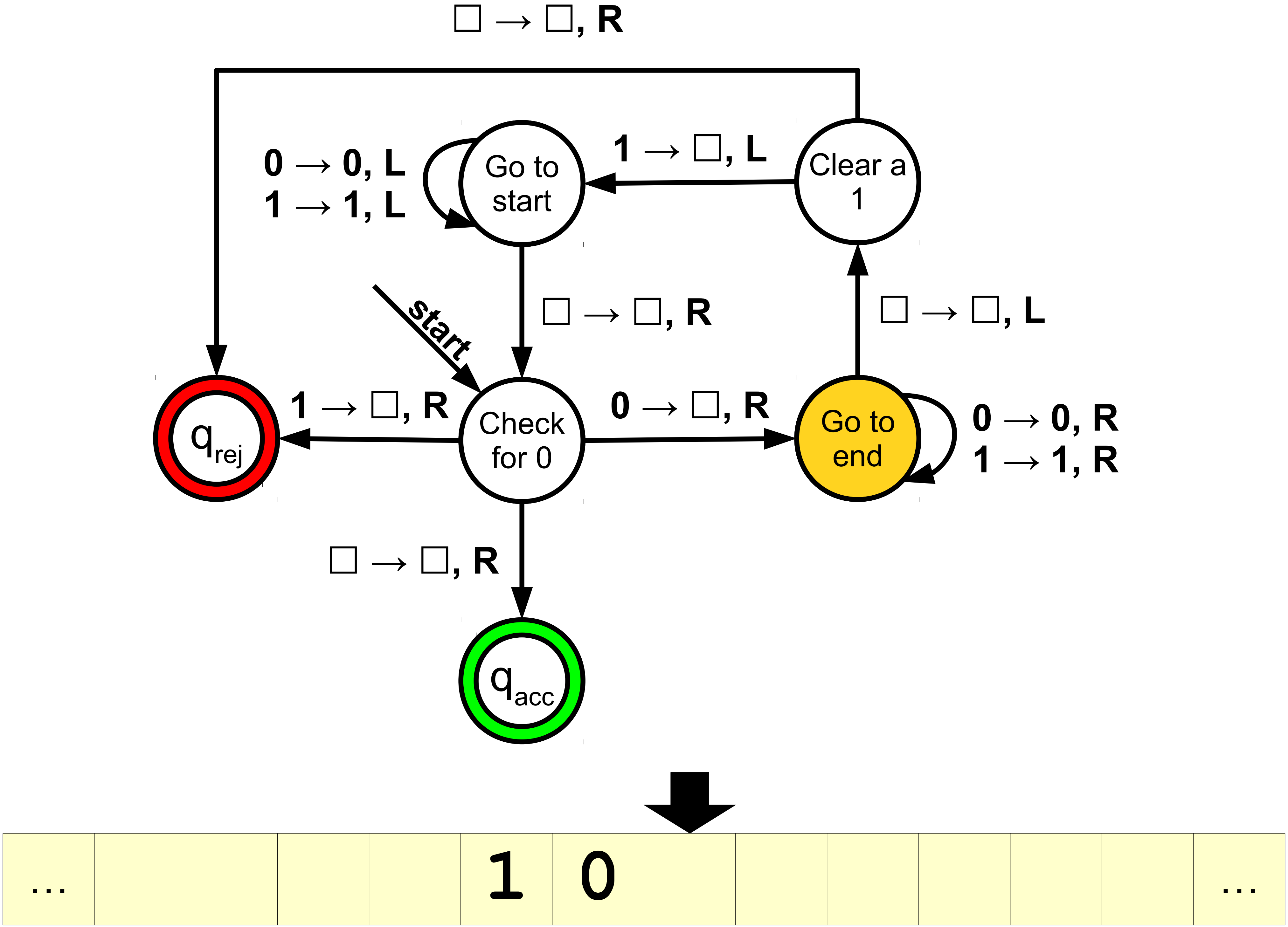

□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
qrej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
qacc


□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
start
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
0
1
0
…

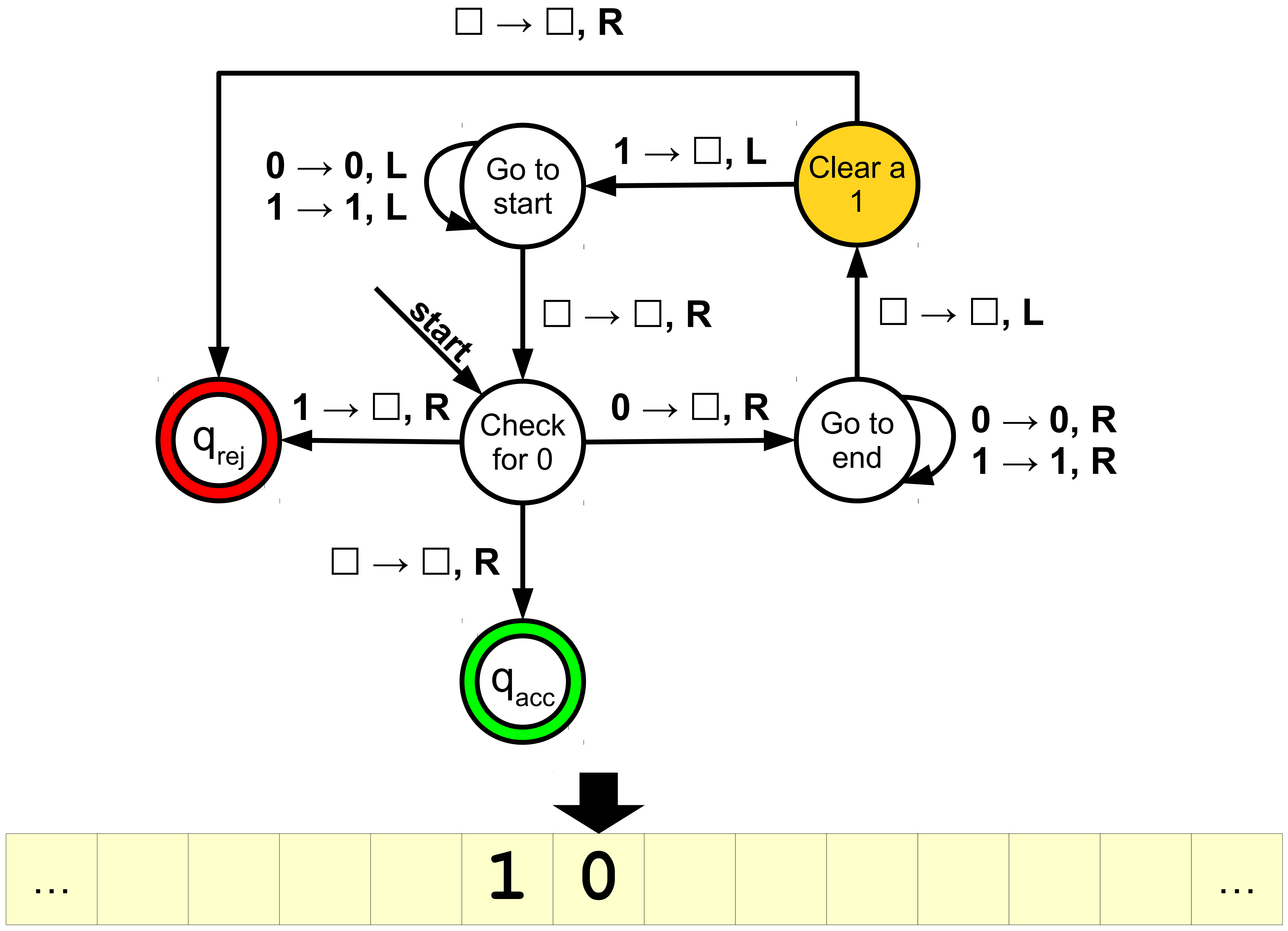

□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
1 → □, R
q_rej
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
0
1
0
…

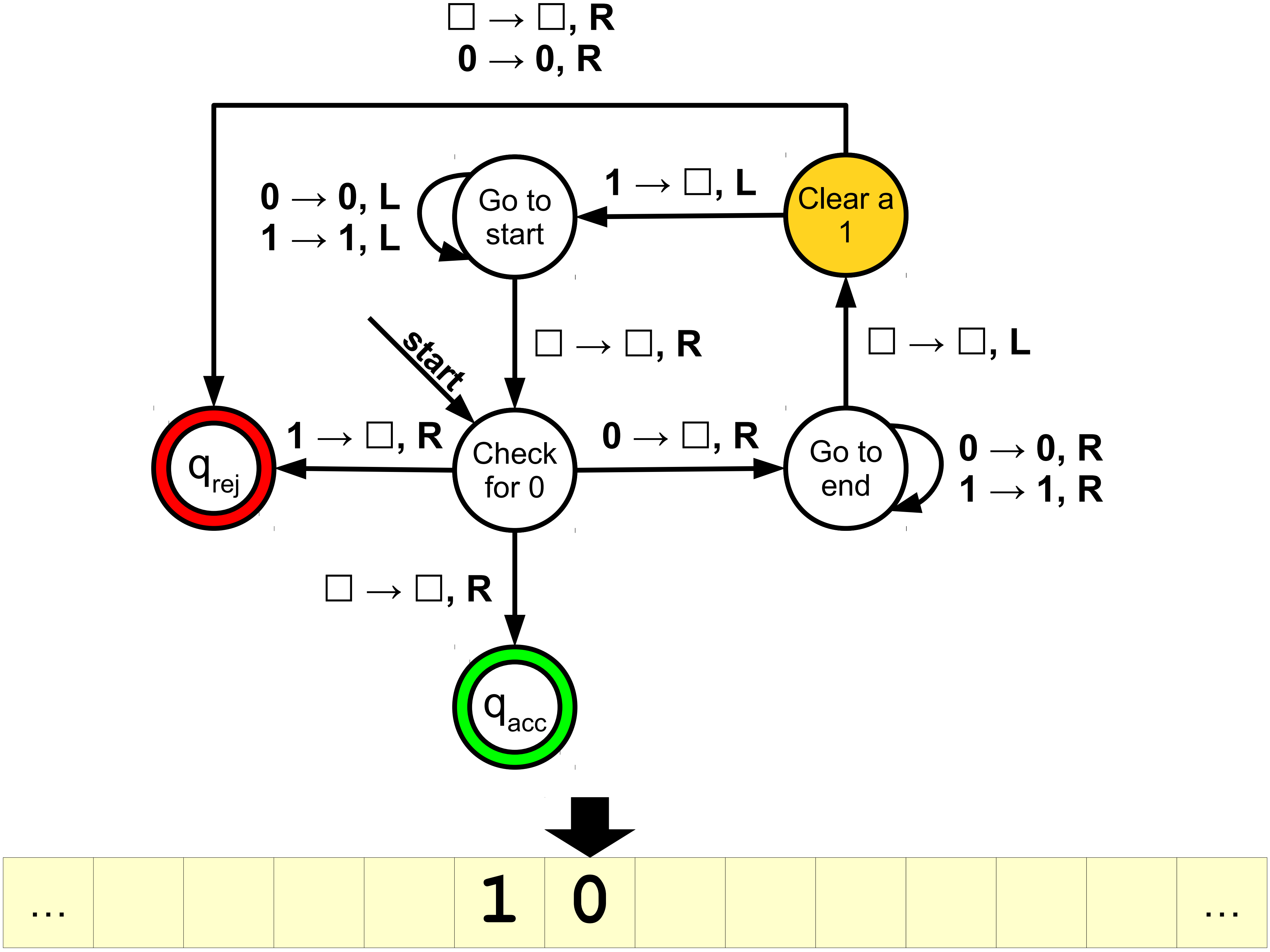

□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
q_{rej}
□ → □, R
q_{acc}
…
1
0
…

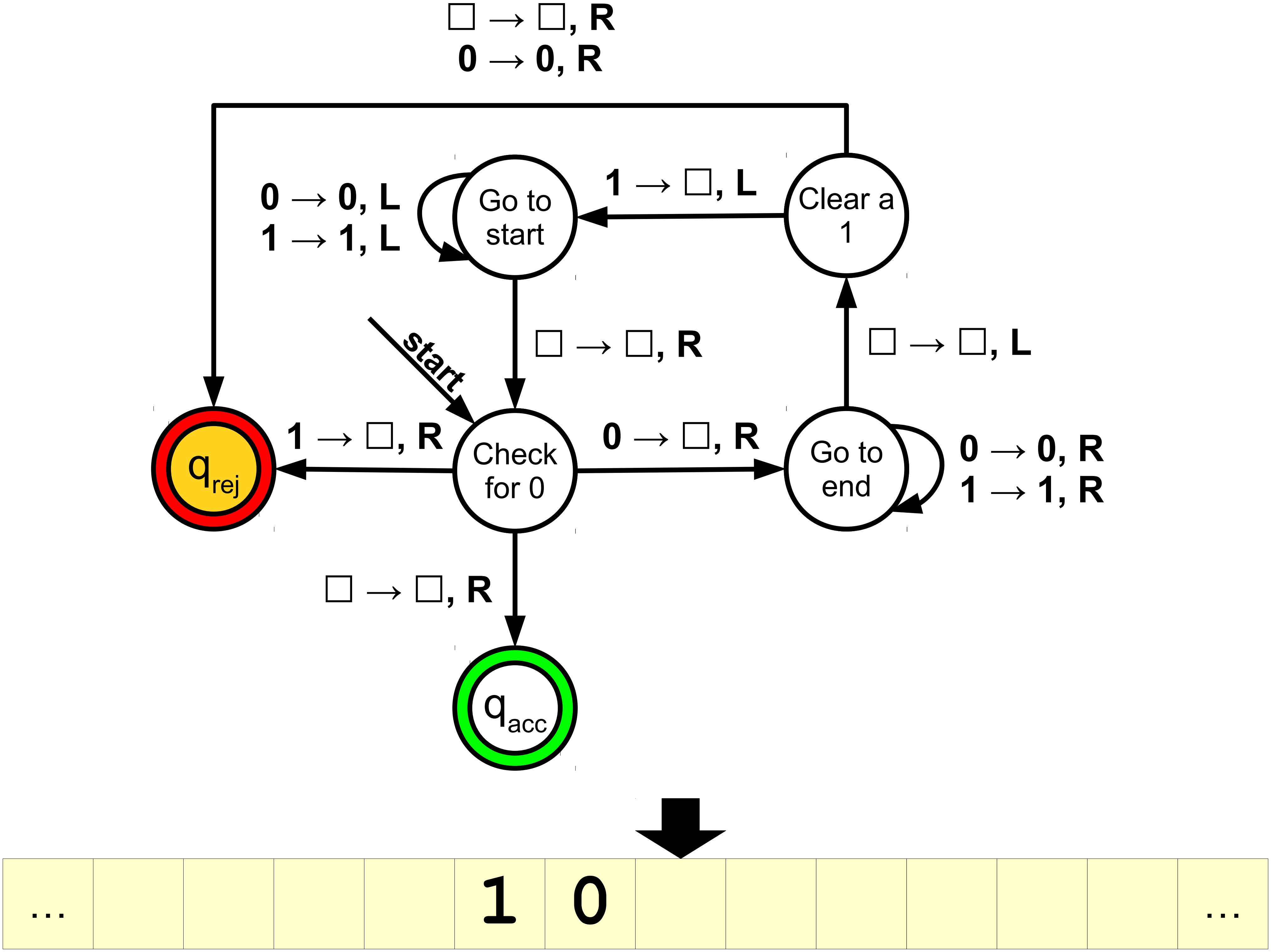

□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
1
0
…

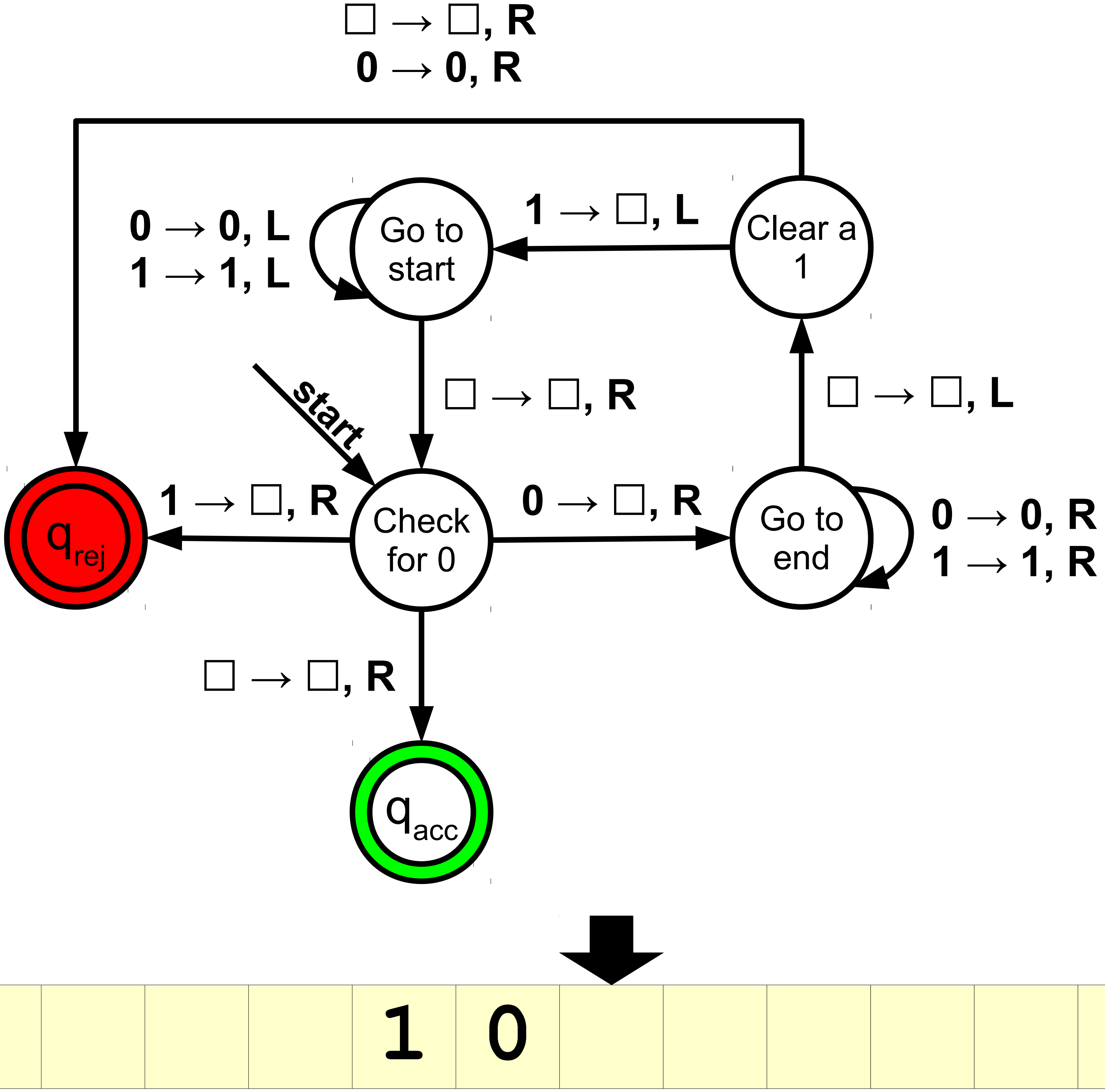


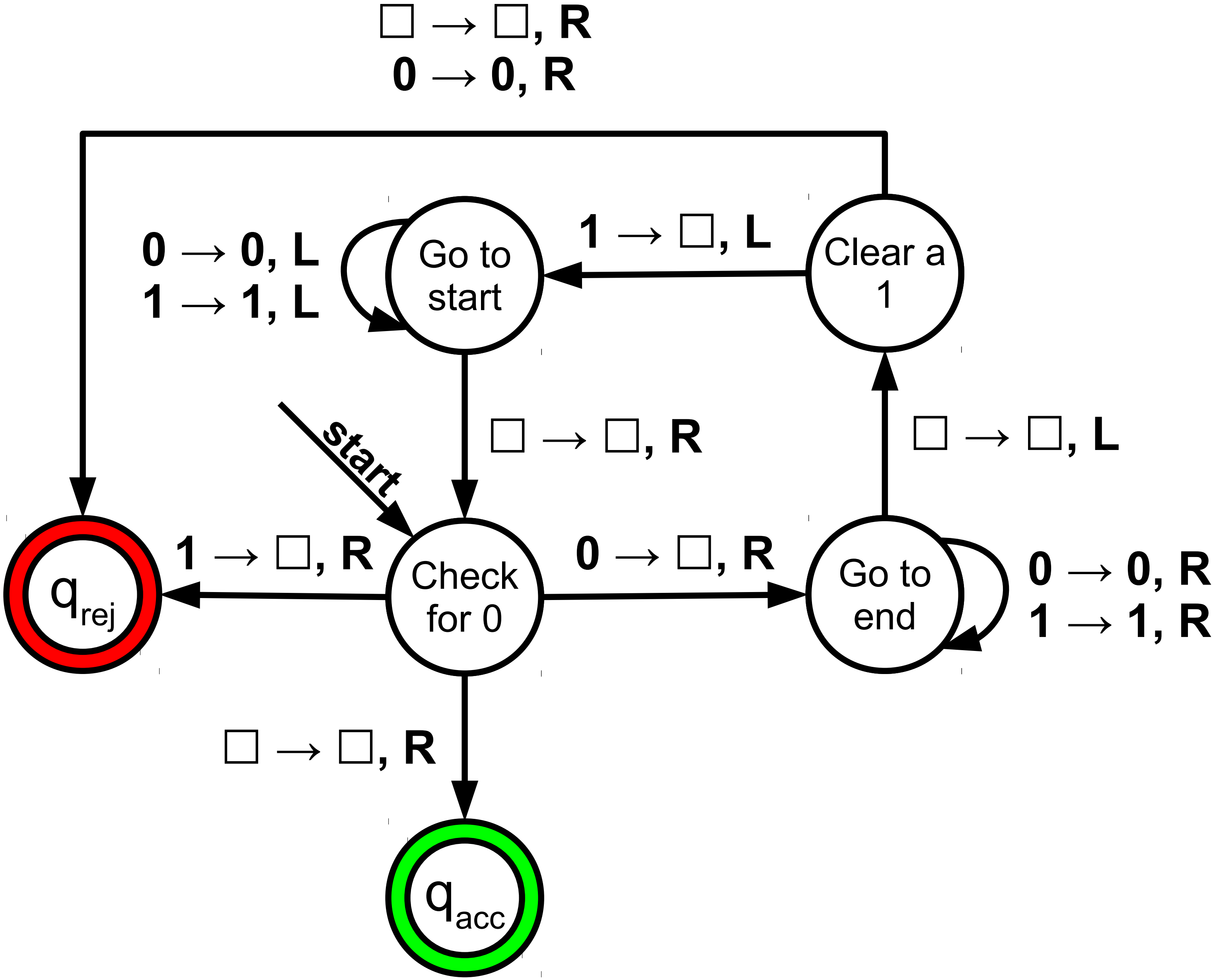
□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q_{rej}
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_{acc}
…
1
0
…


□ → □, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
□ → □, R
start
□ → □, L
q_{rej}
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_{acc}
…
1
0
…


□ → □, R
0 → 0, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
1
0
…


□ → □, R
0 → 0, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc
…
1
0
…


□ → □, R
0 → 0, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
qrej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
qacc
…
1
0
…


□ → □, R
0 → 0, R
0 → 0, L
1 → 1, L
Go to start
1 → □, L
Clear a 1
start
□ → □, R
□ → □, L
q_rej
1 → □, R
Check for 0
0 → □, R
Go to end
0 → 0, R
1 → 1, R
□ → □, R
q_acc

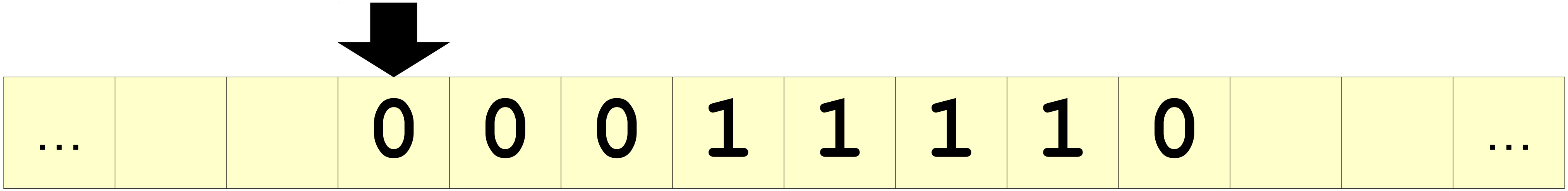
Another TM Design

- We've designed a TM for $\{\mathtt{0}^n\mathtt{1}^n \mid n \in \mathbb{N}\}$.
- Consider this language over $\Sigma = \{\mathtt{0}, \mathtt{1}\}$:

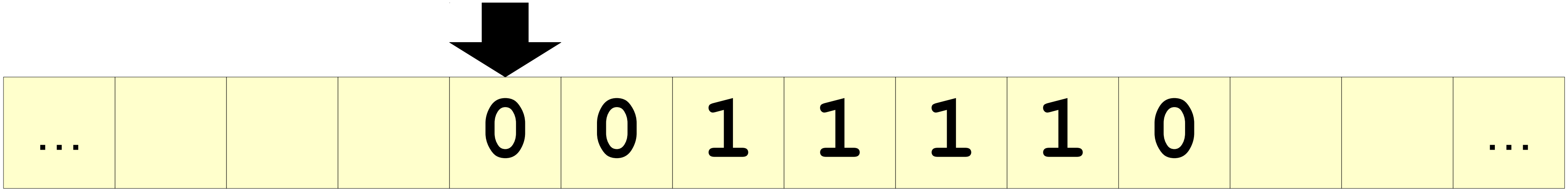
$$L = \{\ w \in \Sigma^* \mid w \text{ has the same number of } \mathtt{0}\text{s and } \mathtt{1}\text{s}\ \}$$

- This language is also not regular, but it is context-free.
- How might we design a TM for it?

A Caveat

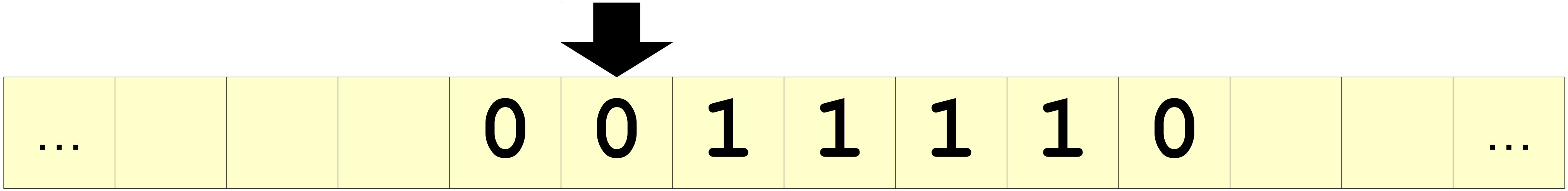


A Caveat

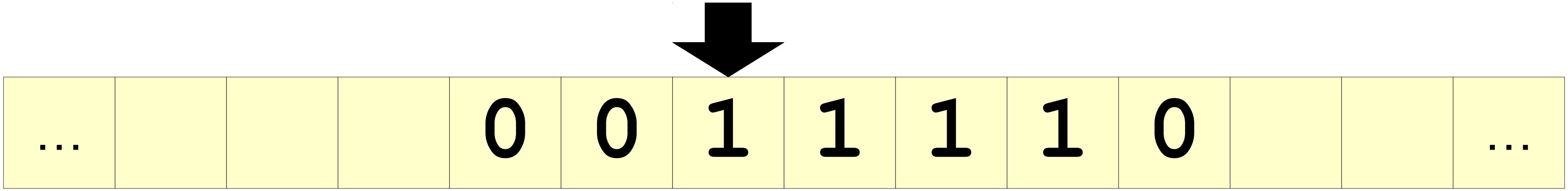


…				0	0	1	1	1	1	0			…

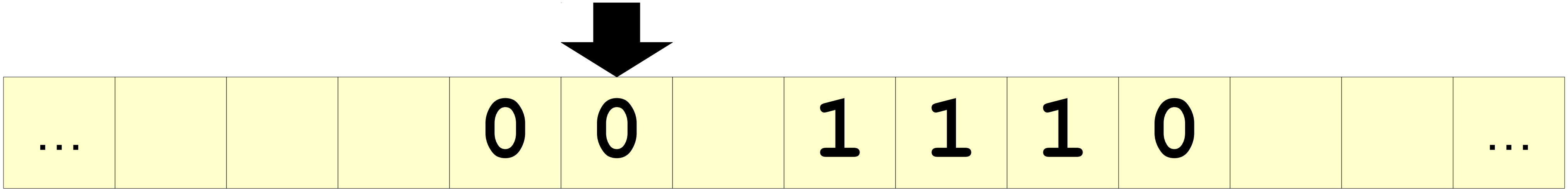
A Caveat



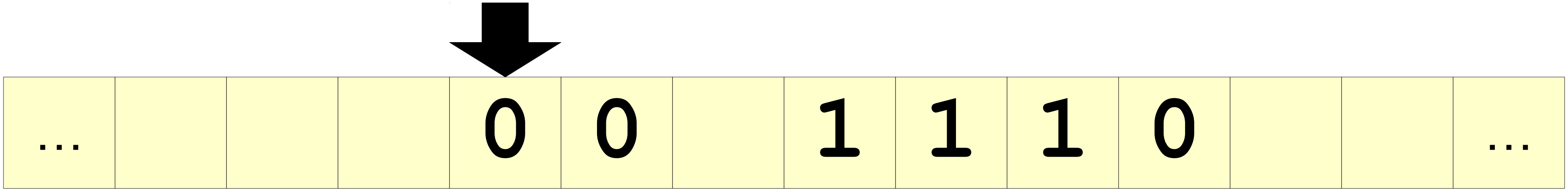
A Caveat



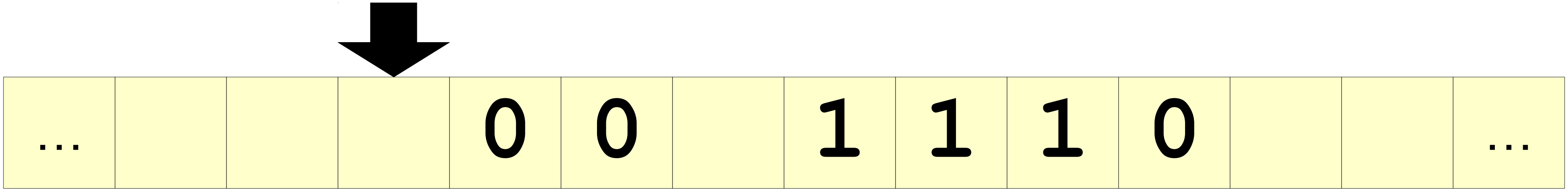
A Caveat



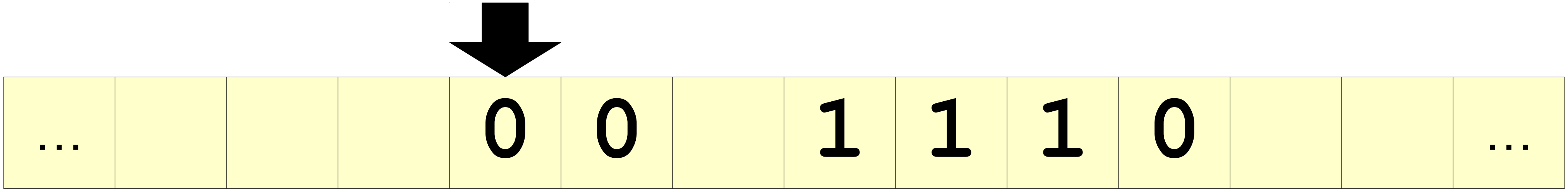
A Caveat



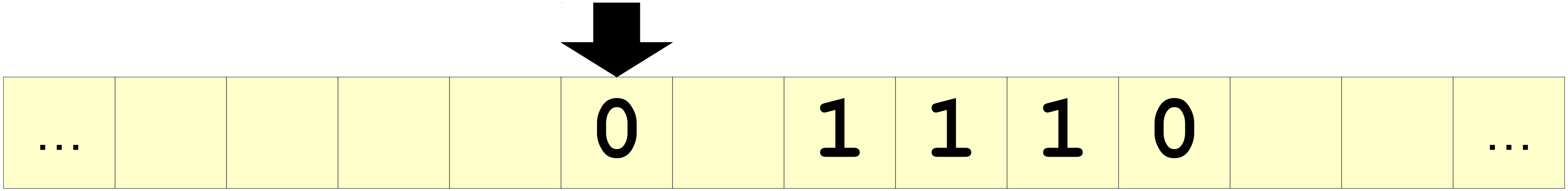
A Caveat



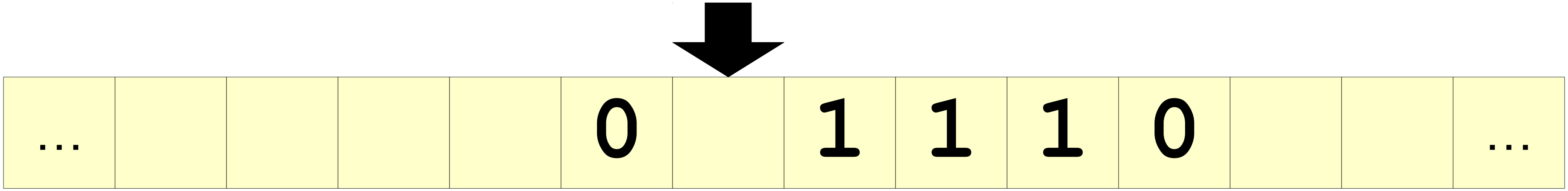
A Caveat



A Caveat

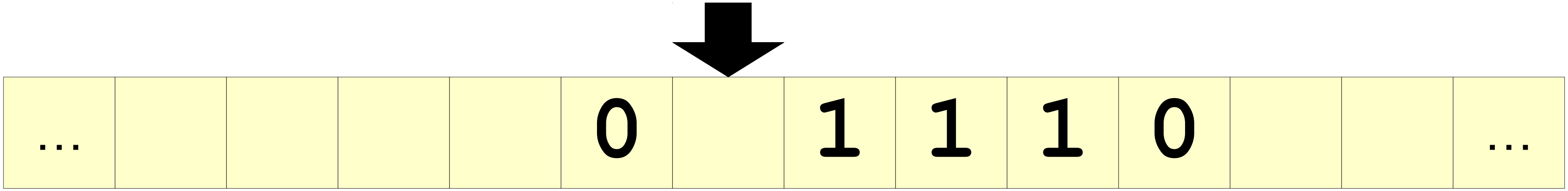


A Caveat



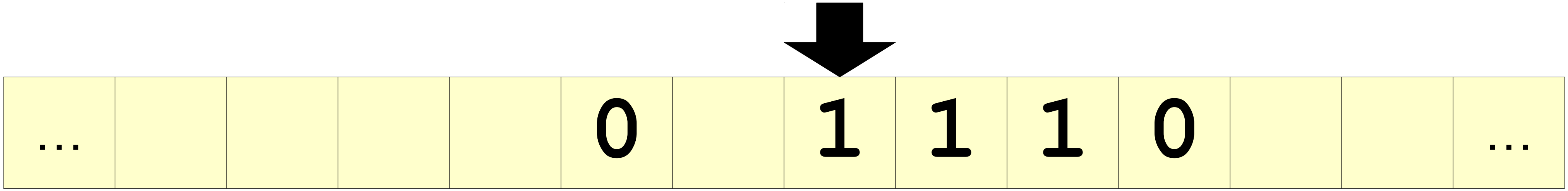
…					0		1	1	1	0			…

A Caveat

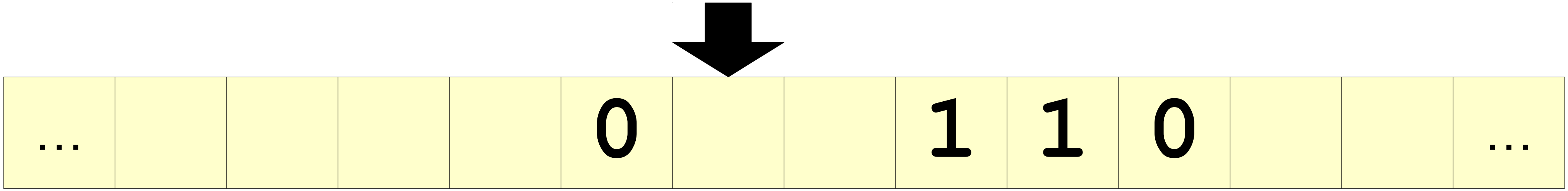


How do we know that this blank isn't one of the infinitely many blanks after our input string?

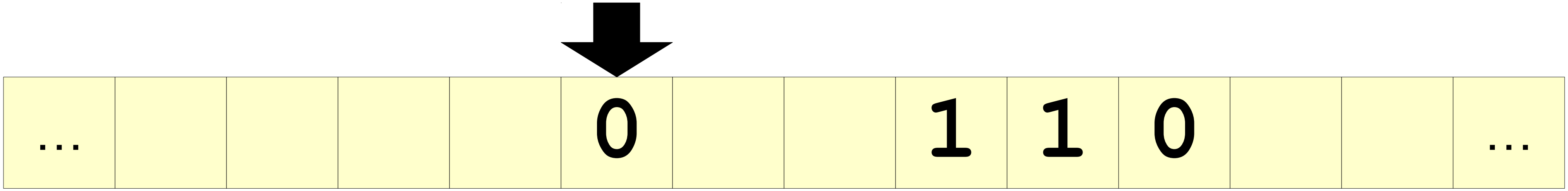
A Caveat



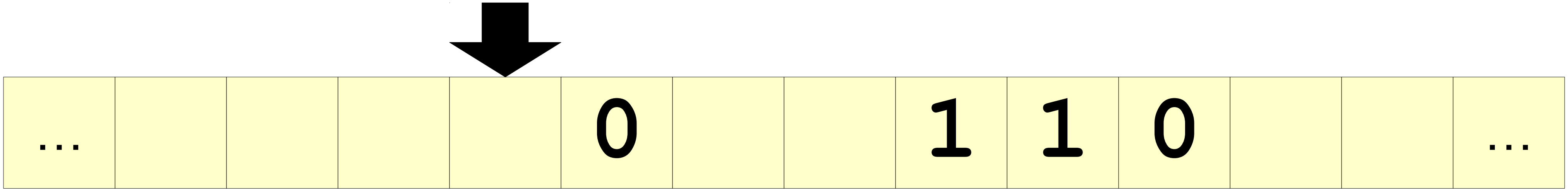
A Caveat



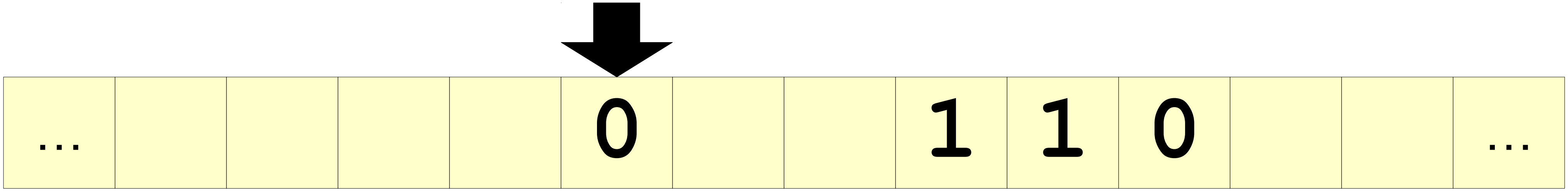
A Caveat



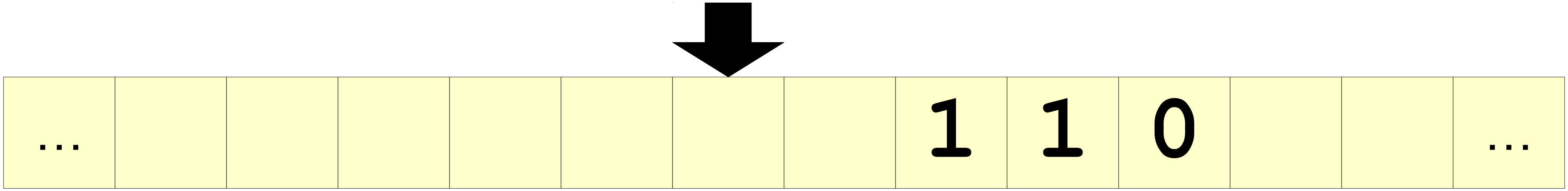
A Caveat



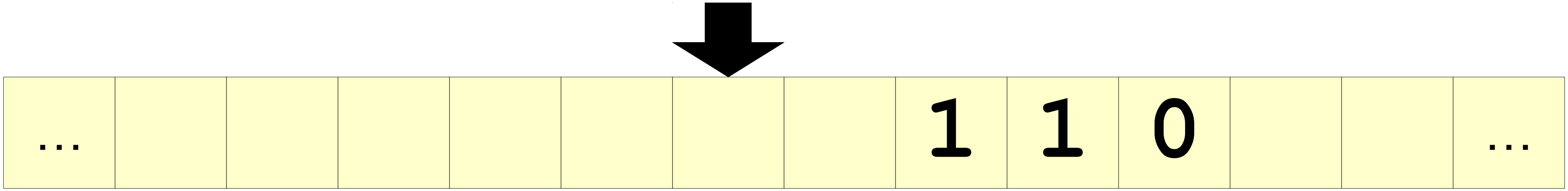
A Caveat



A Caveat

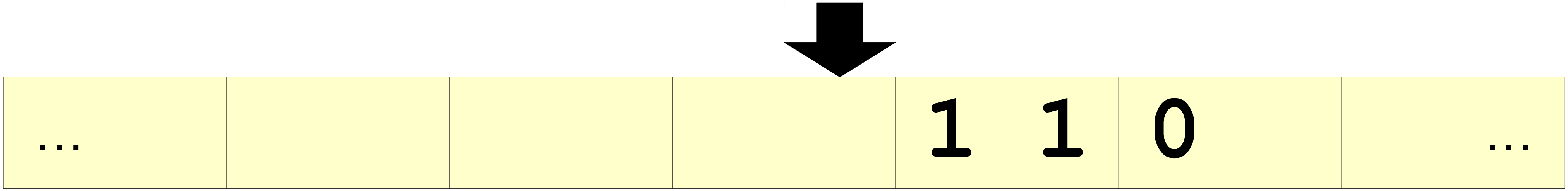


A Caveat

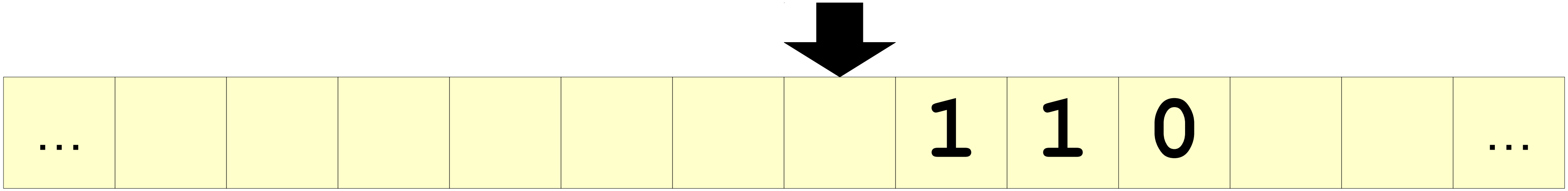


How do we know that this blank isn't one of the infinitely many blanks after our input string?

A Caveat

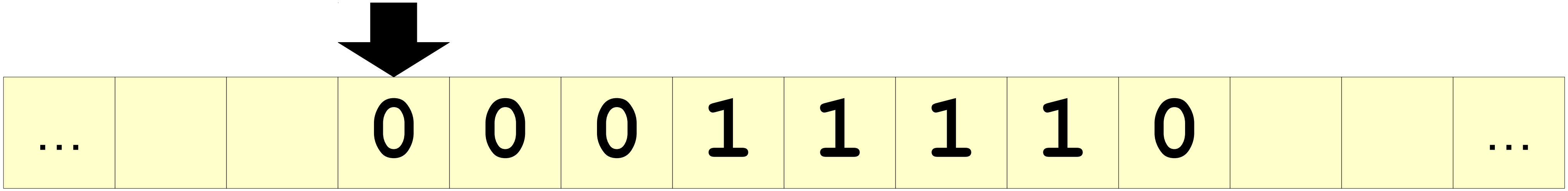


A Caveat

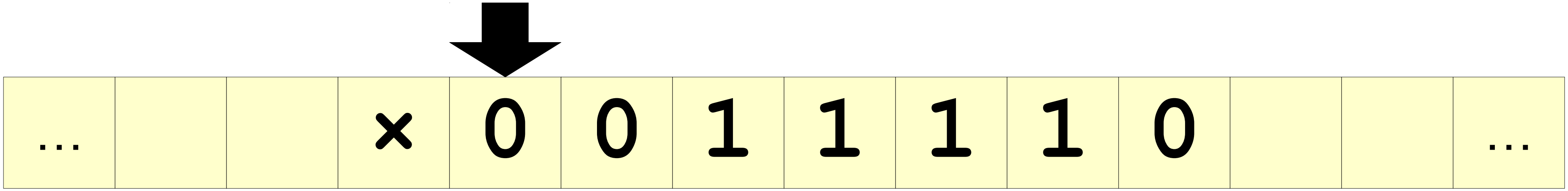


How do we know that this blank isn't one of the infinitely many blanks after our input string?

The Solution

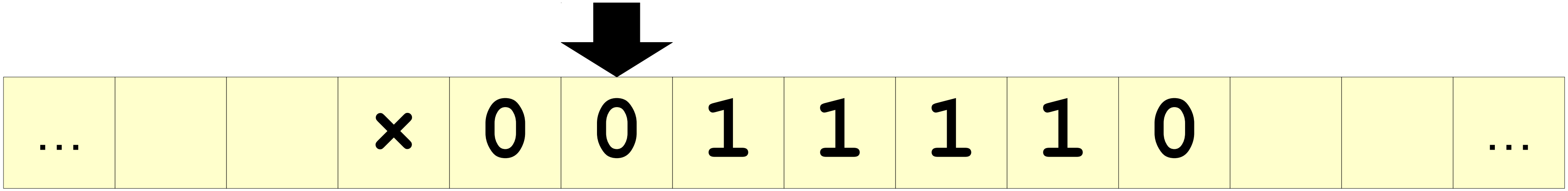


The Solution

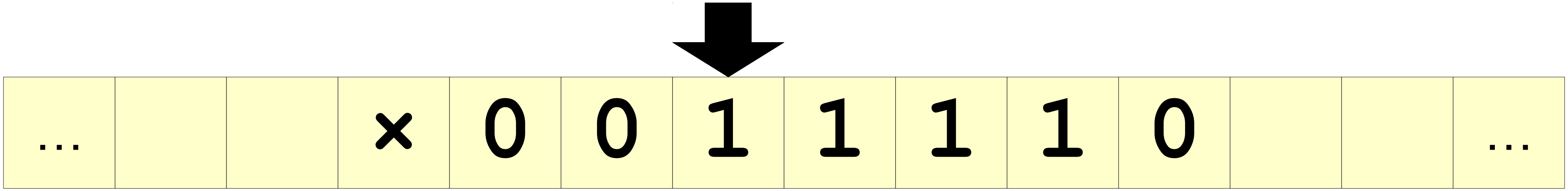


…			×	0	0	1	1	1	1	0			…

The Solution

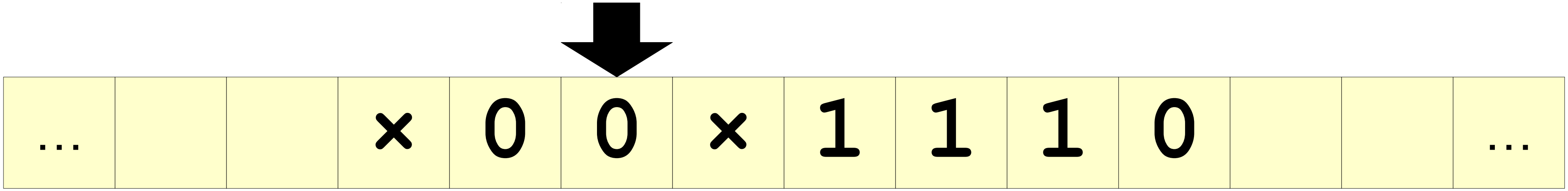


The Solution

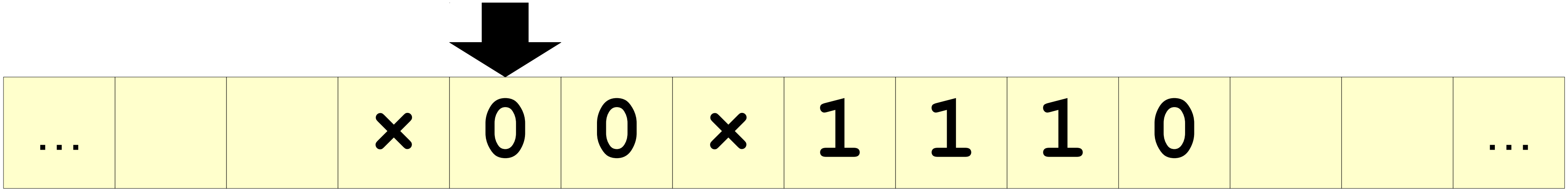


…			×	0	0	1	1	1	1	0			…

The Solution

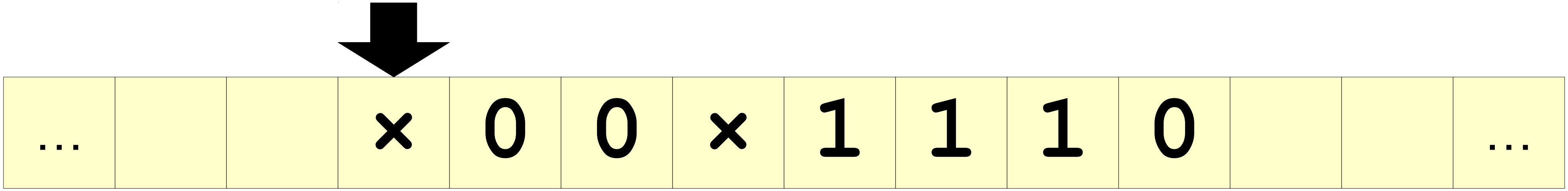


The Solution

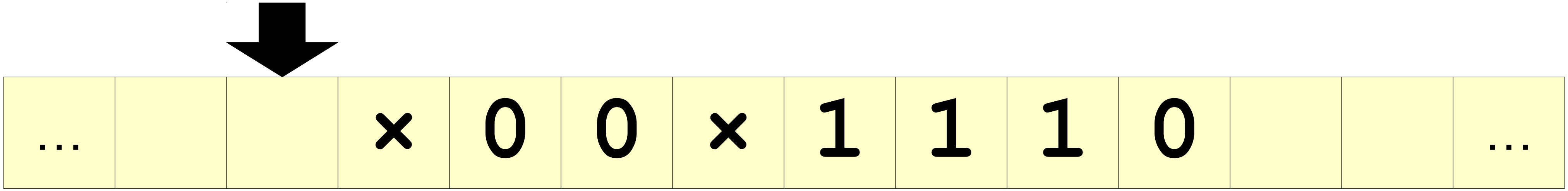


…			×	0	0	×	1	1	1	0			…

The Solution

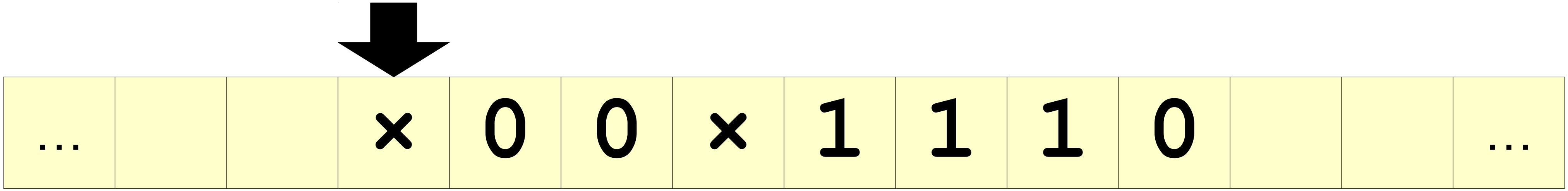


The Solution



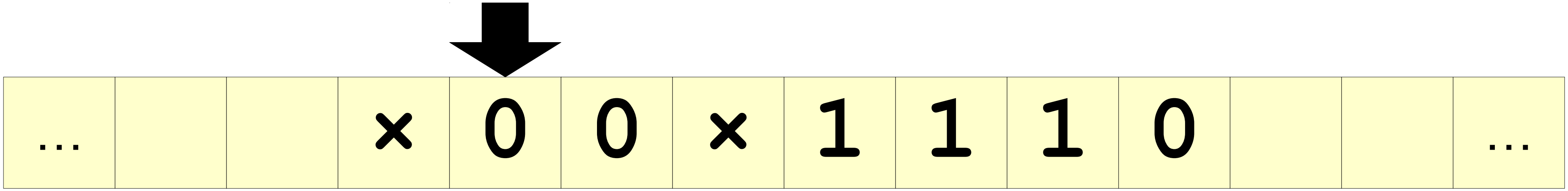
…			×	0	0	×	1	1	1	0			…

The Solution



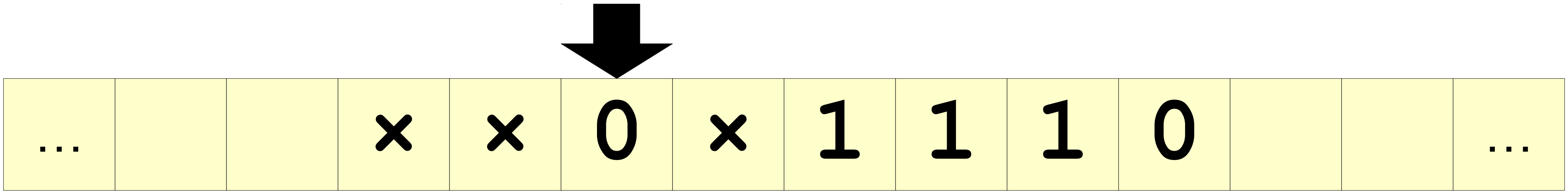
…			×	0	0	×	1	1	1	0			…

The Solution



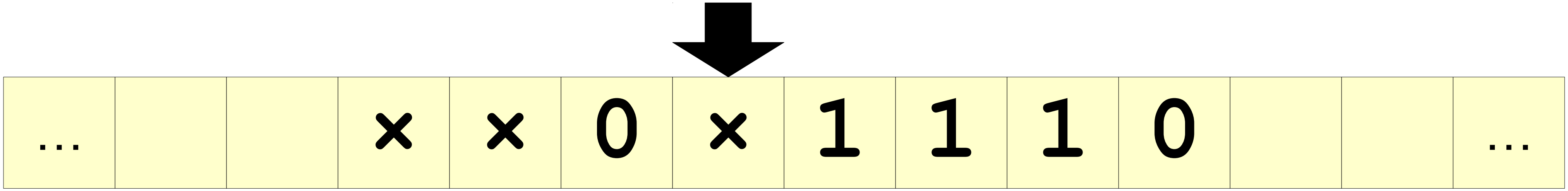
…			×	0	0	×	1	1	1	0			…

The Solution



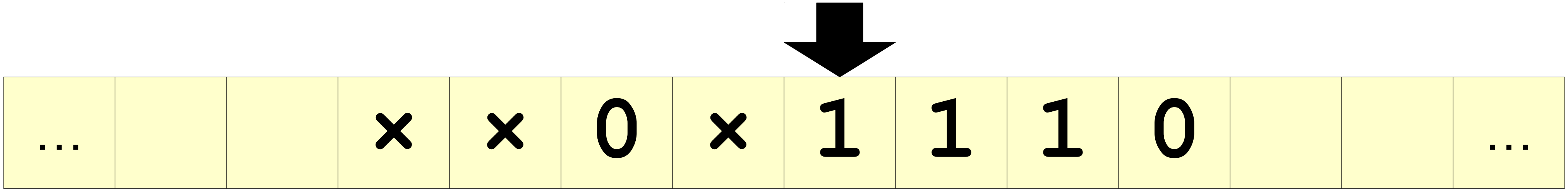
…			×	×	0	×	1	1	1	0			…

The Solution



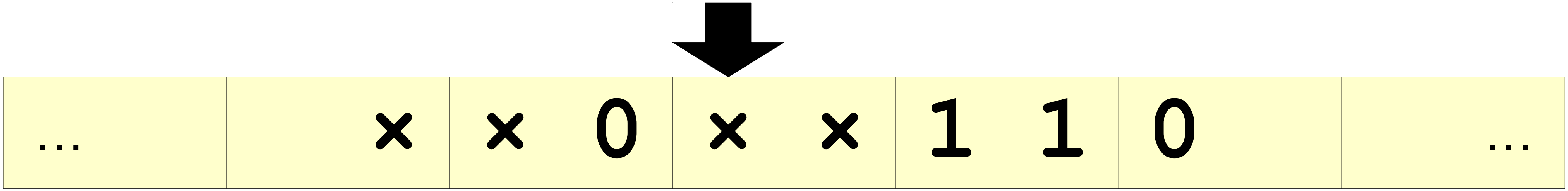
…			×	×	0	×	1	1	1	0			…

The Solution



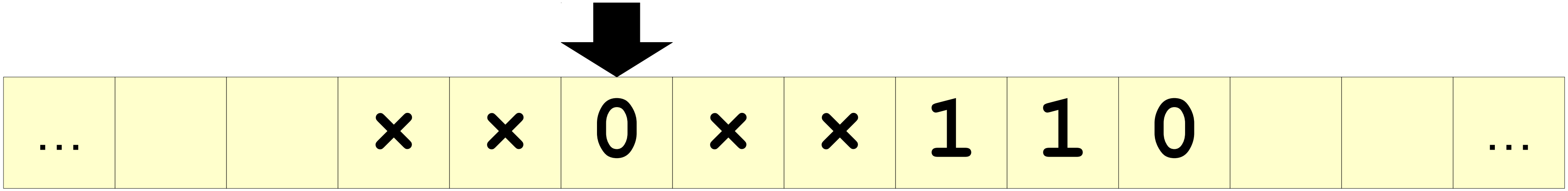
…			×	×	0	×	1	1	1	0			…

The Solution



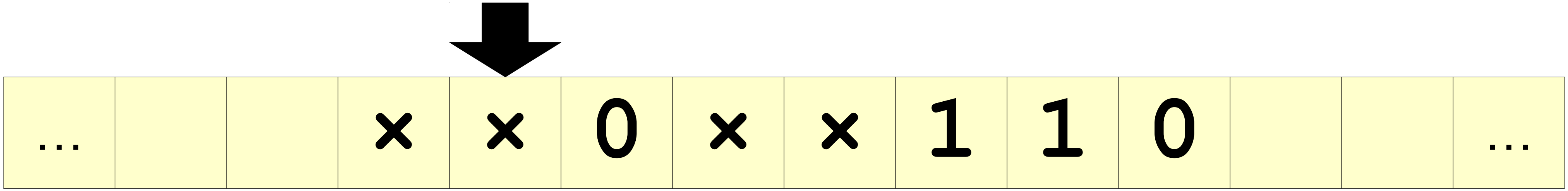
…			×	×	0	×	×	1	1	0			…

The Solution

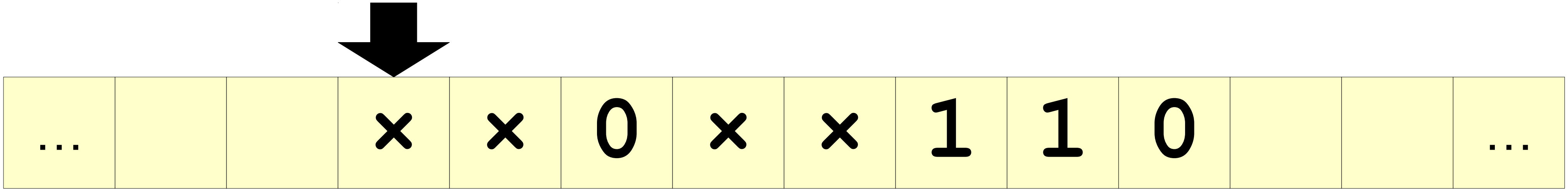


…			×	×	0	×	×	1	1	0			…

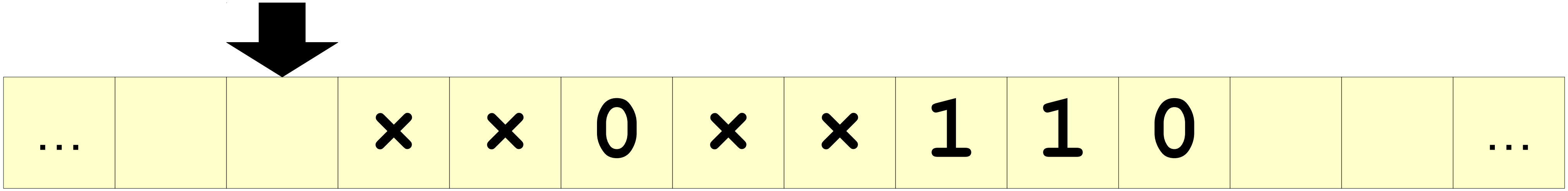
The Solution



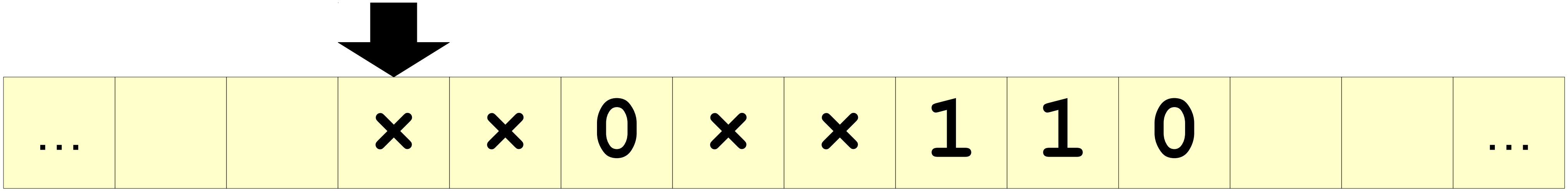
The Solution



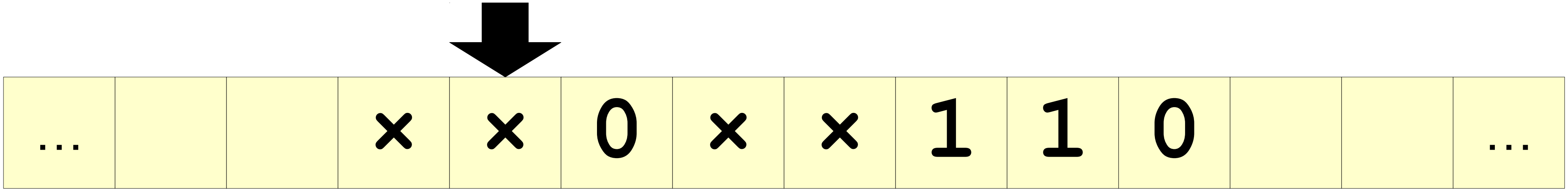
The Solution



The Solution

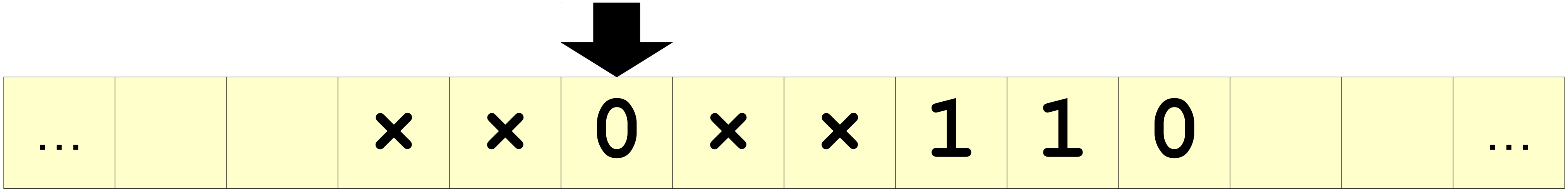


The Solution



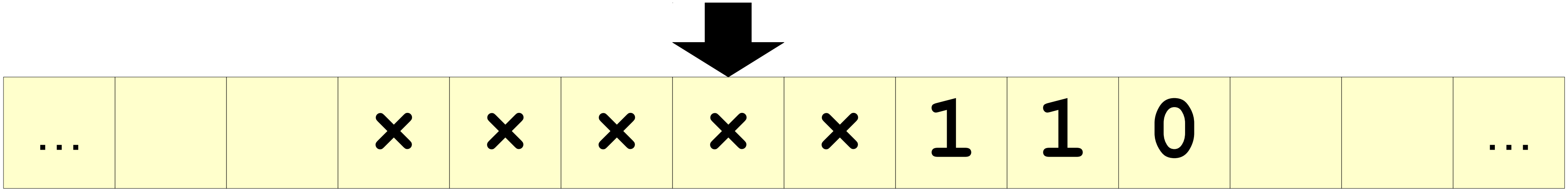
…			×	×	0	×	×	1	1	0			…

The Solution

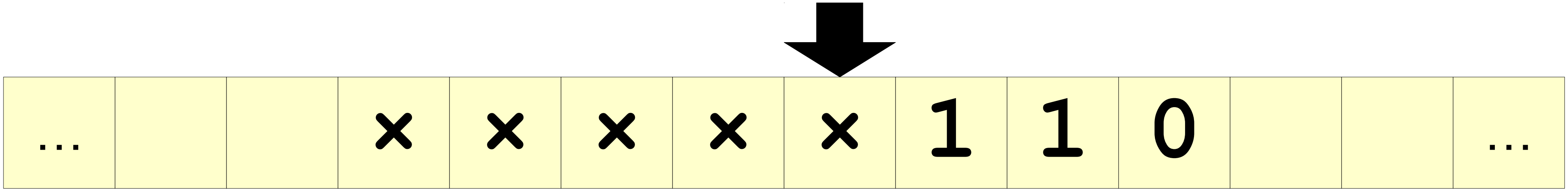


…			×	×	0	×	×	1	1	0			…

The Solution

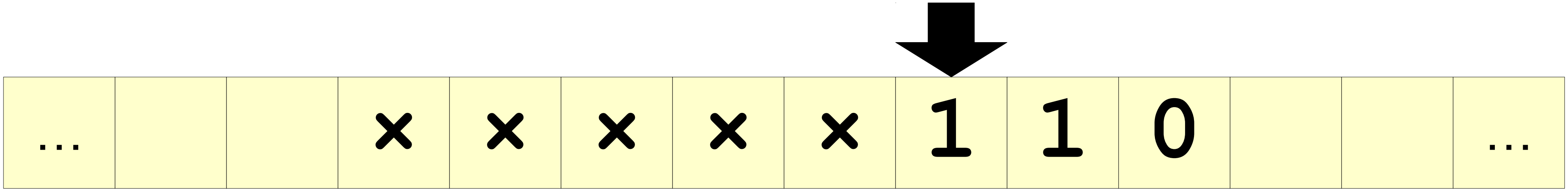


The Solution



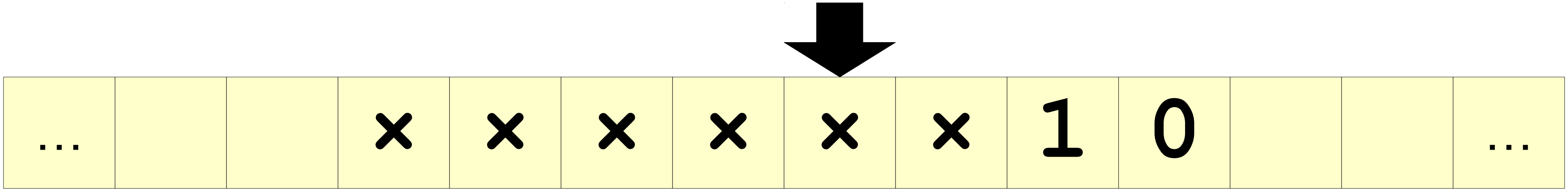
…			×	×	×	×	×	1	1	0			…

The Solution



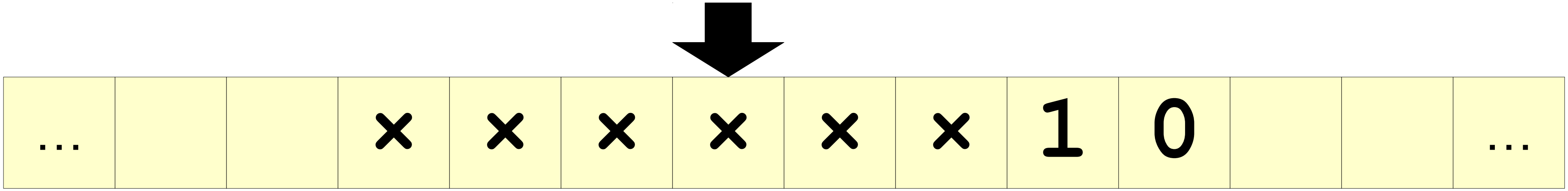
…			×	×	×	×	×	1	1	0			…

The Solution

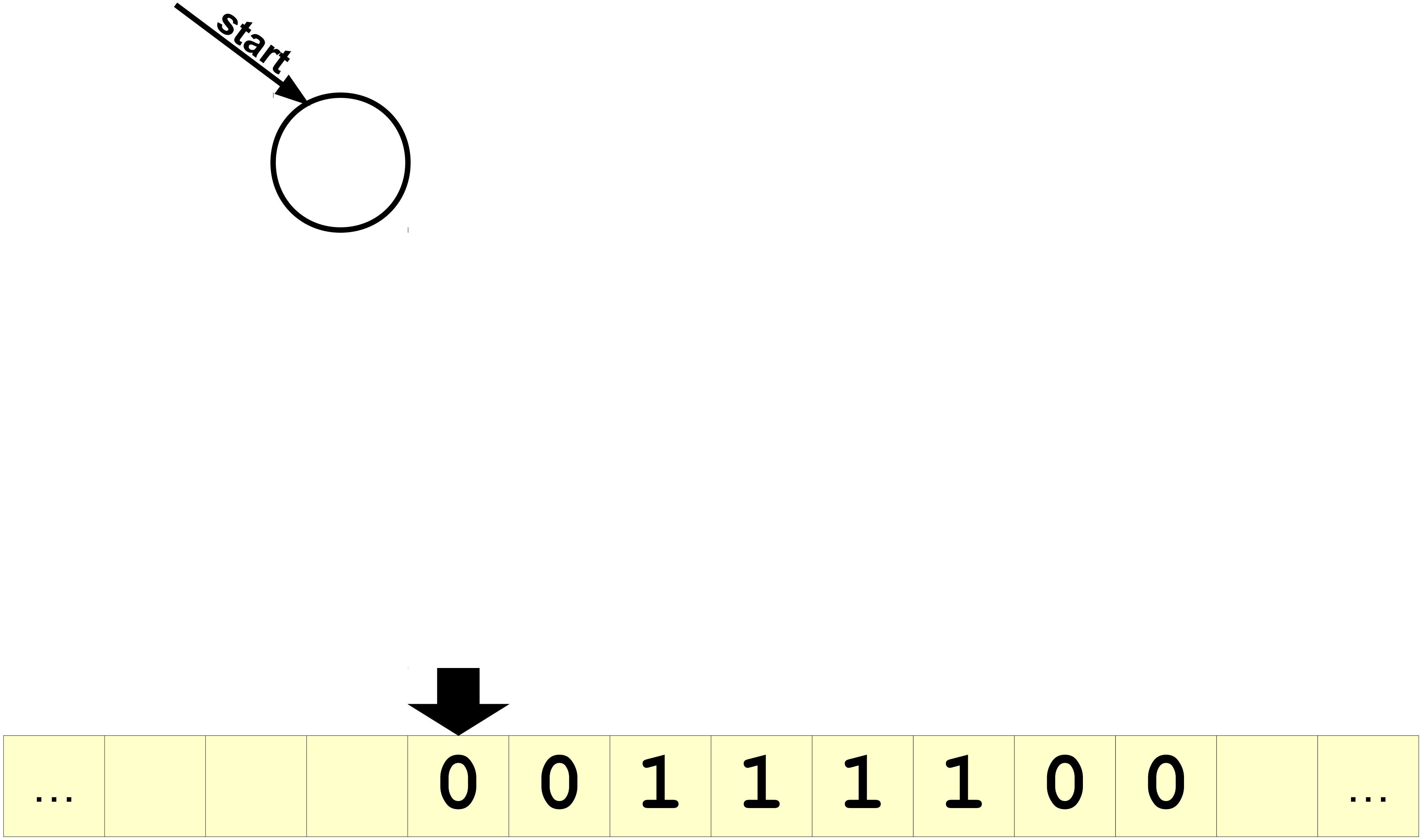


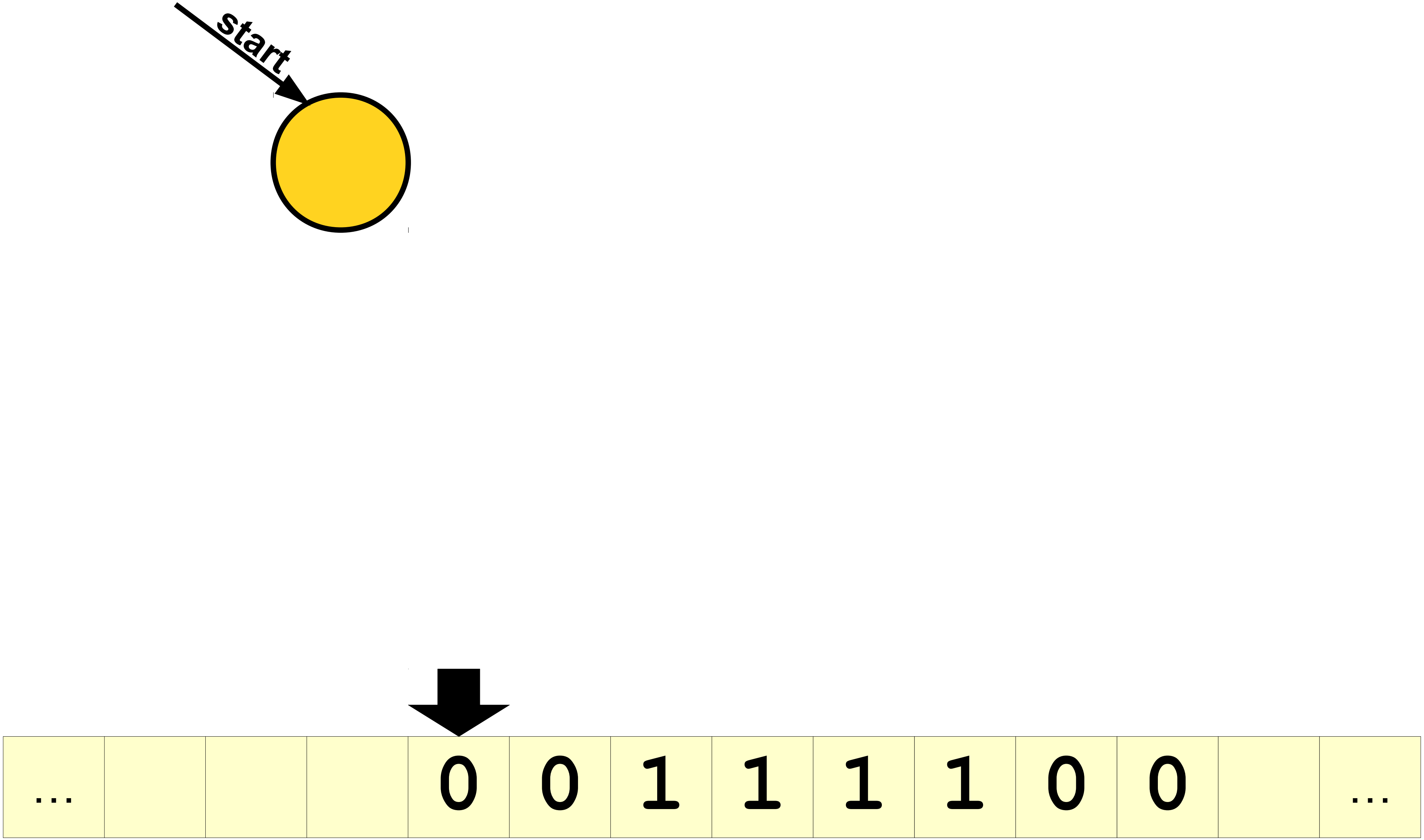
…			×	×	×	×	×	×	1	0			…

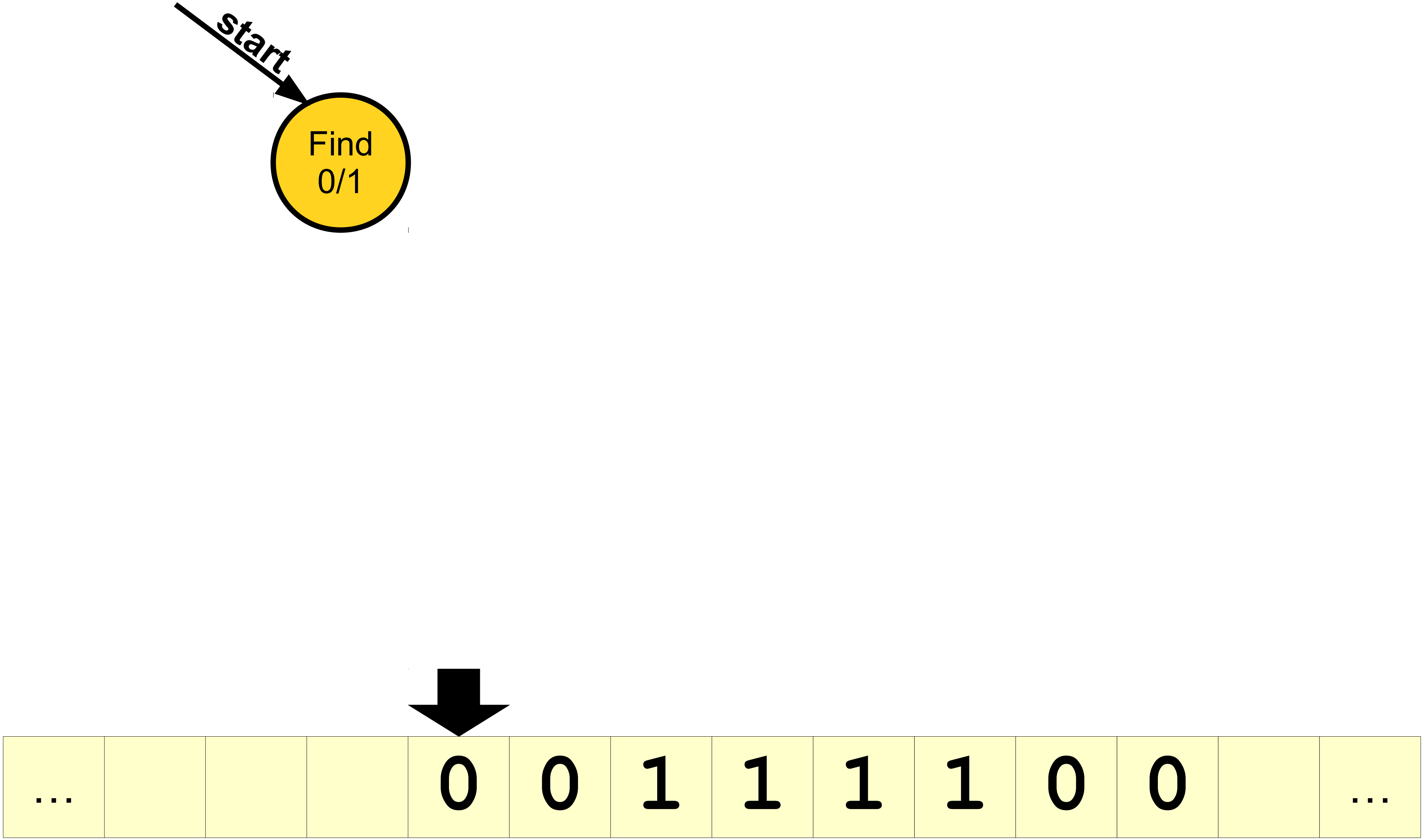
The Solution

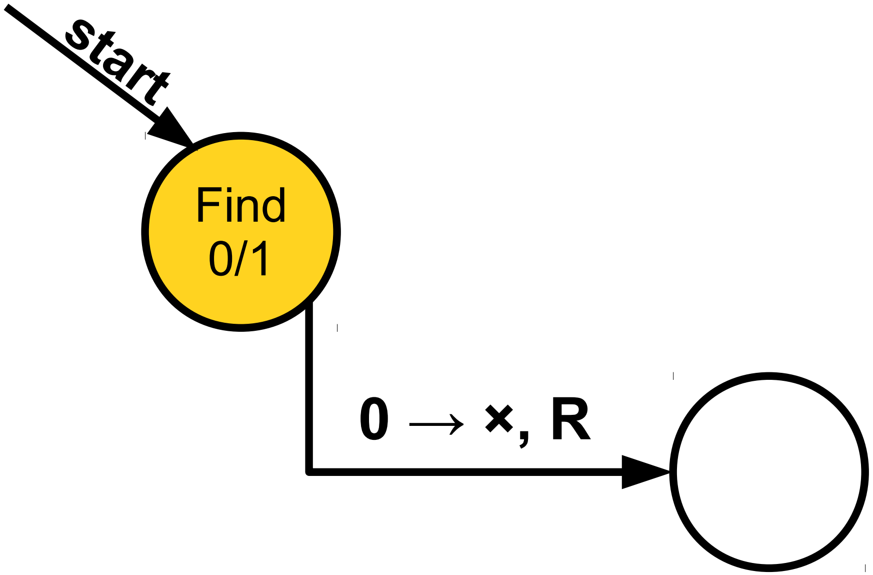


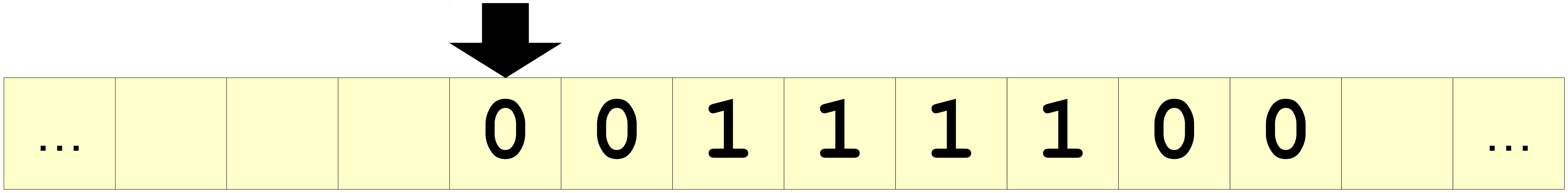
…			×	×	×	×	×	×	1	0			…


start
…
0
0
1
1
1
1
0
0
…

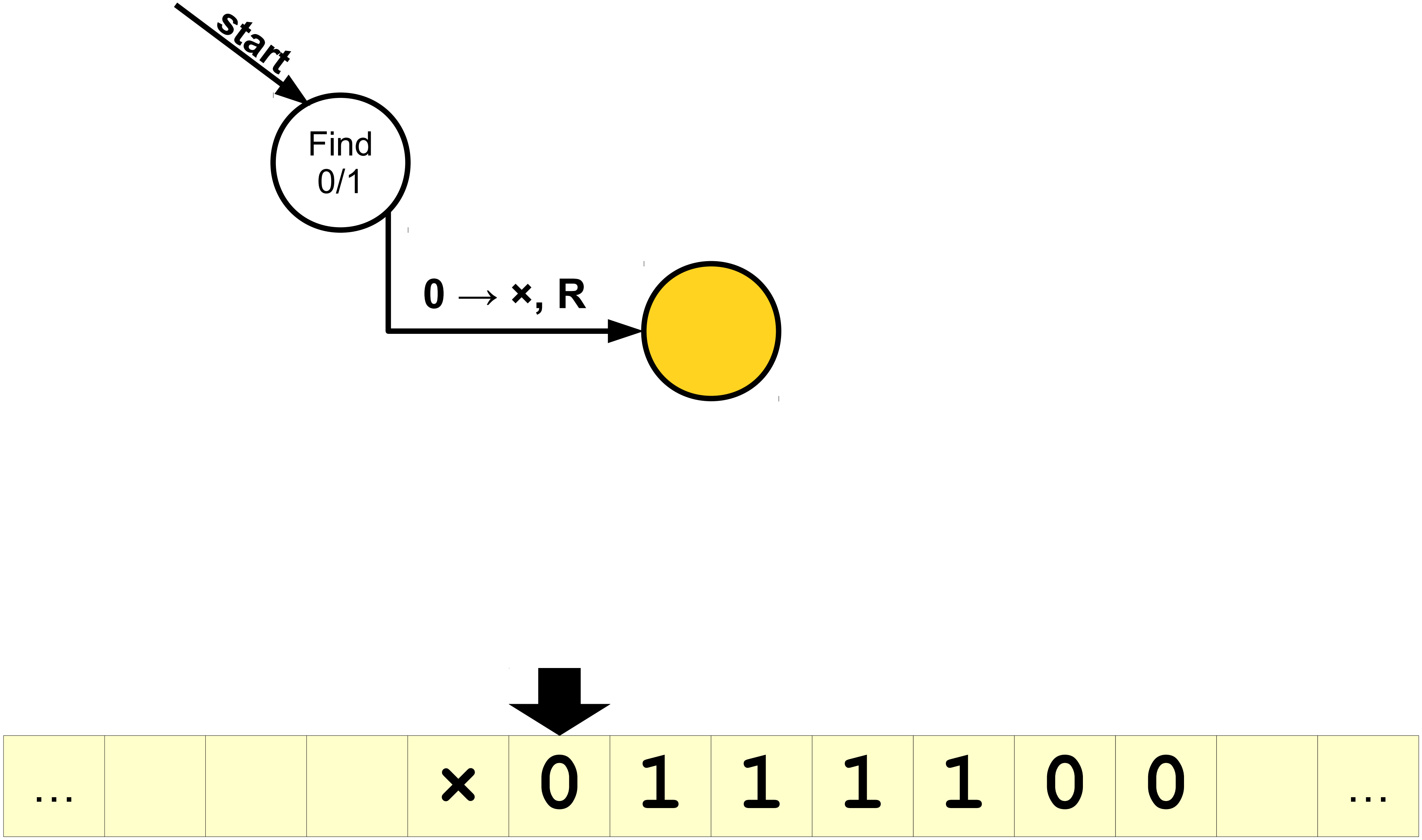

start
…
0 0 1 1 1 1 0 0
…

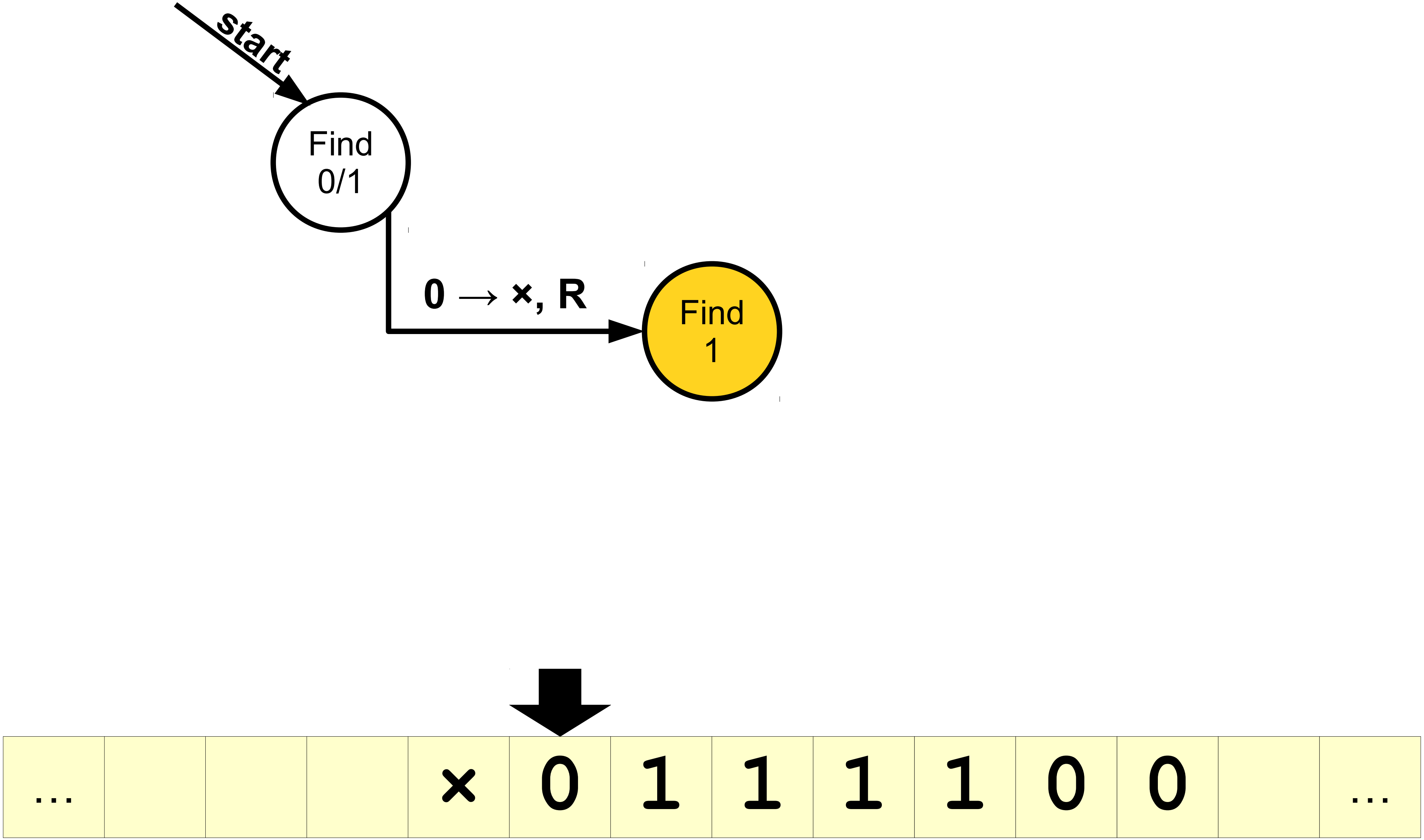

start
Find 0/1
… 0 0 1 1 1 1 0 0 …

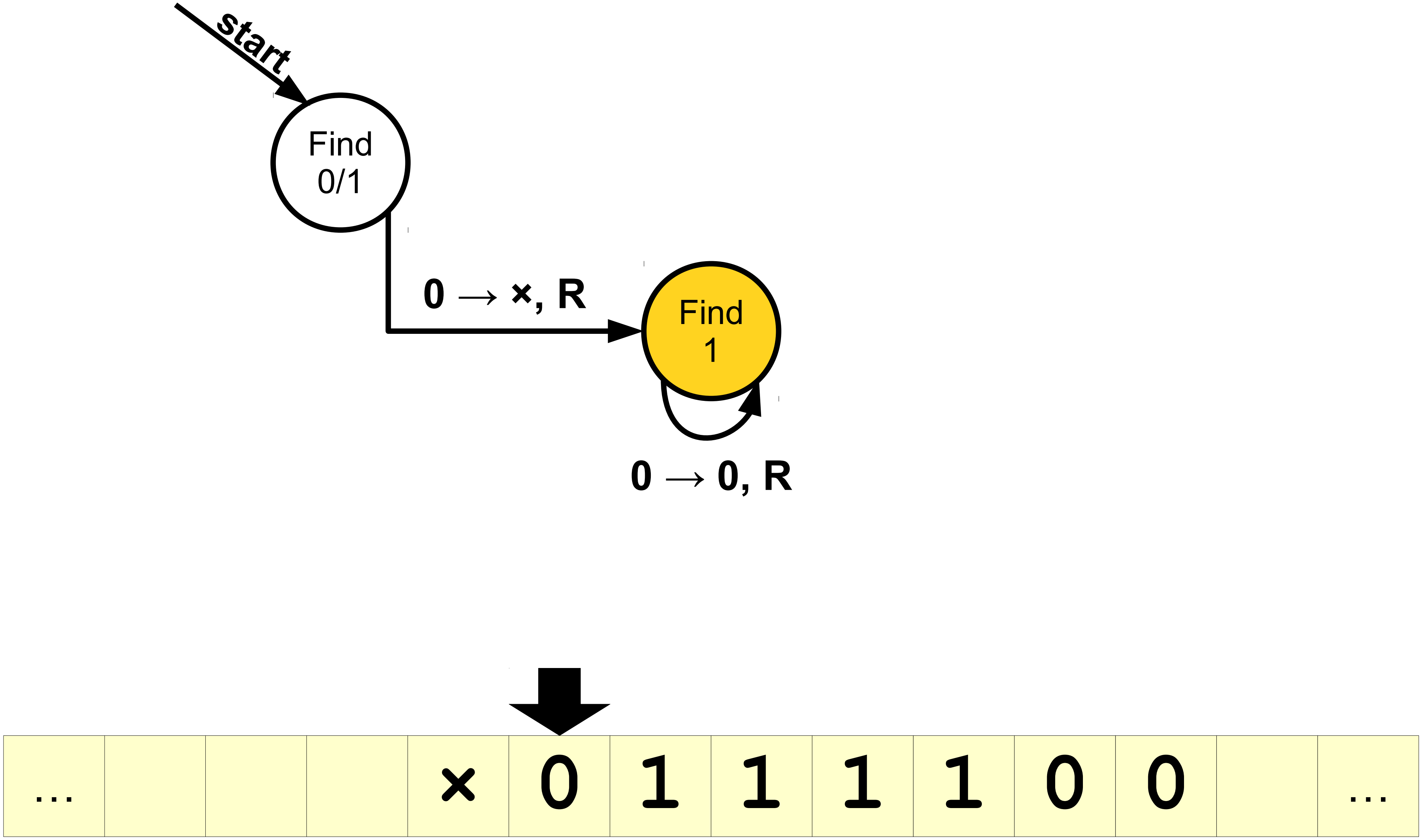


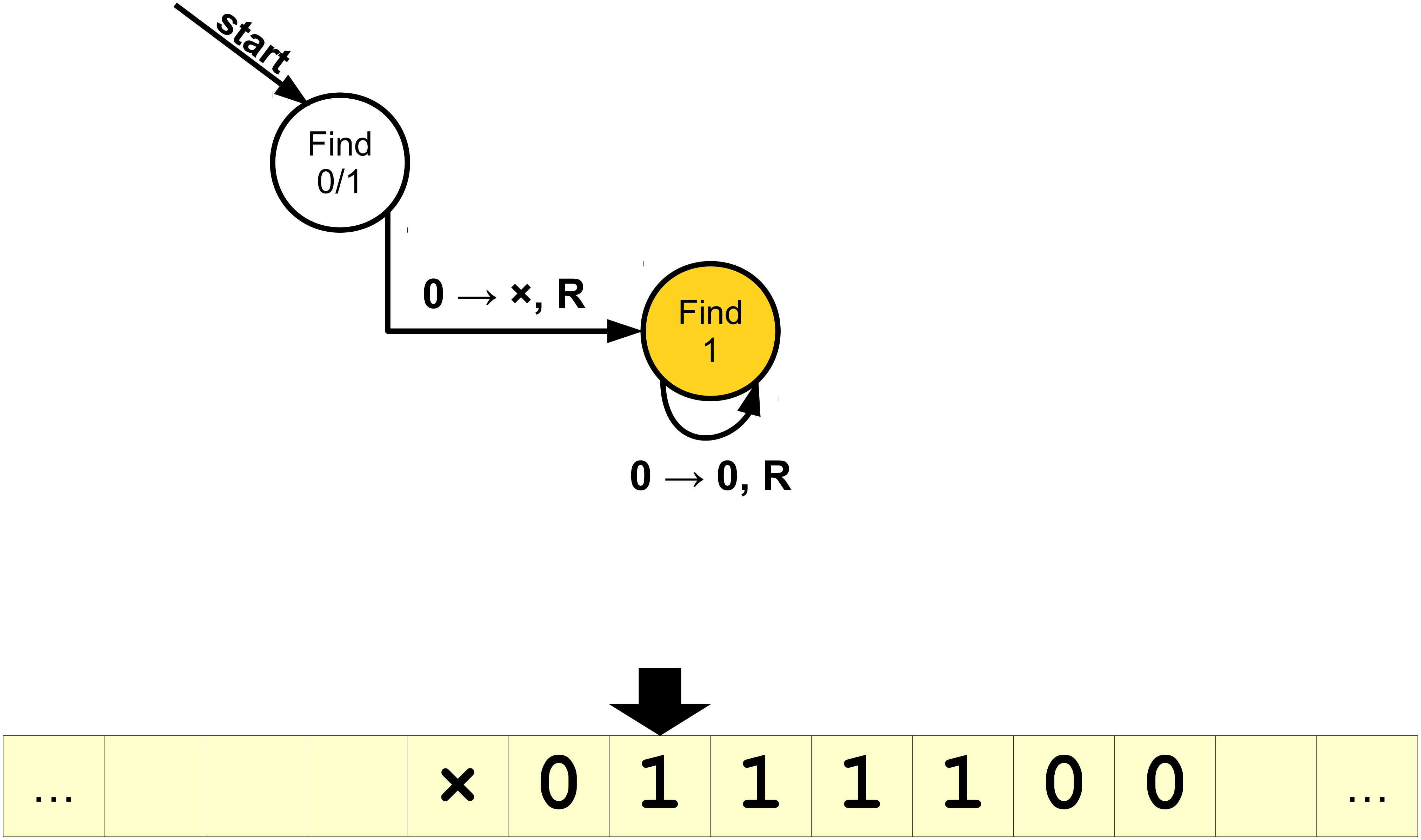


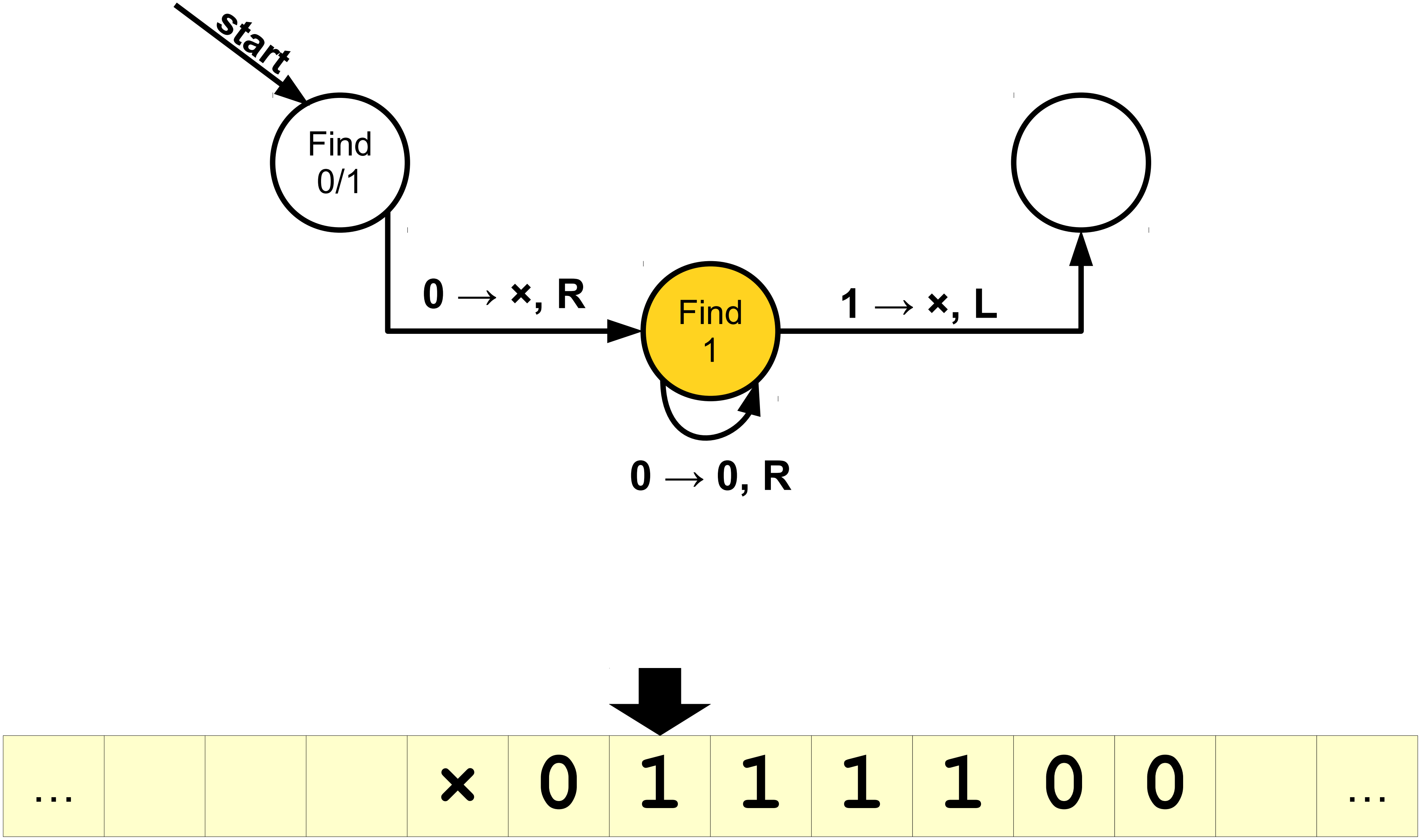
…				0	0	1	1	1	1	0	0		…

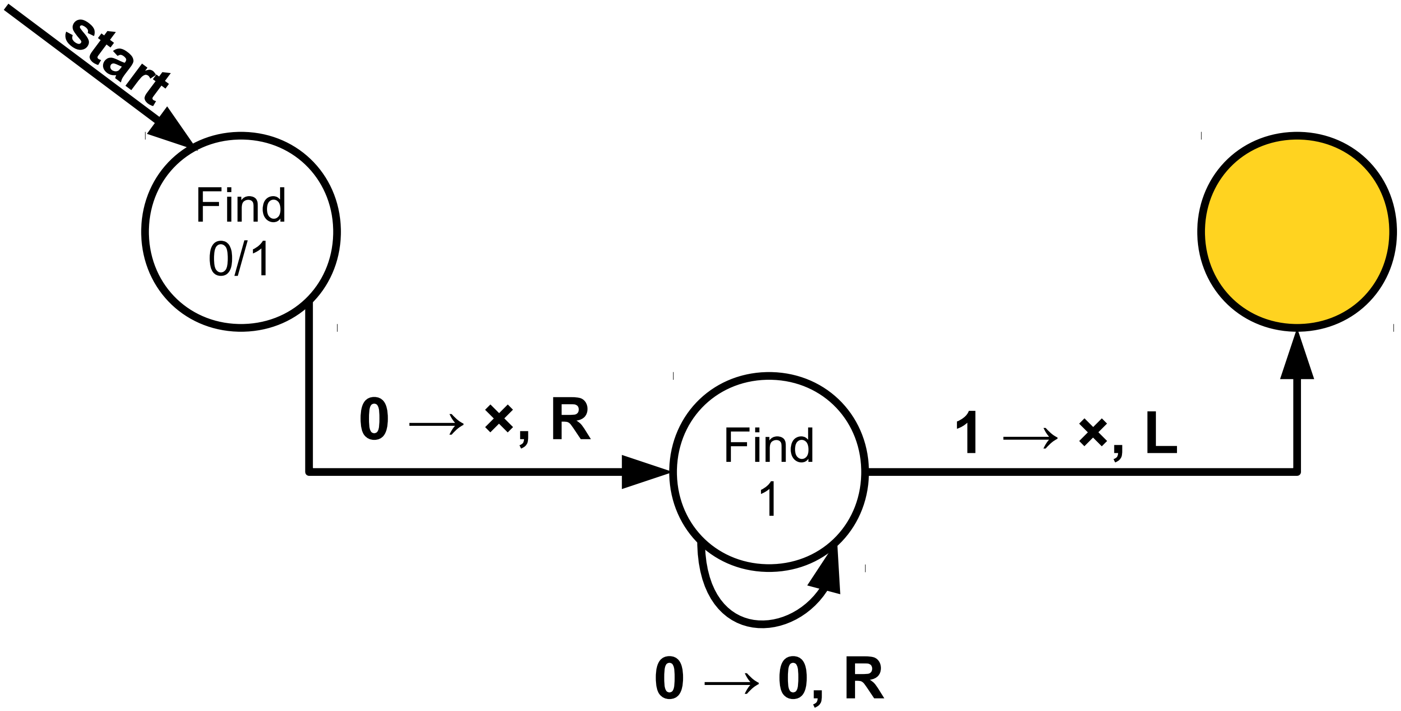

start
Find 0/1
0 → ×, R
…
×
0
1
1
1
1
0
0
…

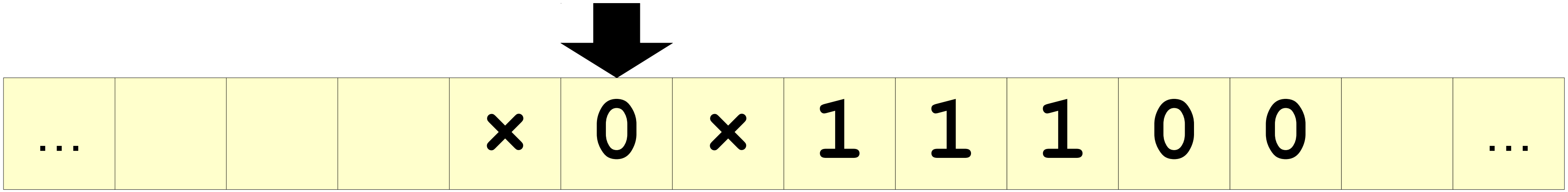

start
Find 0/1
0 → ×, R
Find 1
…
×
0
1
1
1
1
0
0
…


start
Find 0/1
0 → ×, R
Find 1
0 → 0, R
… × 0 1 1 1 1 0 0 …

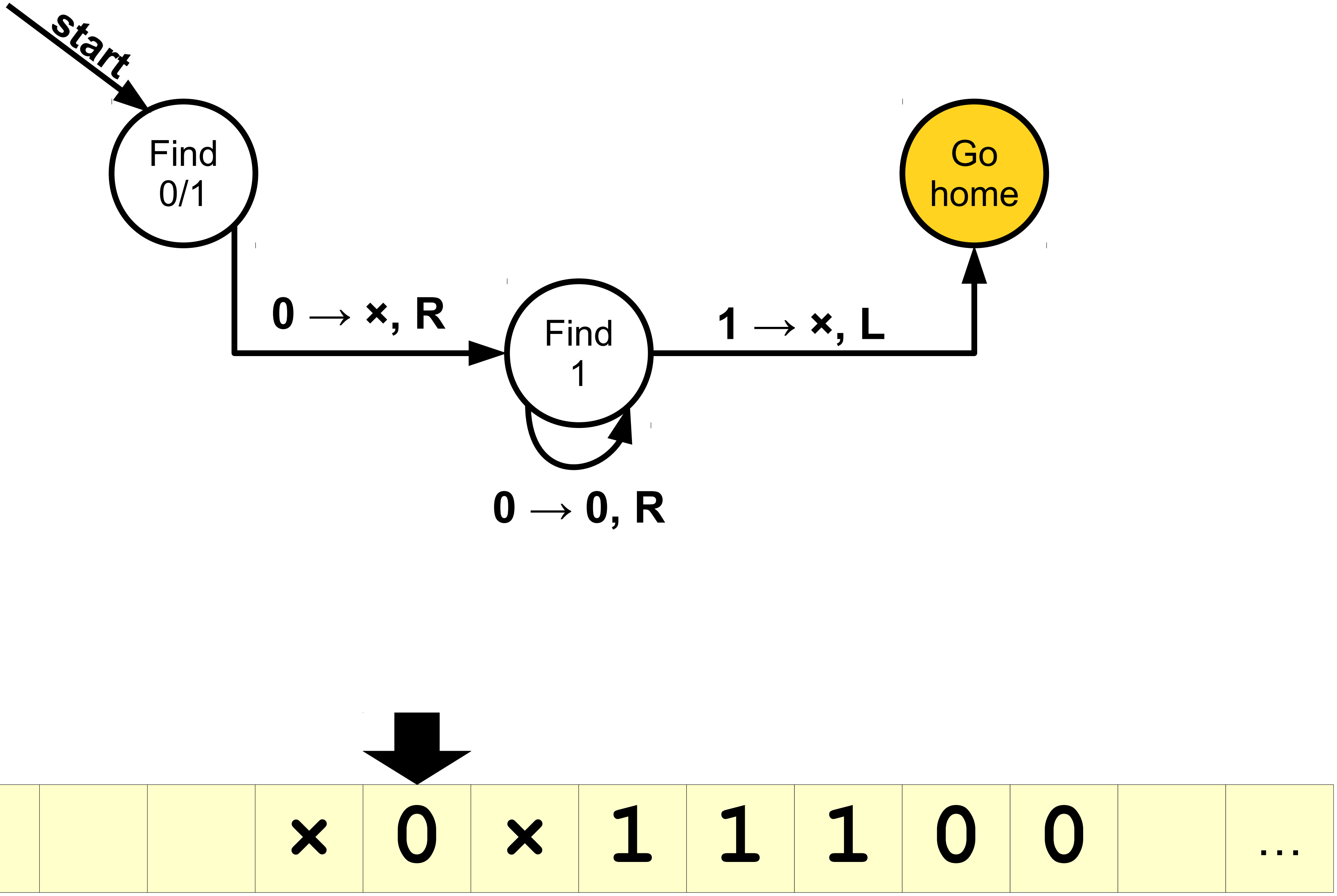

start
Find 0/1
0 → ×, R
Find 1
0 → 0, R
…
×
0
1
1
1
1
0
0
…


start
Find 0/1
0 → ×, R
Find 1
0 → 0, R
1 → ×, L
…
×
0
1
1
1
1
0
0
…

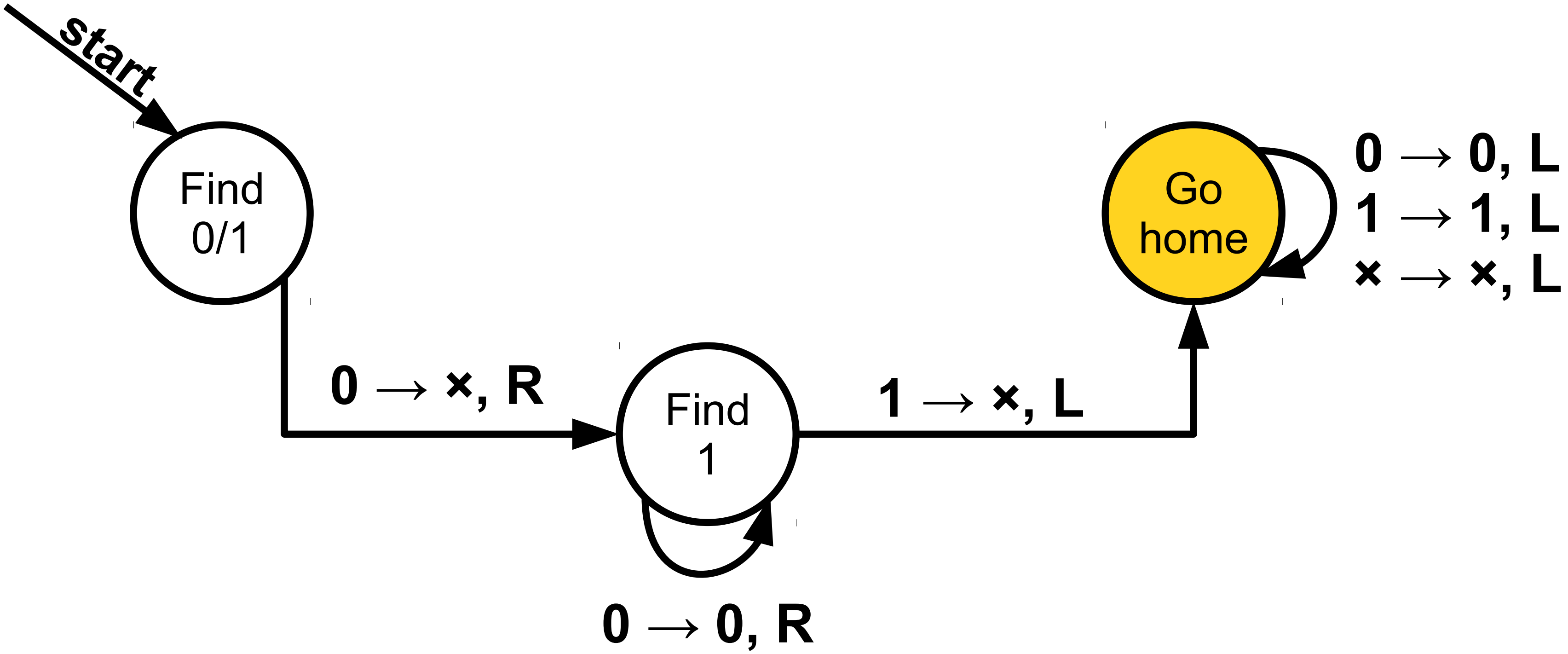


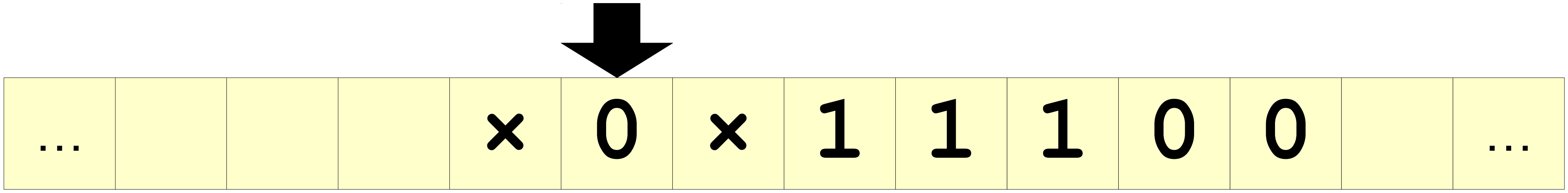


…				×	0	×	1	1	1	0	0		…

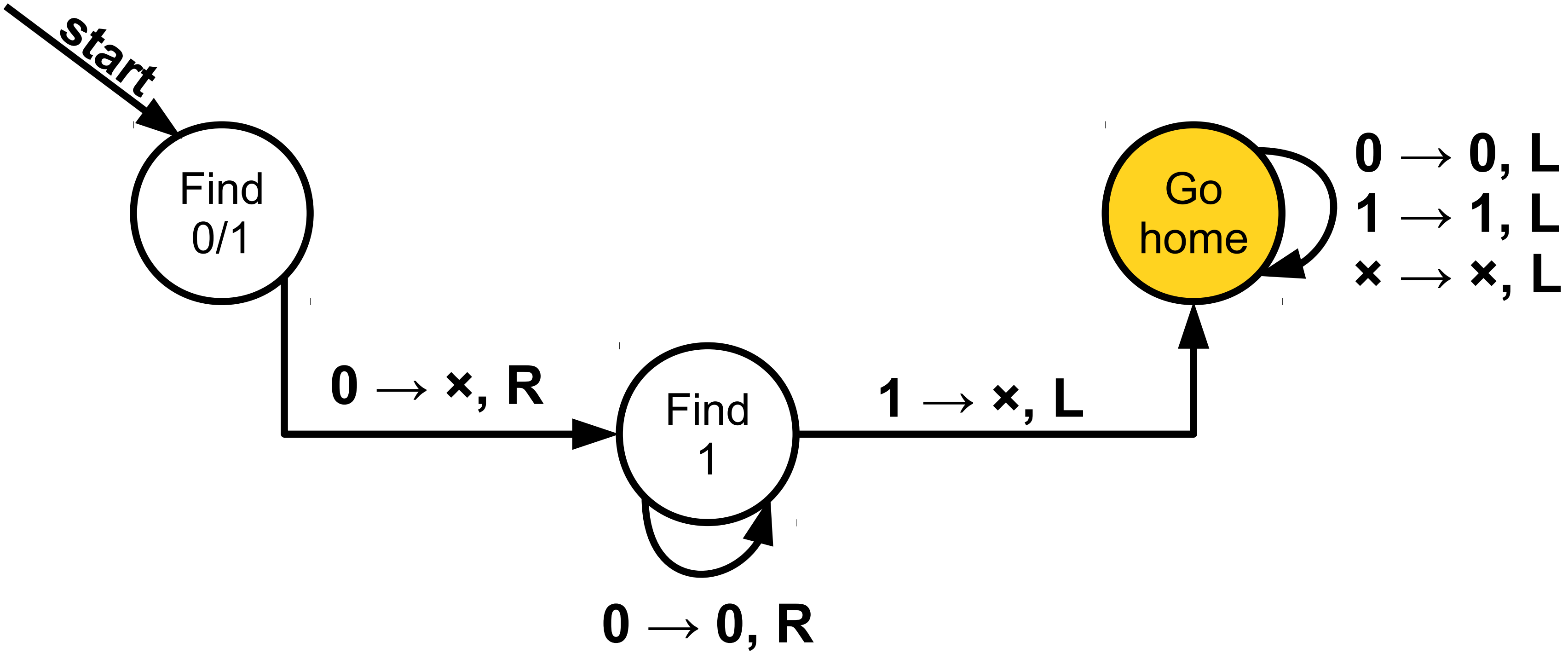


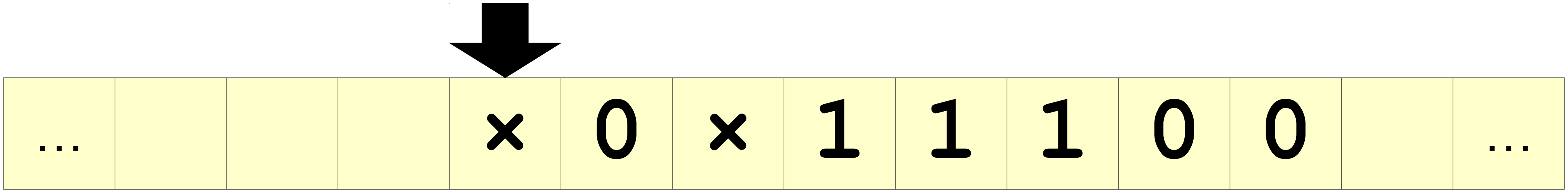
…				×	0	×	1	1	1	0	0		…



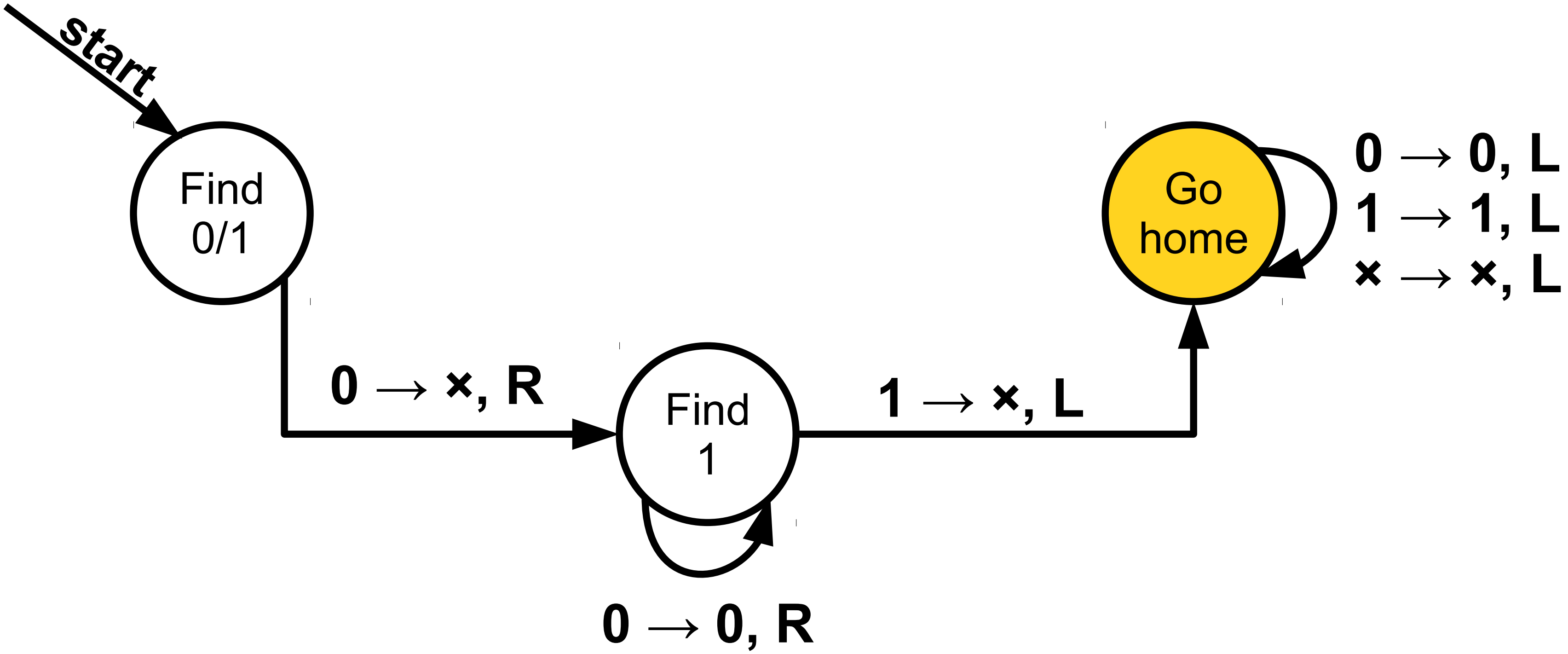


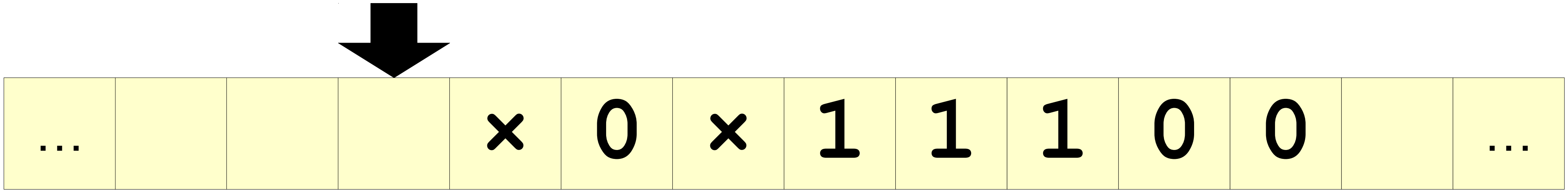
…				×	0	×	1	1	1	0	0		…



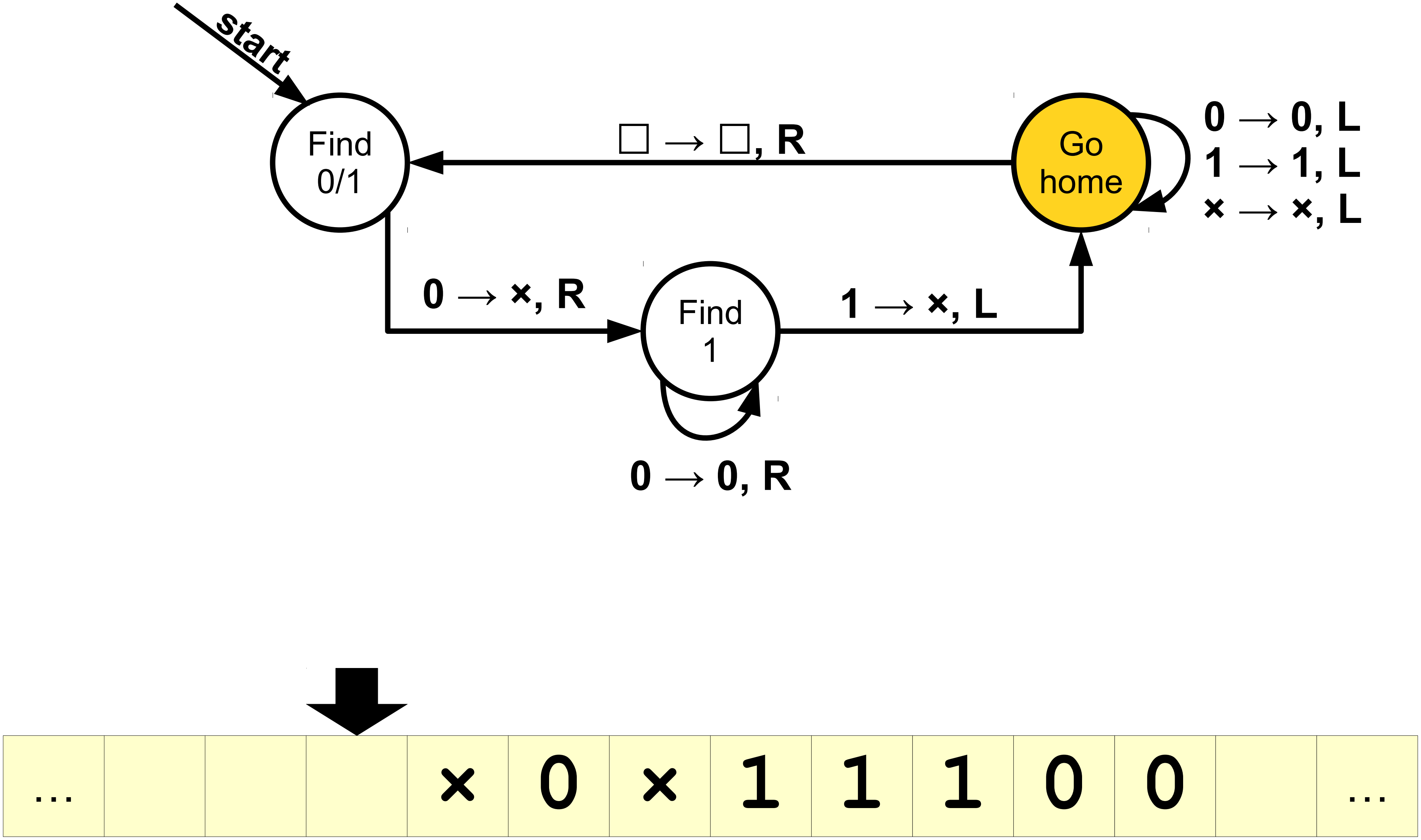


…				×	0	×	1	1	1	0	0		…

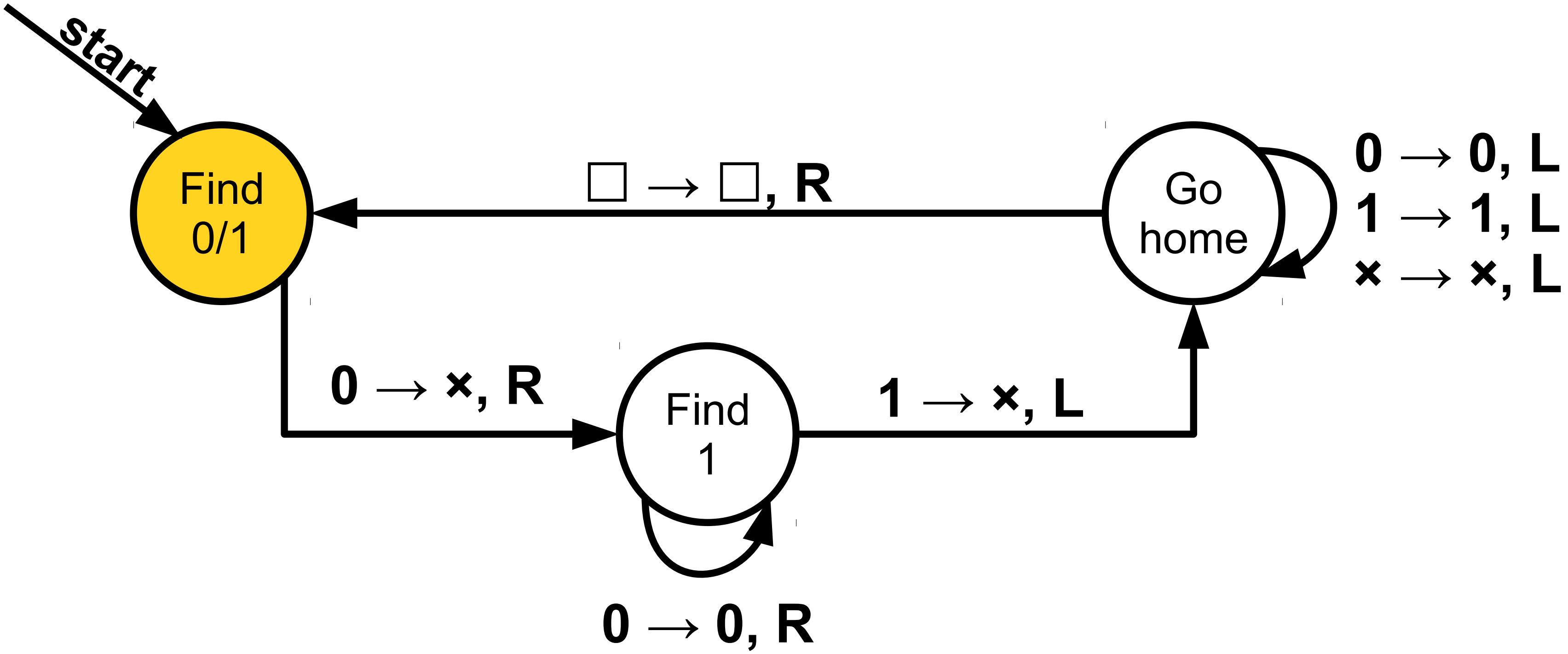




…				×	0	×	1	1	1	0	0		…



…				×	0	×	1	1	1	0	0		…



start

Find 0/1

Go home

Find 1

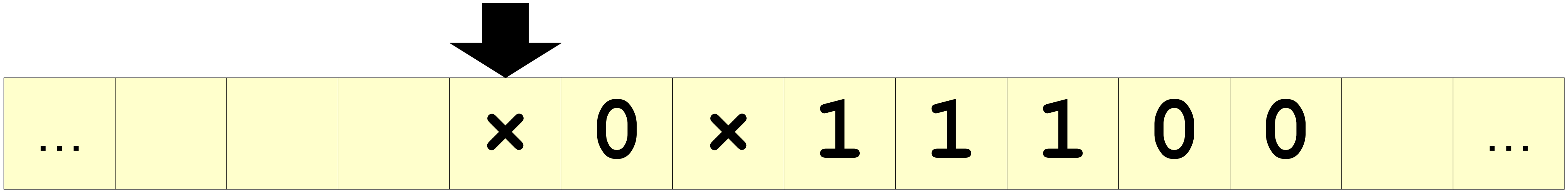
□ → □, R

0 → 0, L
1 → 1, L
× → ×, L

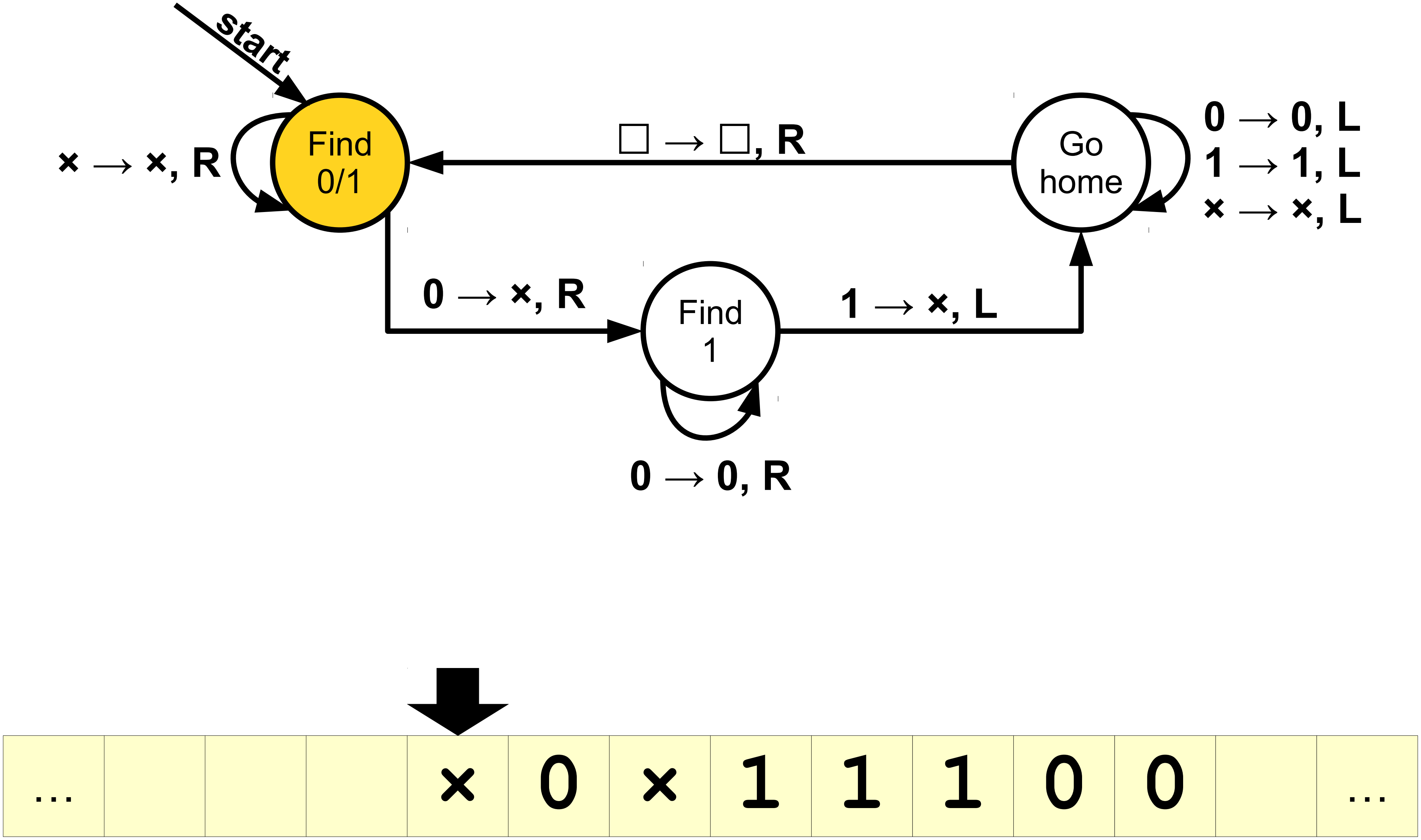
0 → ×, R

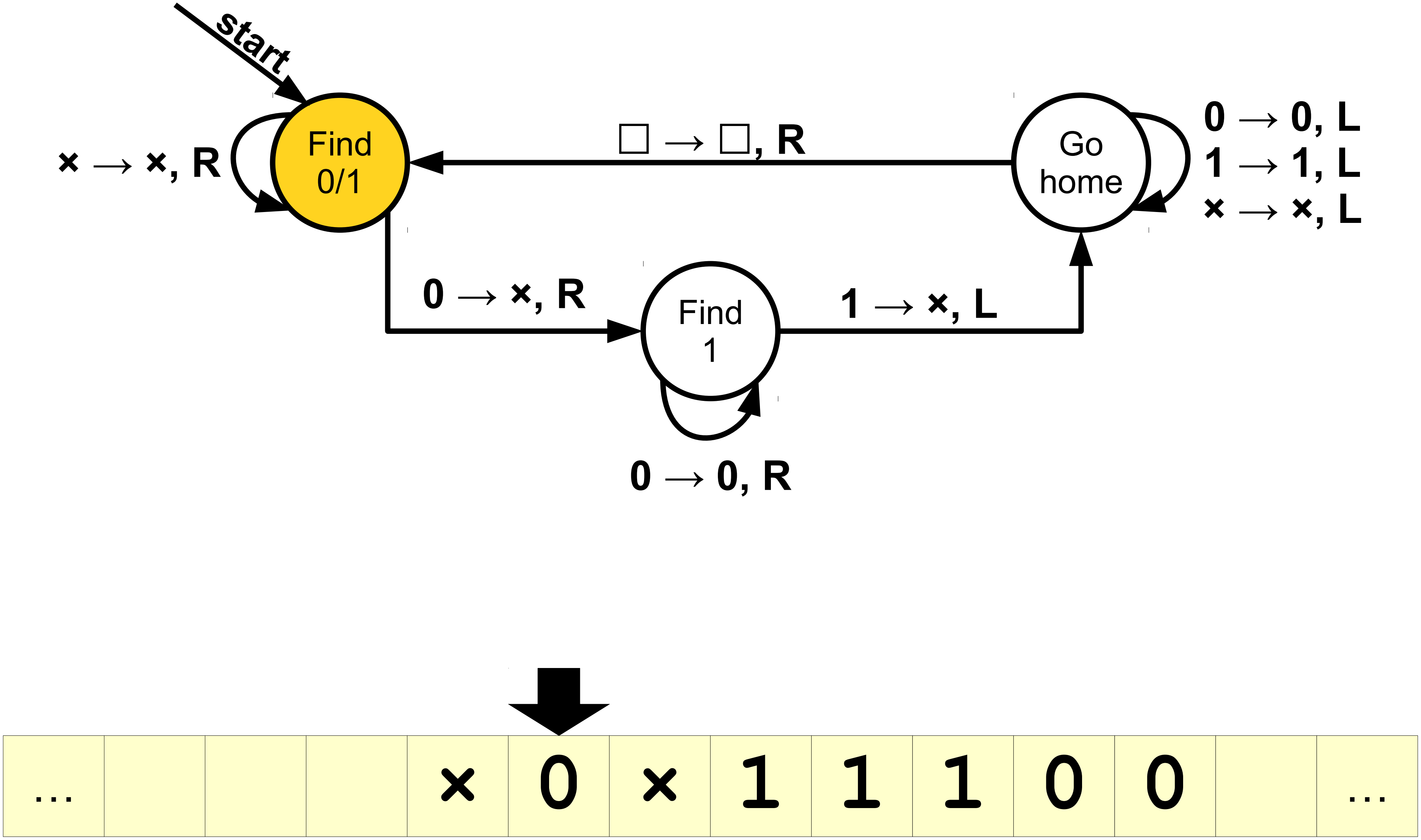
1 → ×, L

0 → 0, R

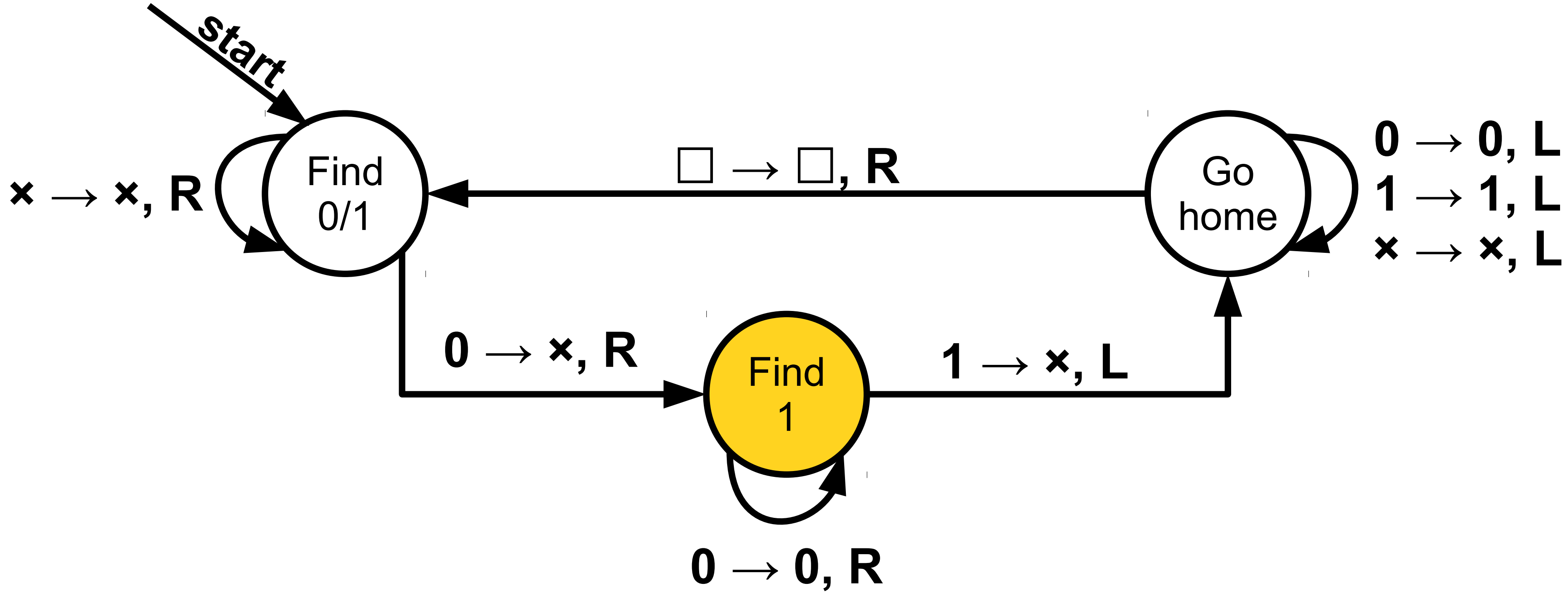


…				×	0	×	1	1	1	0	0		…

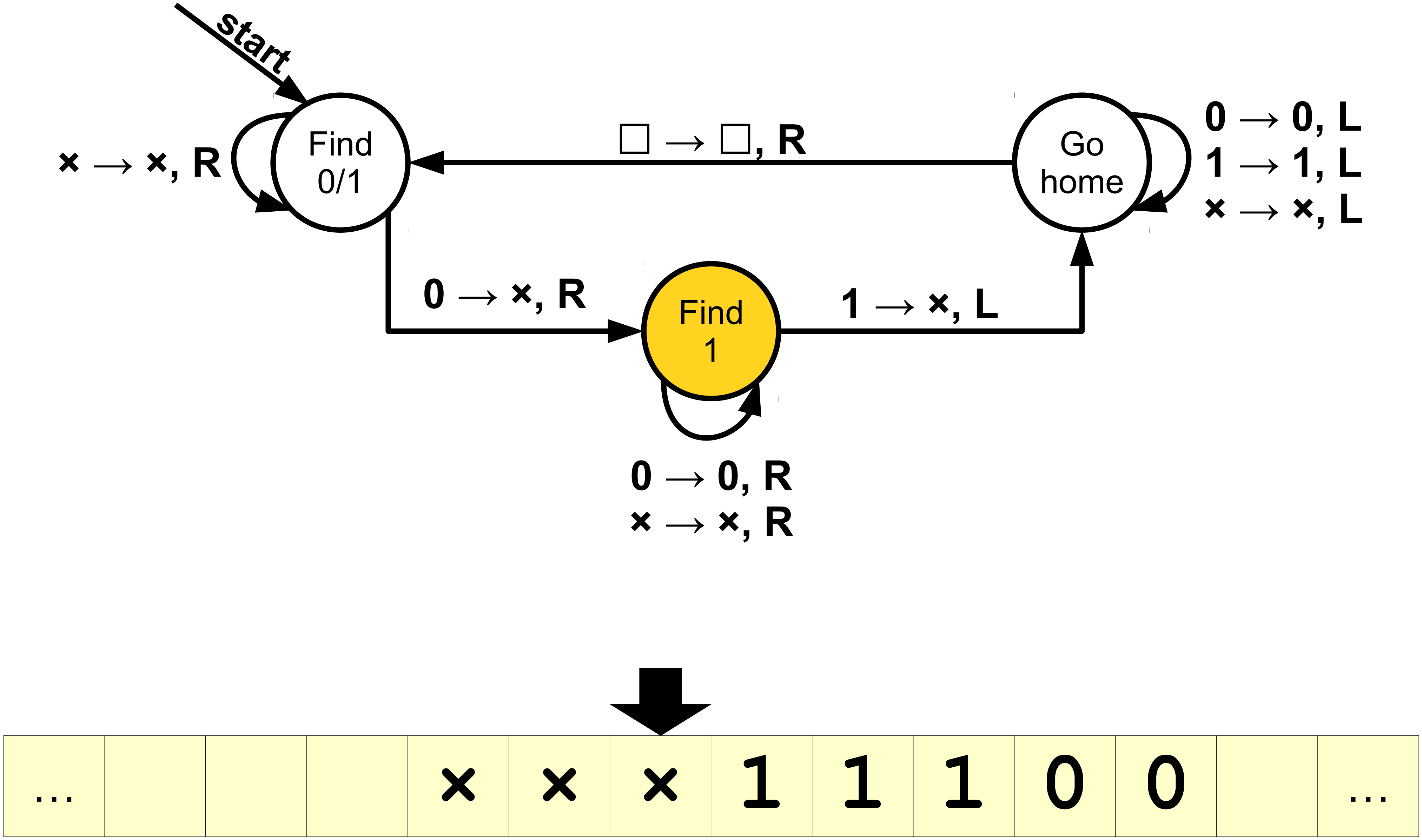

start
Find 0/1
× → ×, R
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
…
×
0
×
1
1
1
0
0
…



…				×	0	×	1	1	1	0	0		…



…				×	×	×	1	1	1	0	0		…



start

Find 0/1

× → ×, R

□ → □, R

Go home

0 → 0, L
1 → 1, L
× → ×, L

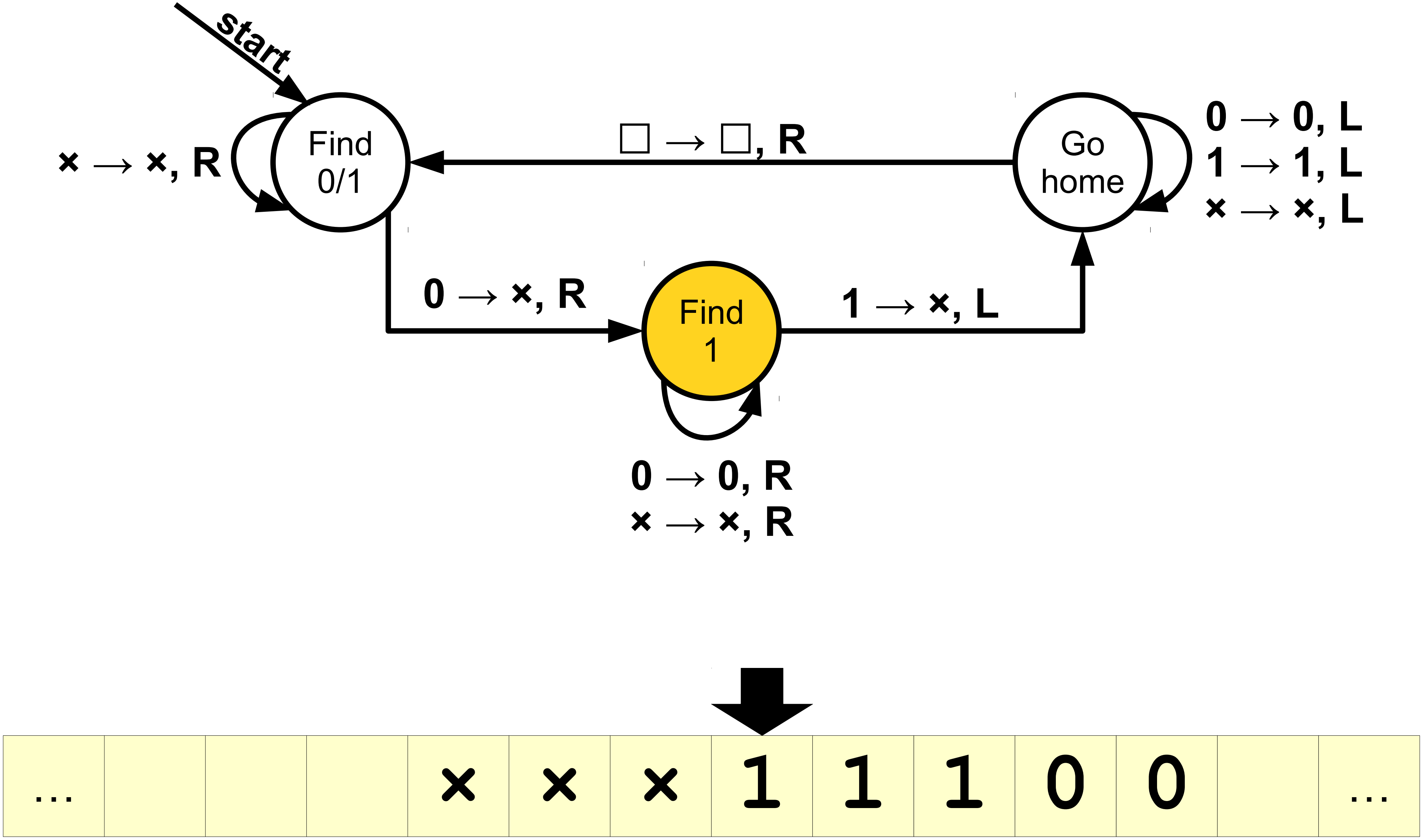
0 → ×, R

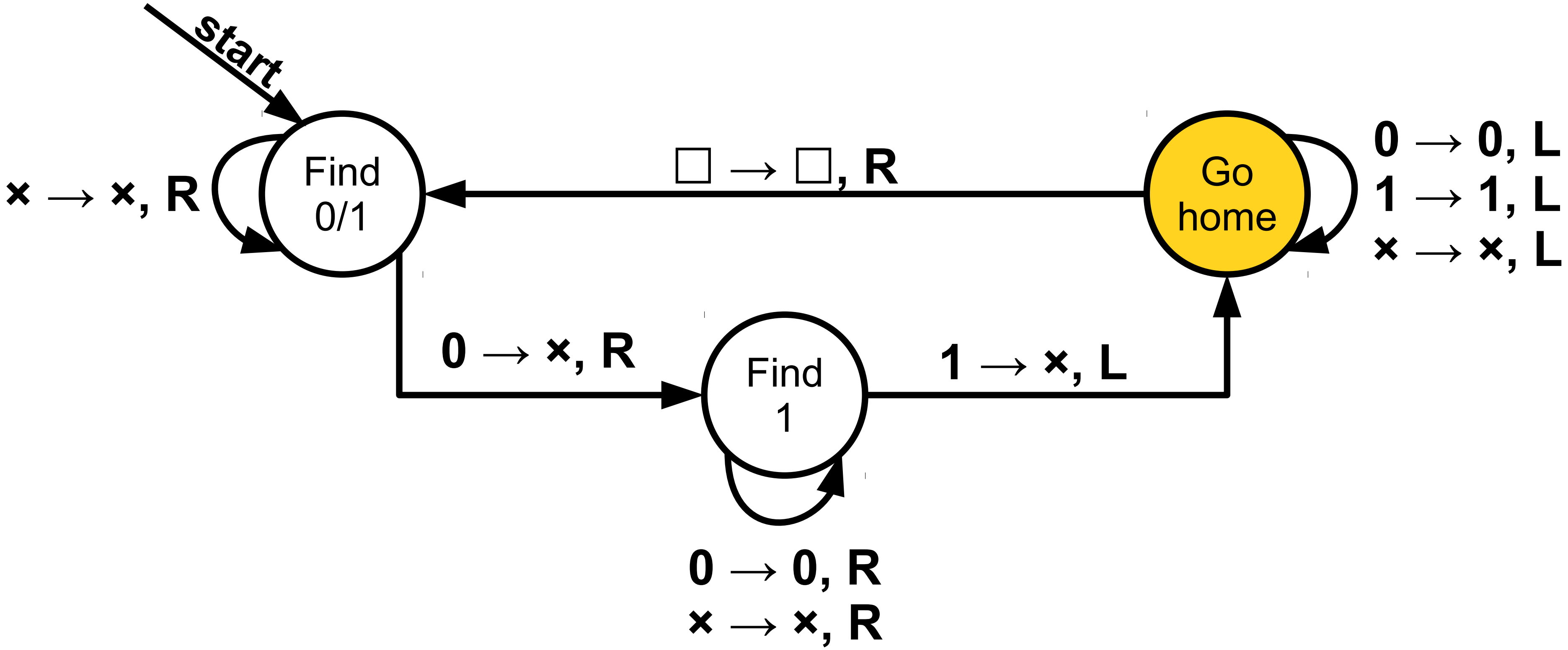
Find 1

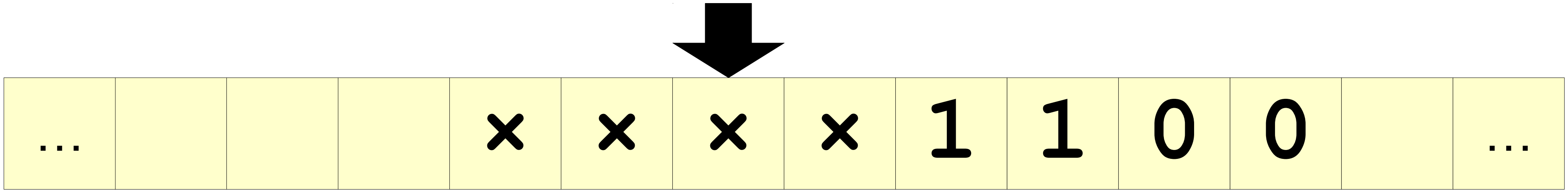
1 → ×, L

0 → 0, R
× → ×, R

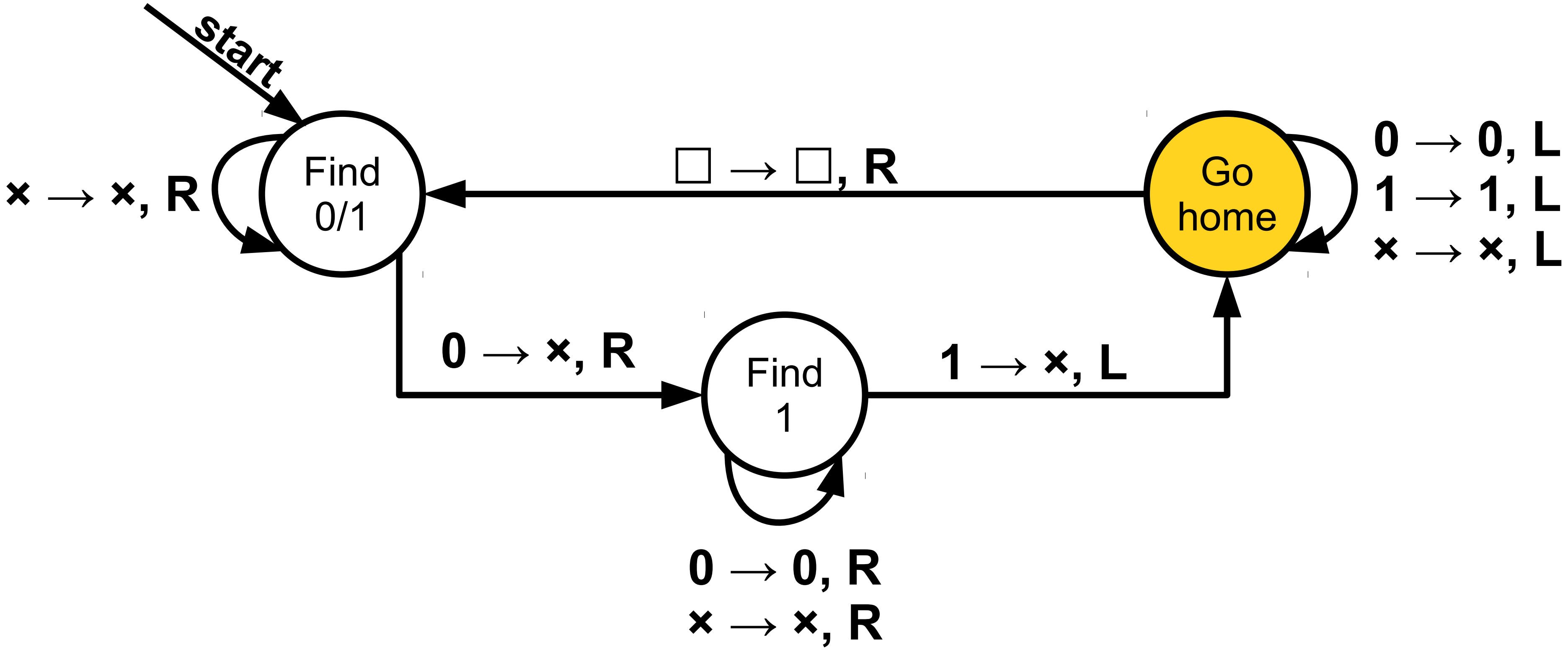
…				×	×	×	1	1	1	0	0		…


start
Find 0/1
× → ×, R
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R
…
×
×
×
1
1
1
0
0
…

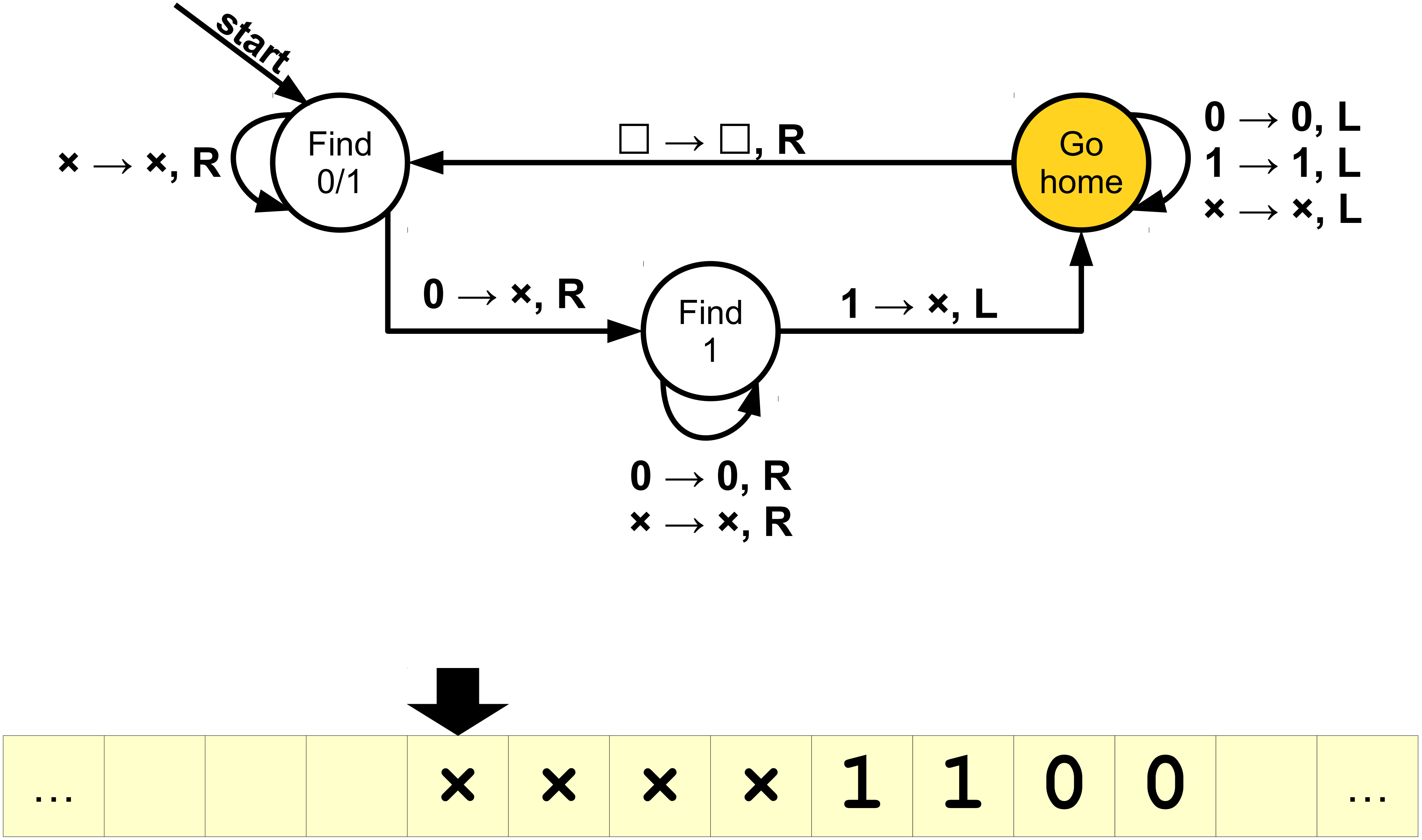


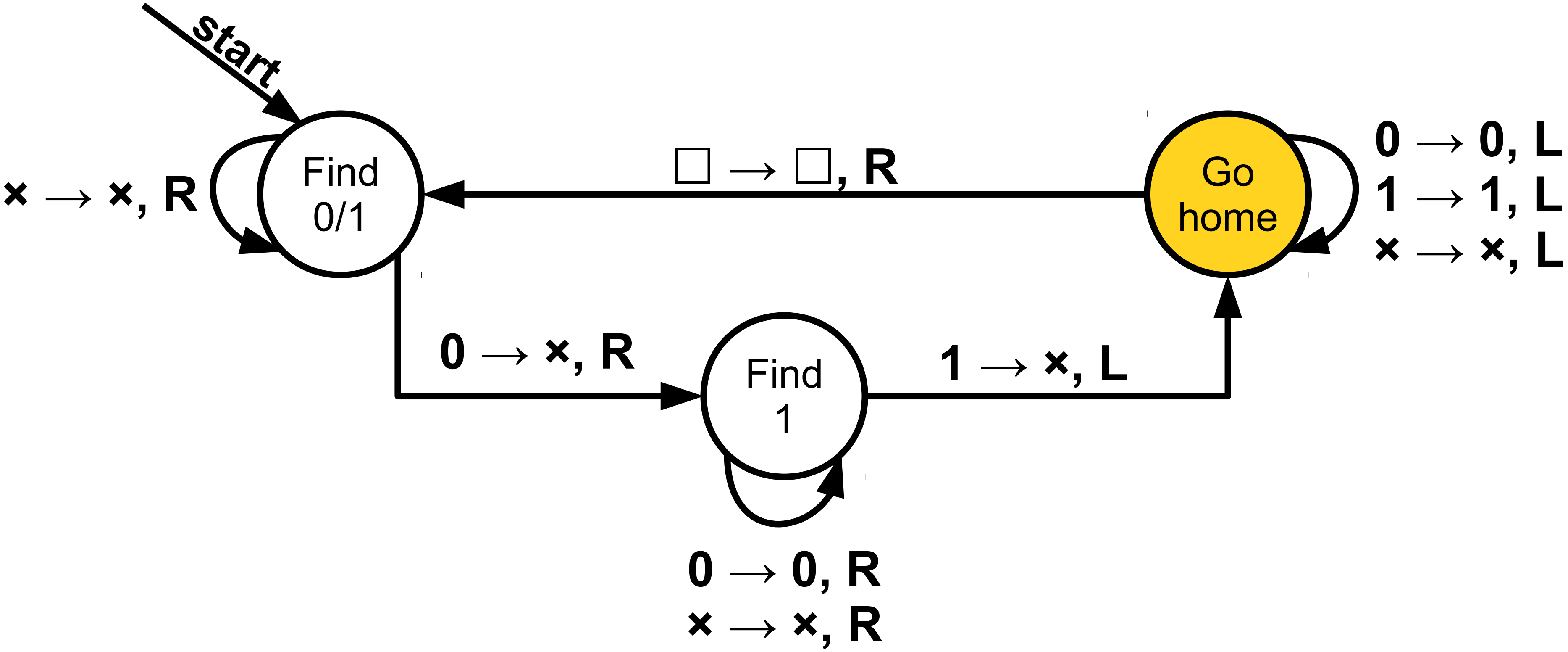


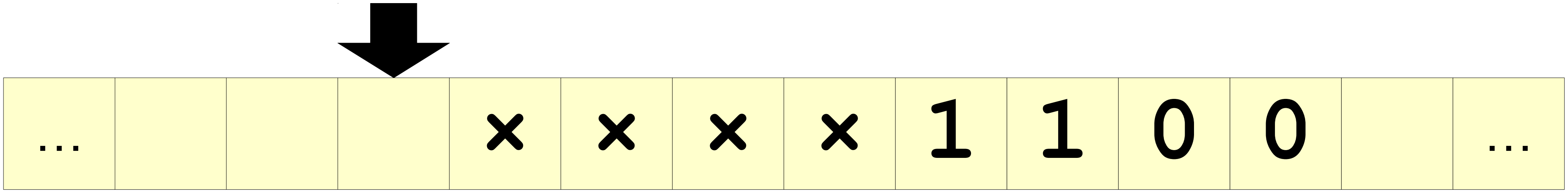
…				×	×	×	×	1	1	0	0		…



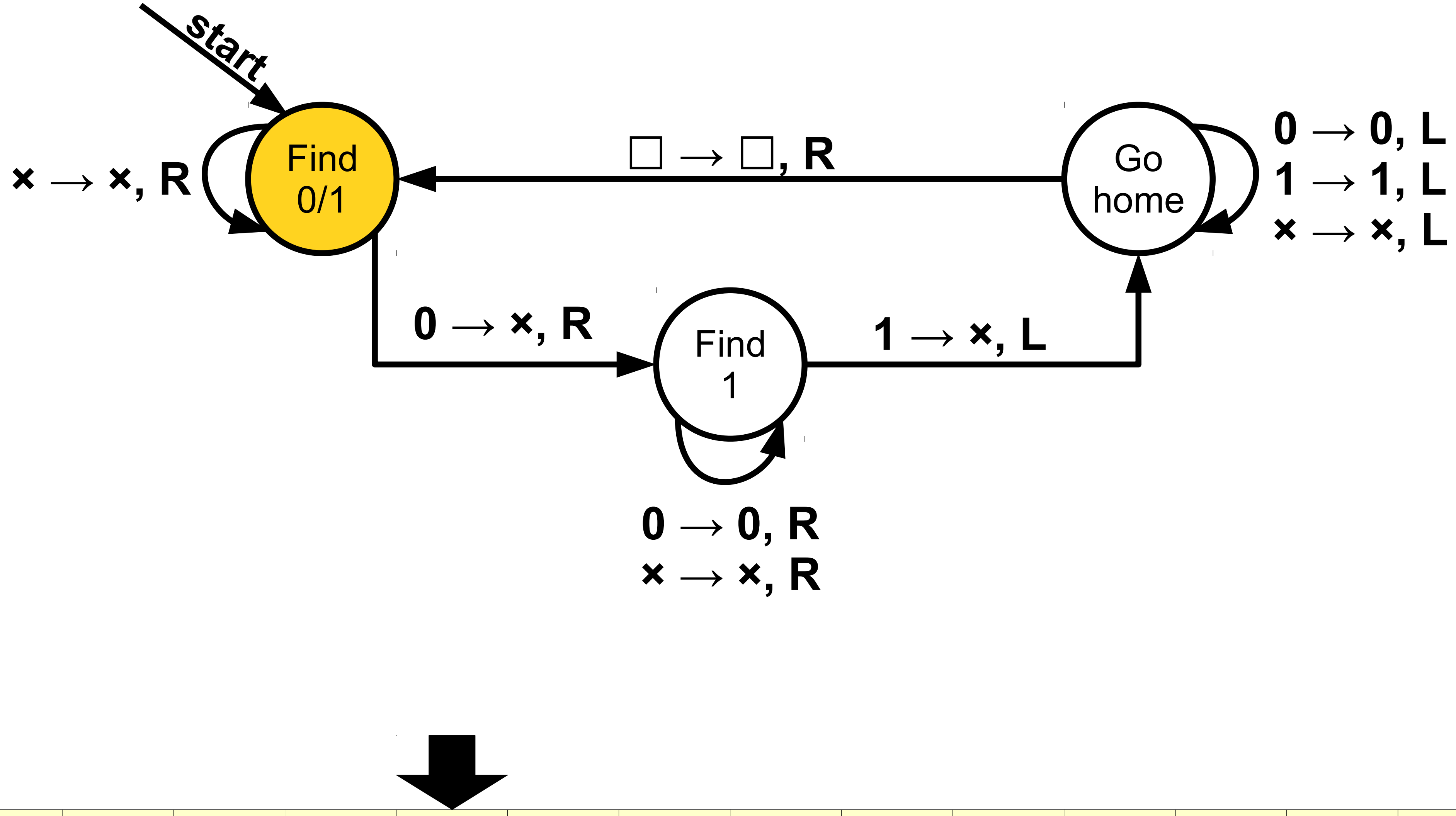
…				×	×	×	×	1	1	0	0		…


start
Find 0/1
× → ×, R
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
Go home
0 → 0, L
1 → 1, L
× → ×, L
□ → □, R
…
×
×
×
×
1
1
0
0
…

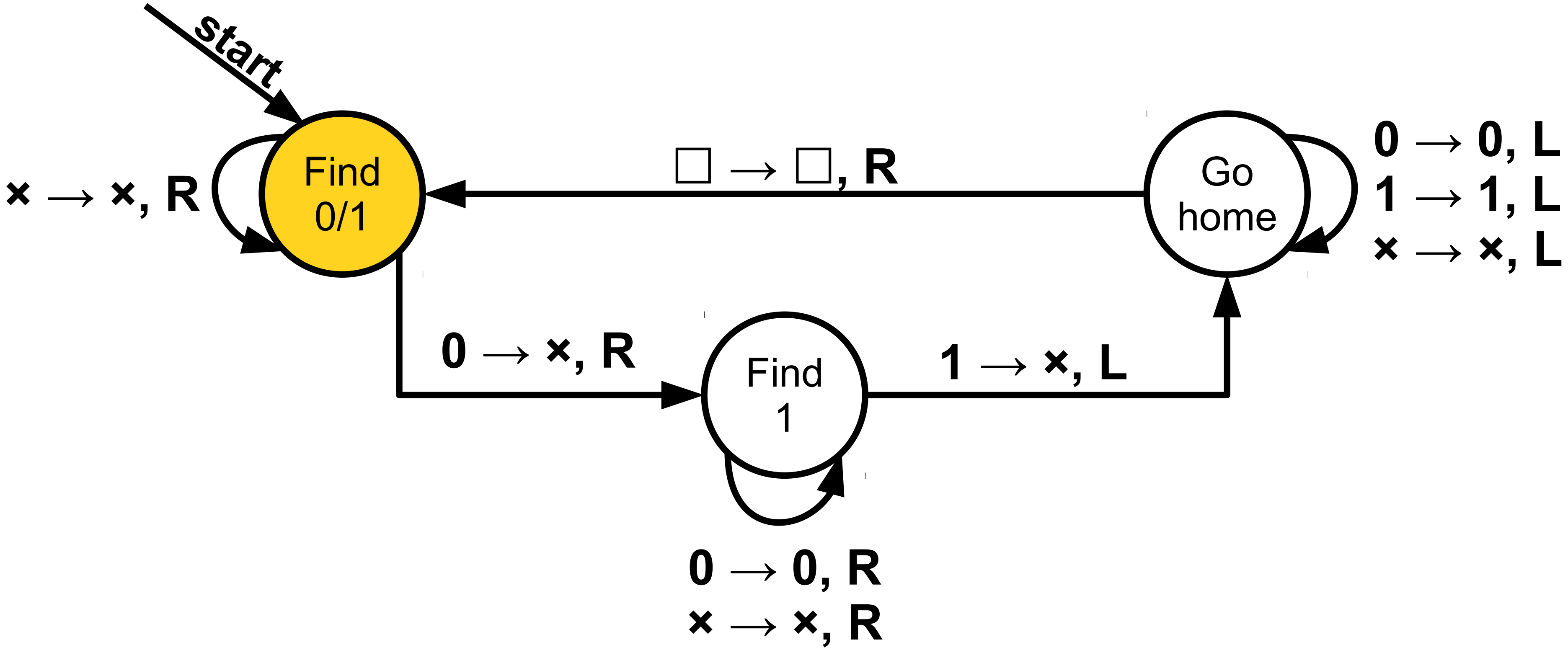


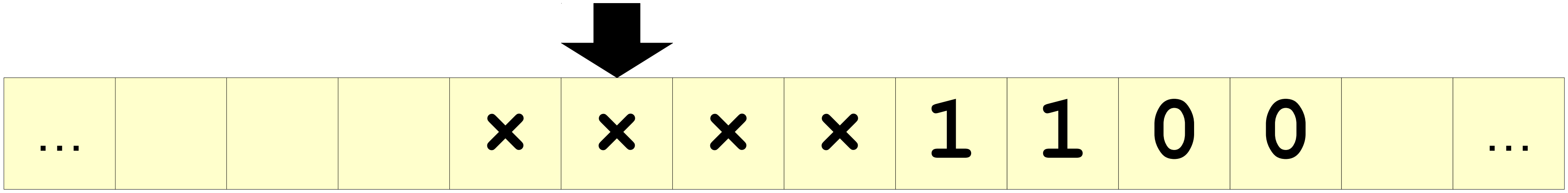


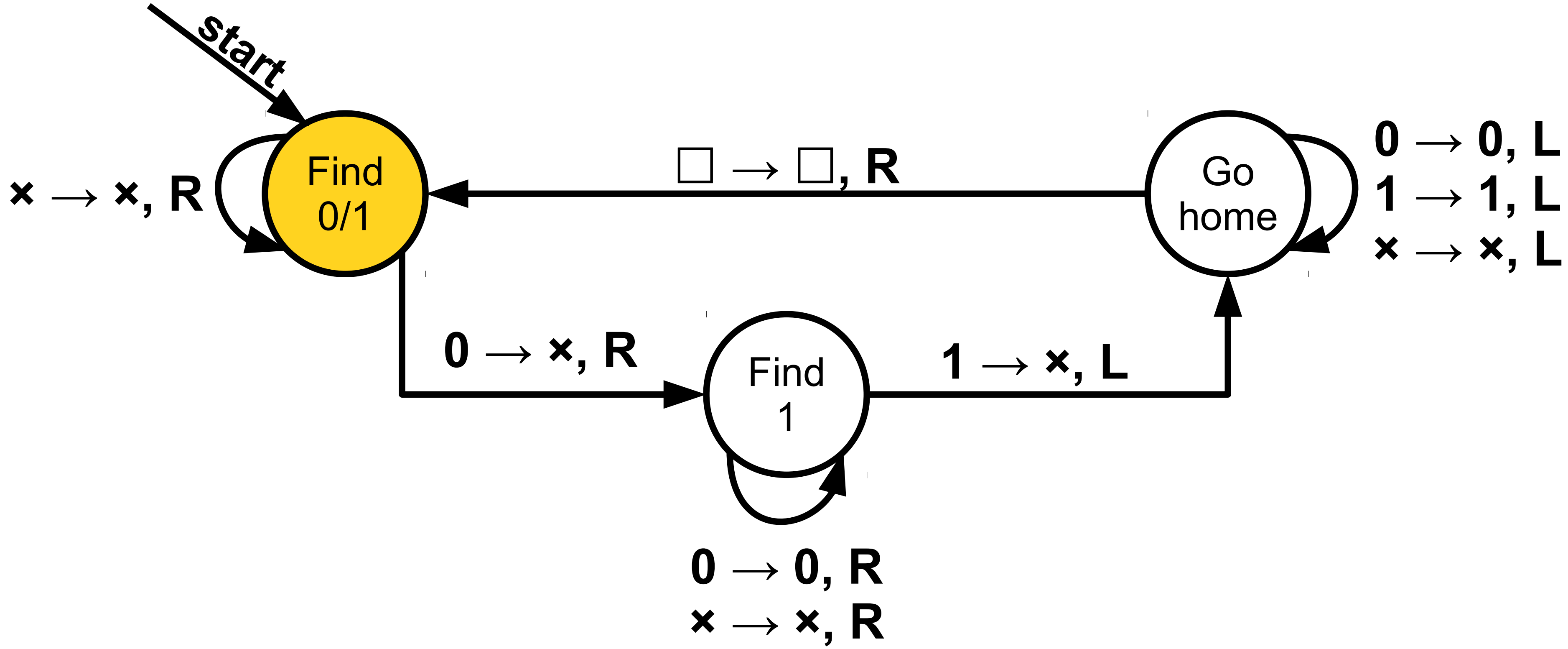
…				×	×	×	×	1	1	0	0		…



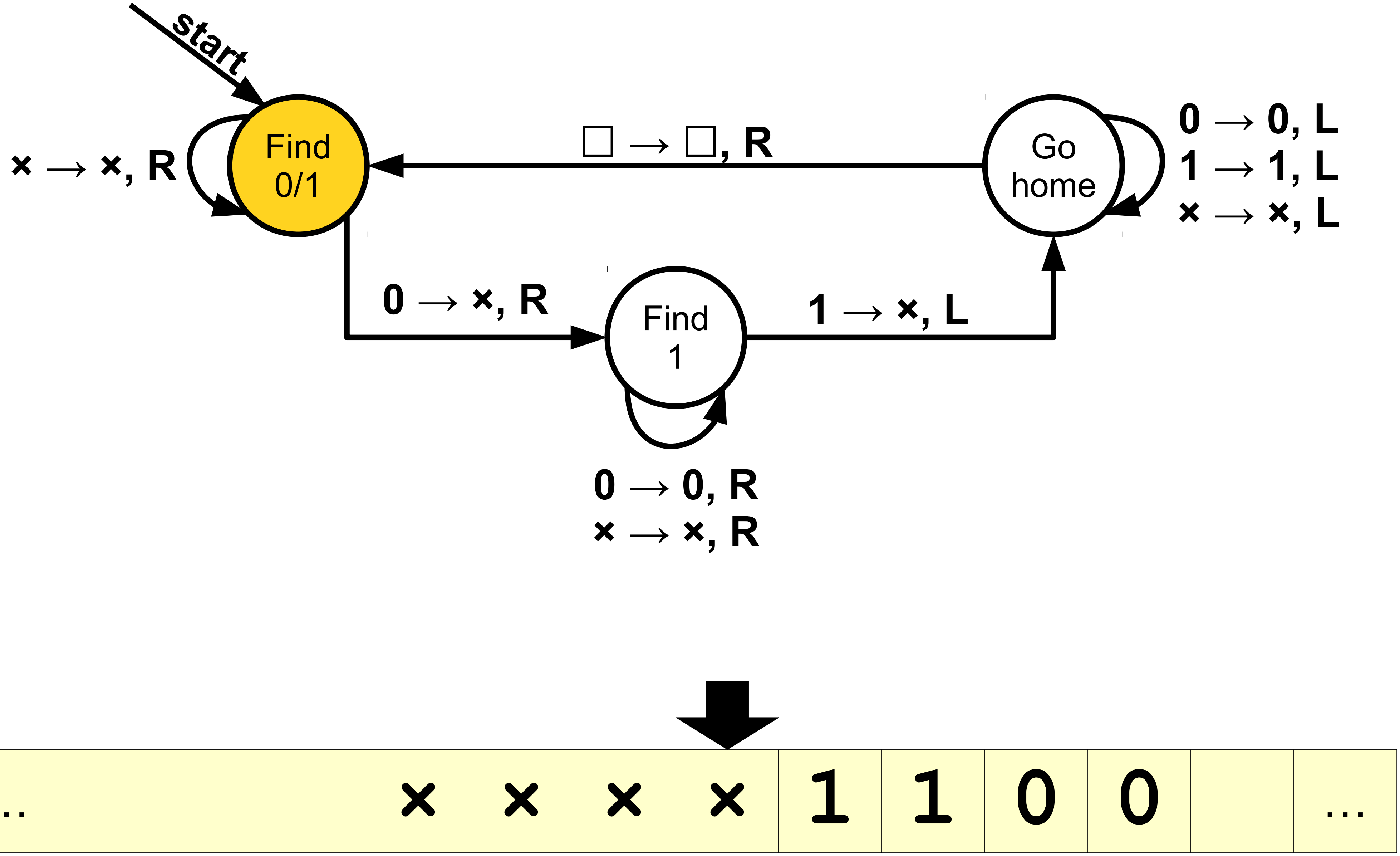
…				×	×	×	×	1	1	0	0		…


start
Find 0/1
× → ×, R
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R

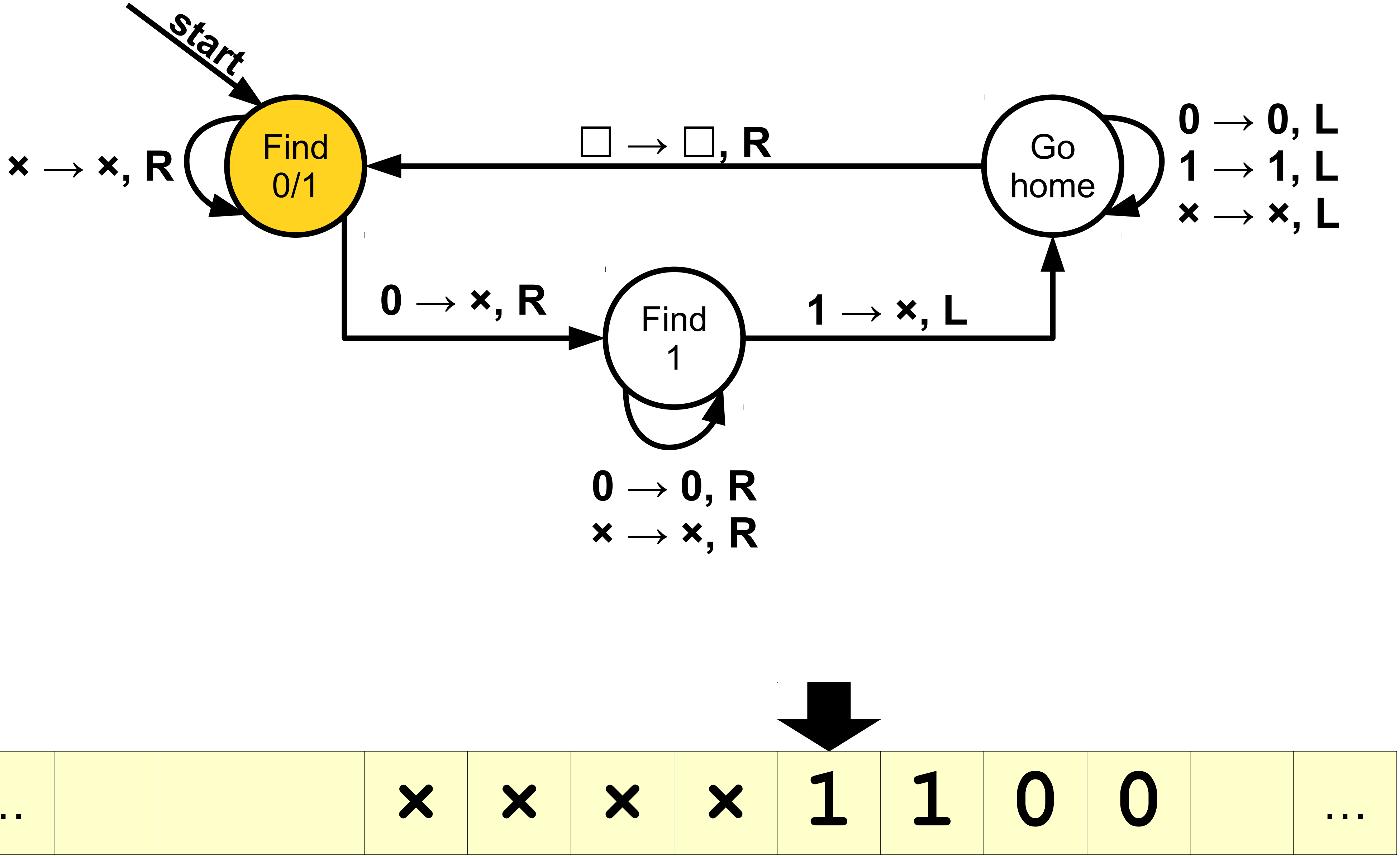

…
×
×
×
×
1
1
0
0
…



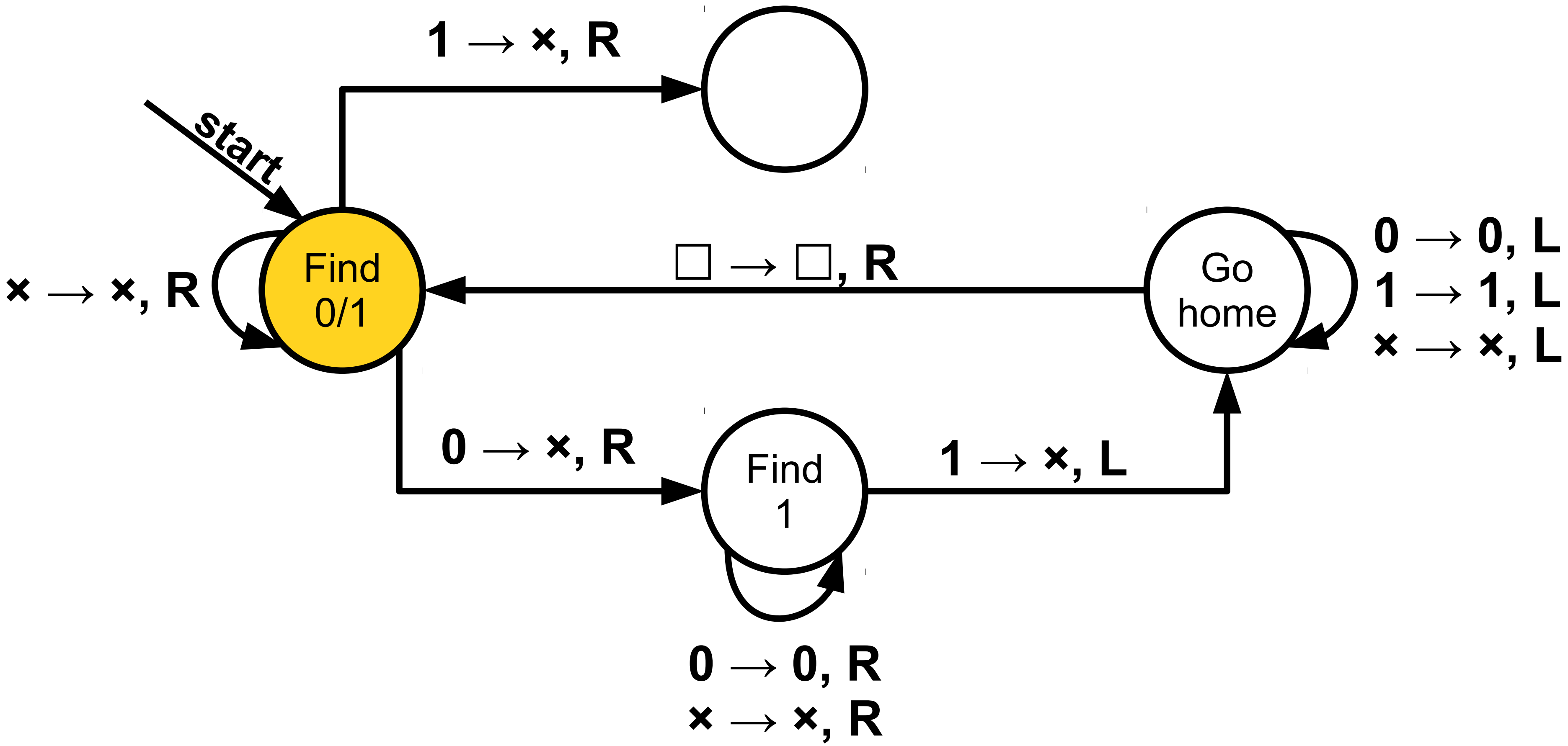
…				×	×	×	×	1	1	0	0		…



…				×	×	×	×	1	1	0	0		…



…				×	×	×	×	1	1	0	0		…



start

Find 0/1

× → ×, R

1 → ×, R

□ → □, R

0 → ×, R

Go home

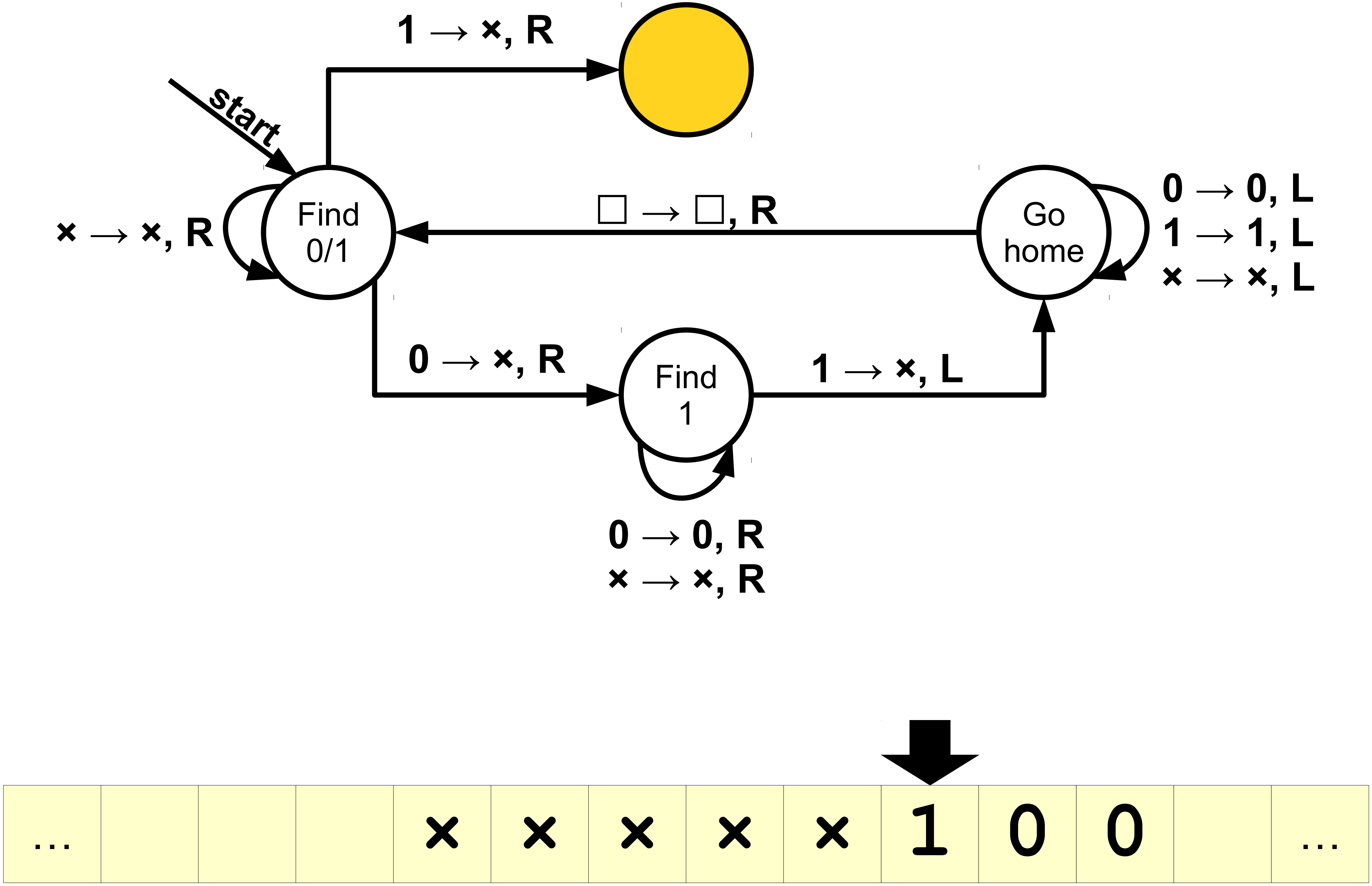
0 → 0, L
1 → 1, L
× → ×, L

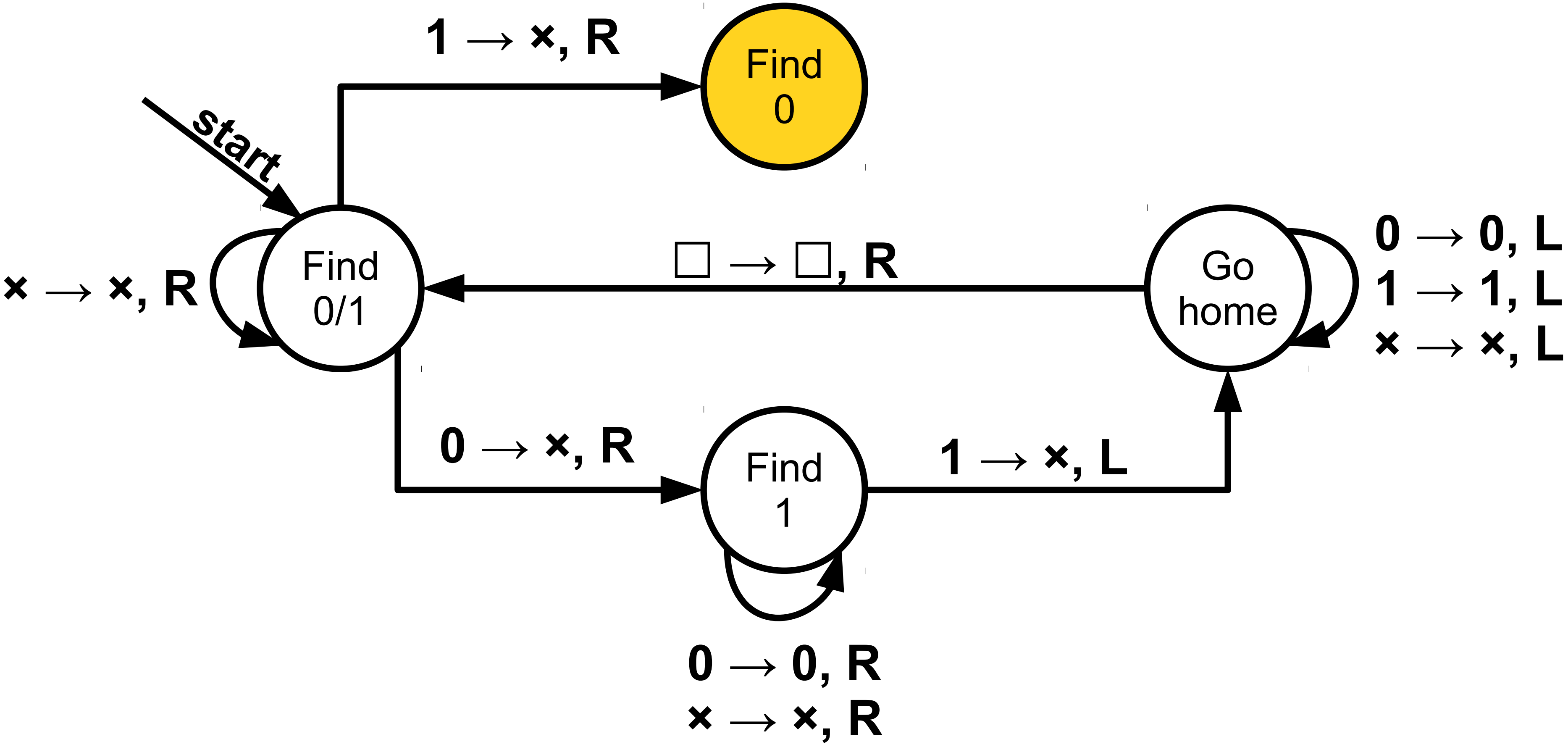
Find 1

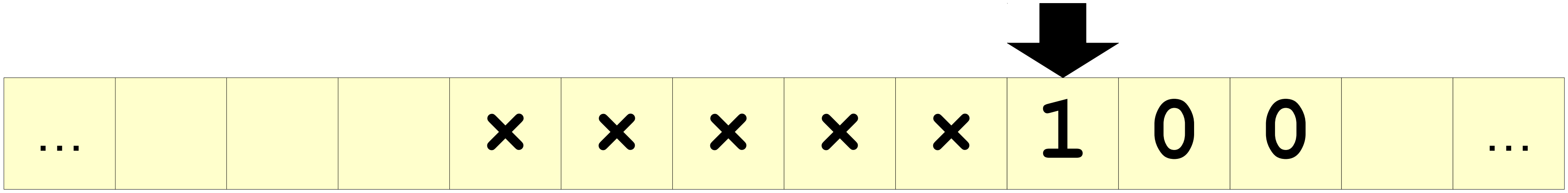
1 → ×, L

0 → 0, R
× → ×, R

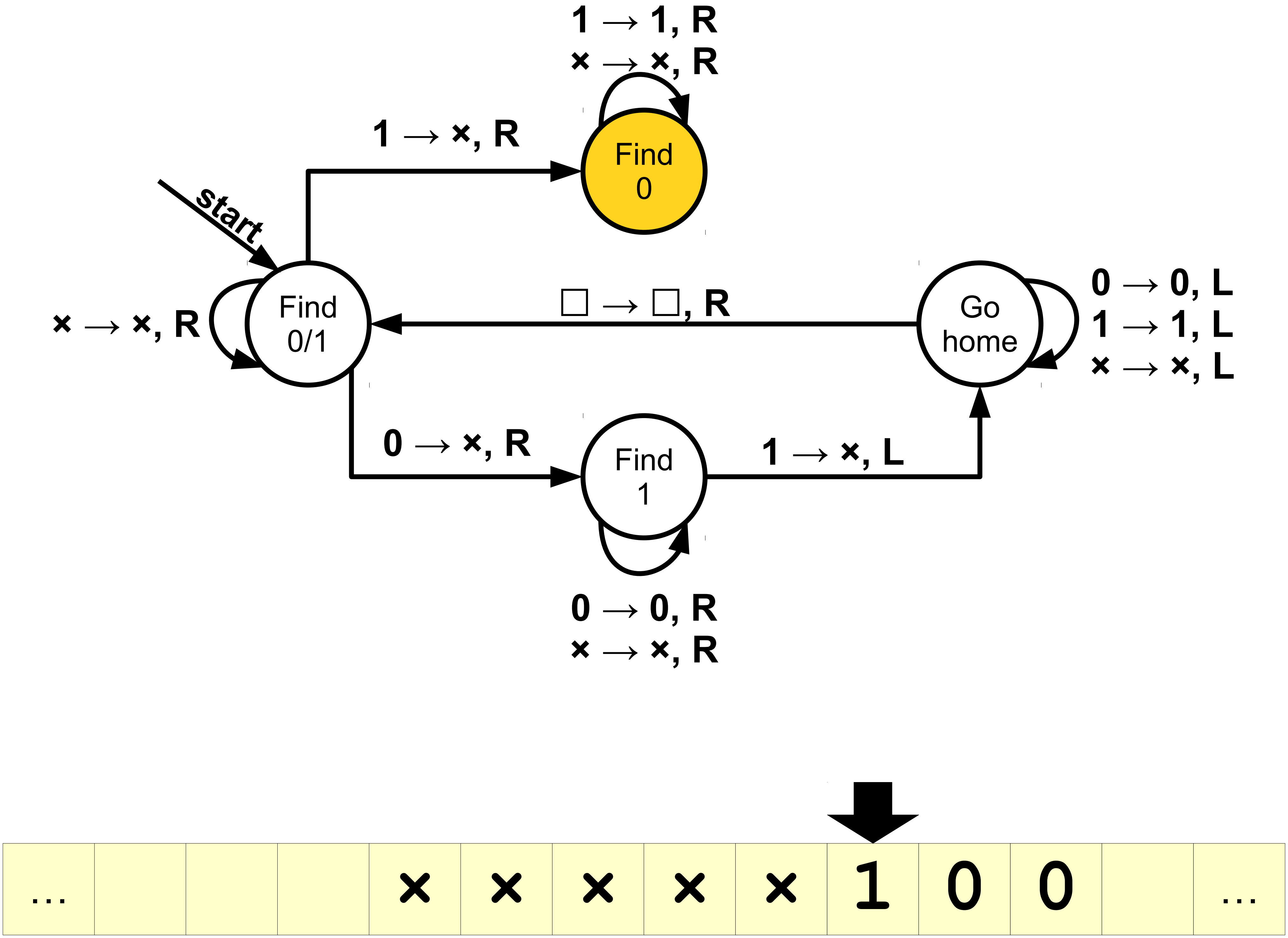
…				×	×	×	×	1	1	0	0		…

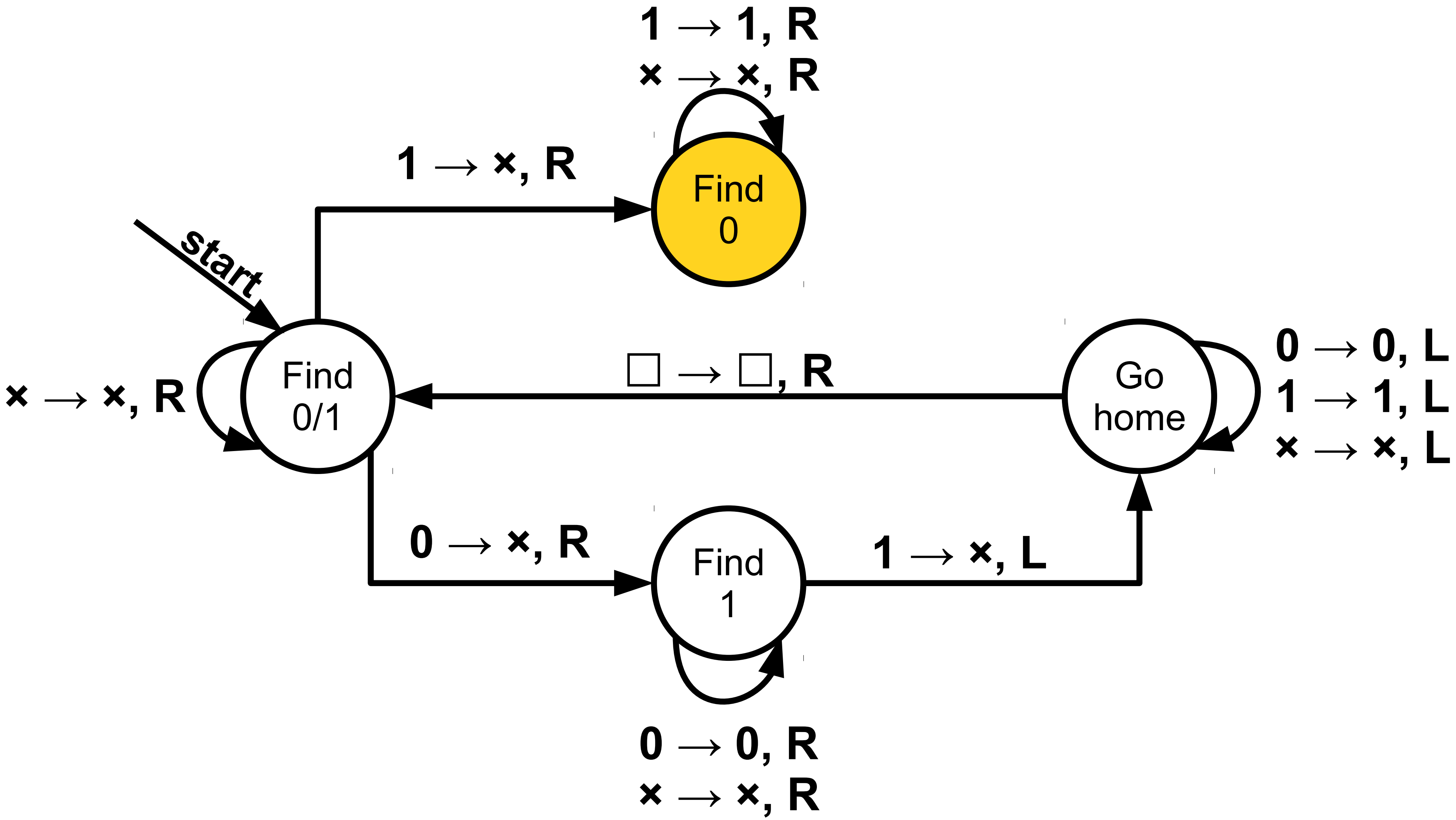

start
1 → ×, R
× → ×, R
Find 0/1
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R
… × × × × × 1 0 0 …

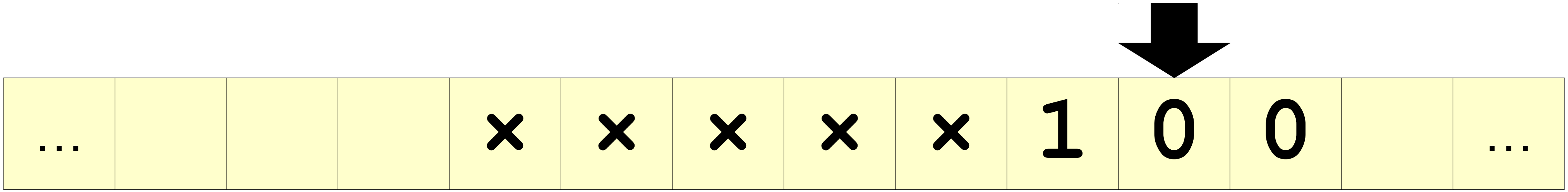


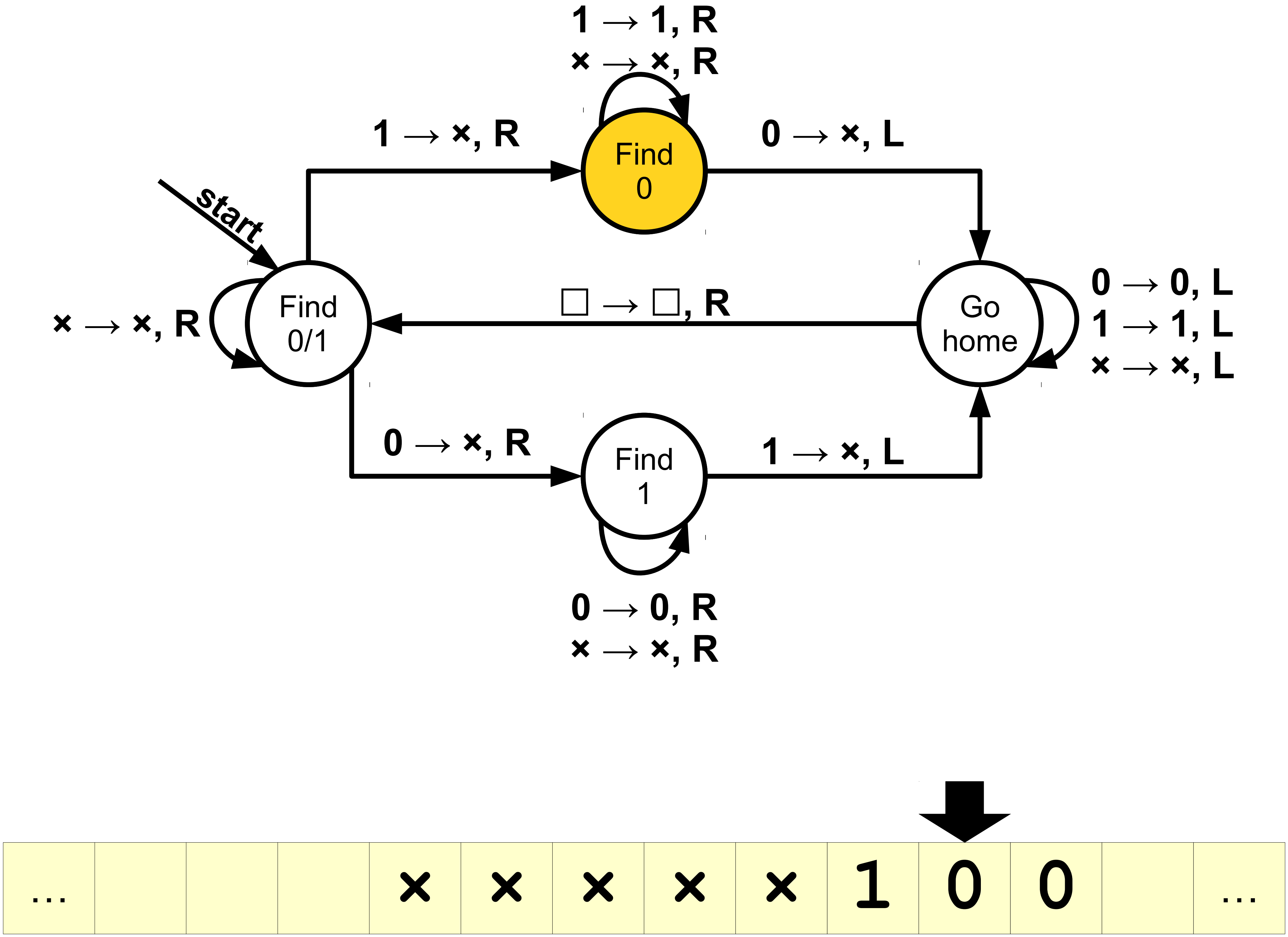


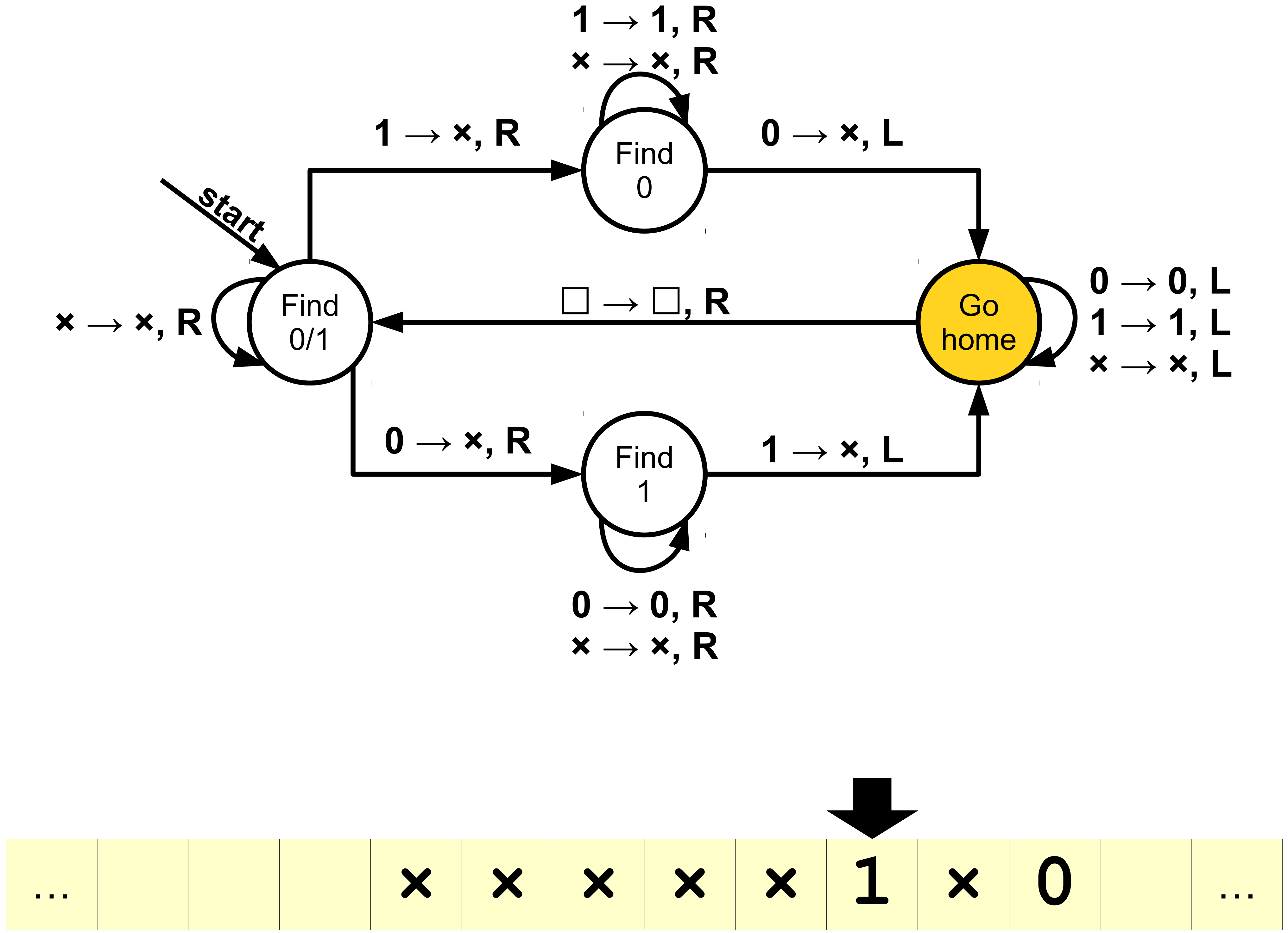
…				×	×	×	×	×	1	0	0		…

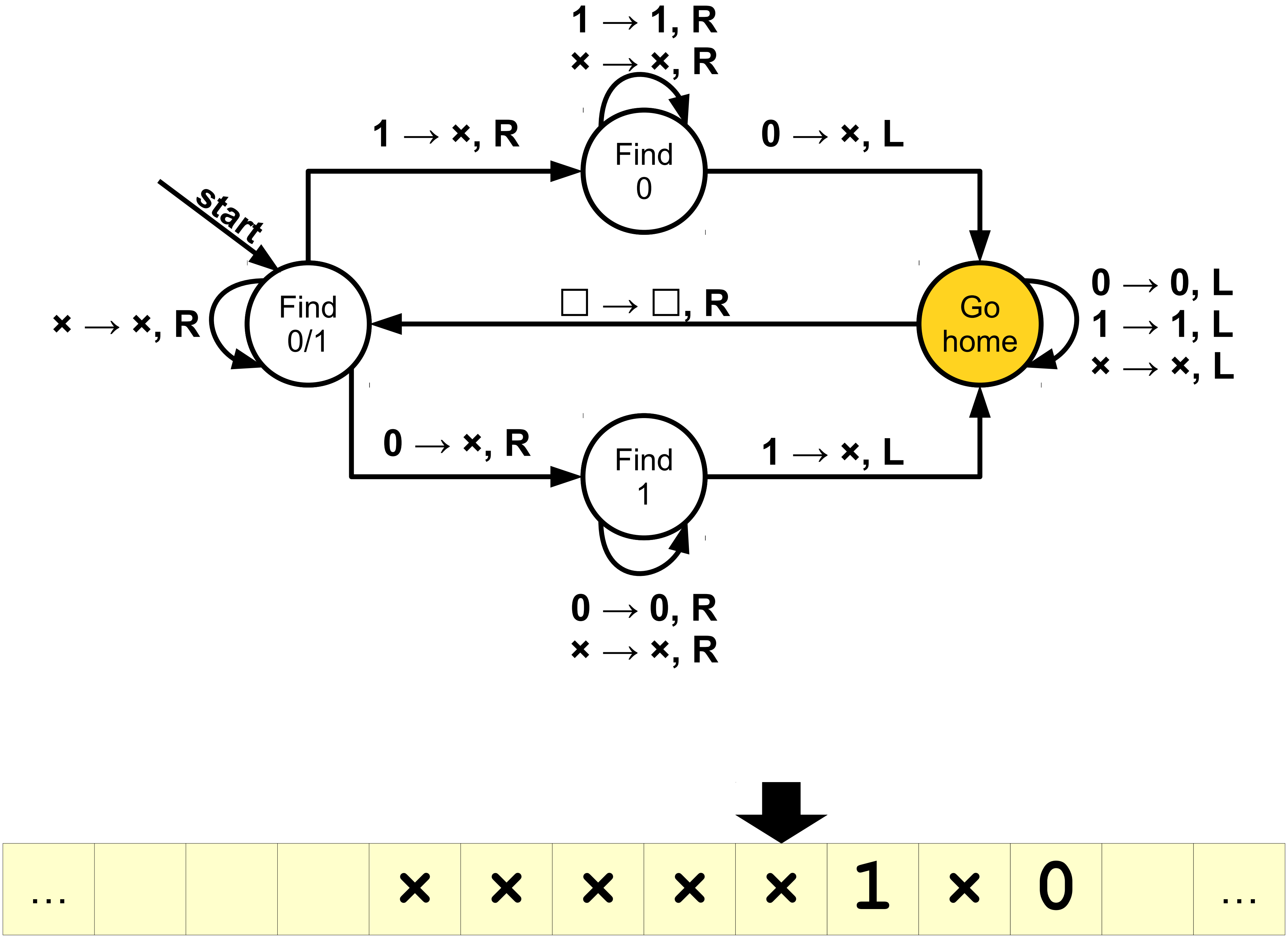

start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
…
×
×
×
×
×
1
0
0
…


1 → 1, R
× → ×, R
1 → ×, R
Find
0
start
× → ×, R
Find
0/1
□ → □, R
Go
home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find
1
1 → ×, L
0 → 0, R
× → ×, R

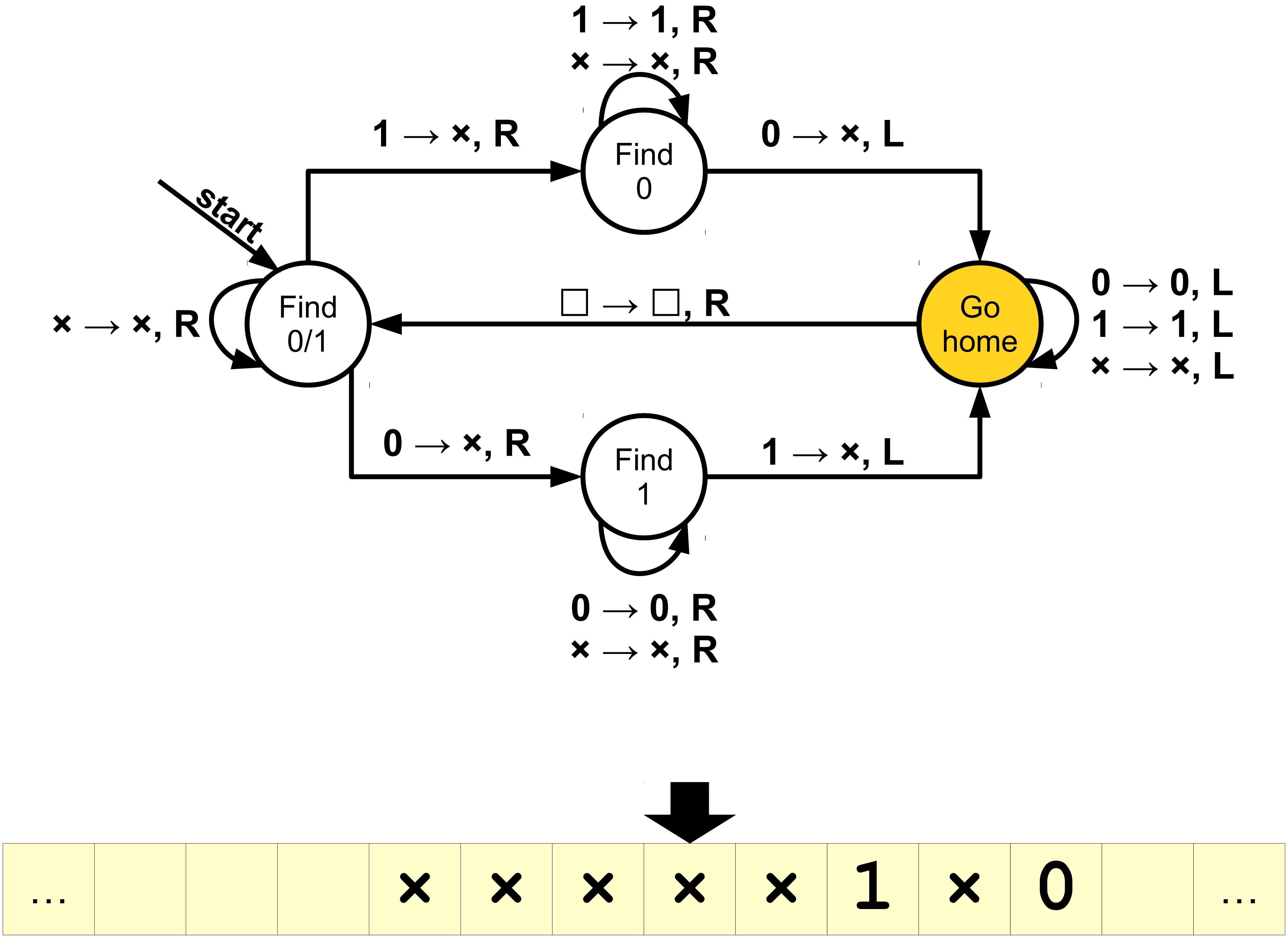

…
×
×
×
×
×
1
0
0
…

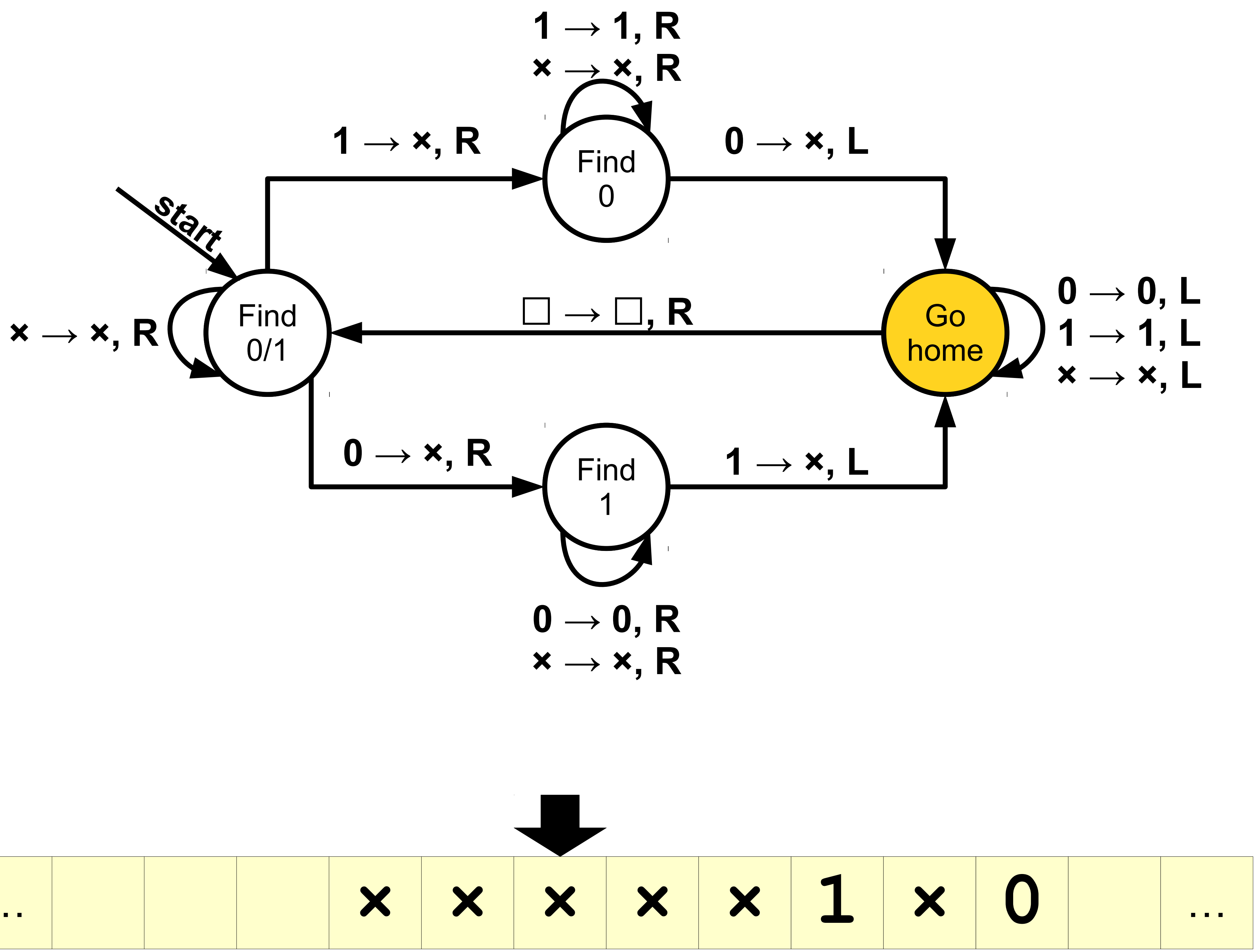

start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
0 → ×, L
Go home
0 → 0, L
1 → 1, L
× → ×, L
□ → □, R
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
…
×
×
×
×
×
1
0
0
…


1 → 1, R
× → ×, R
1 → ×, R
0 → ×, L
start
Find 0
× → ×, R
Find 0/1
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R
…
×
×
×
×
×
1
×
0
…

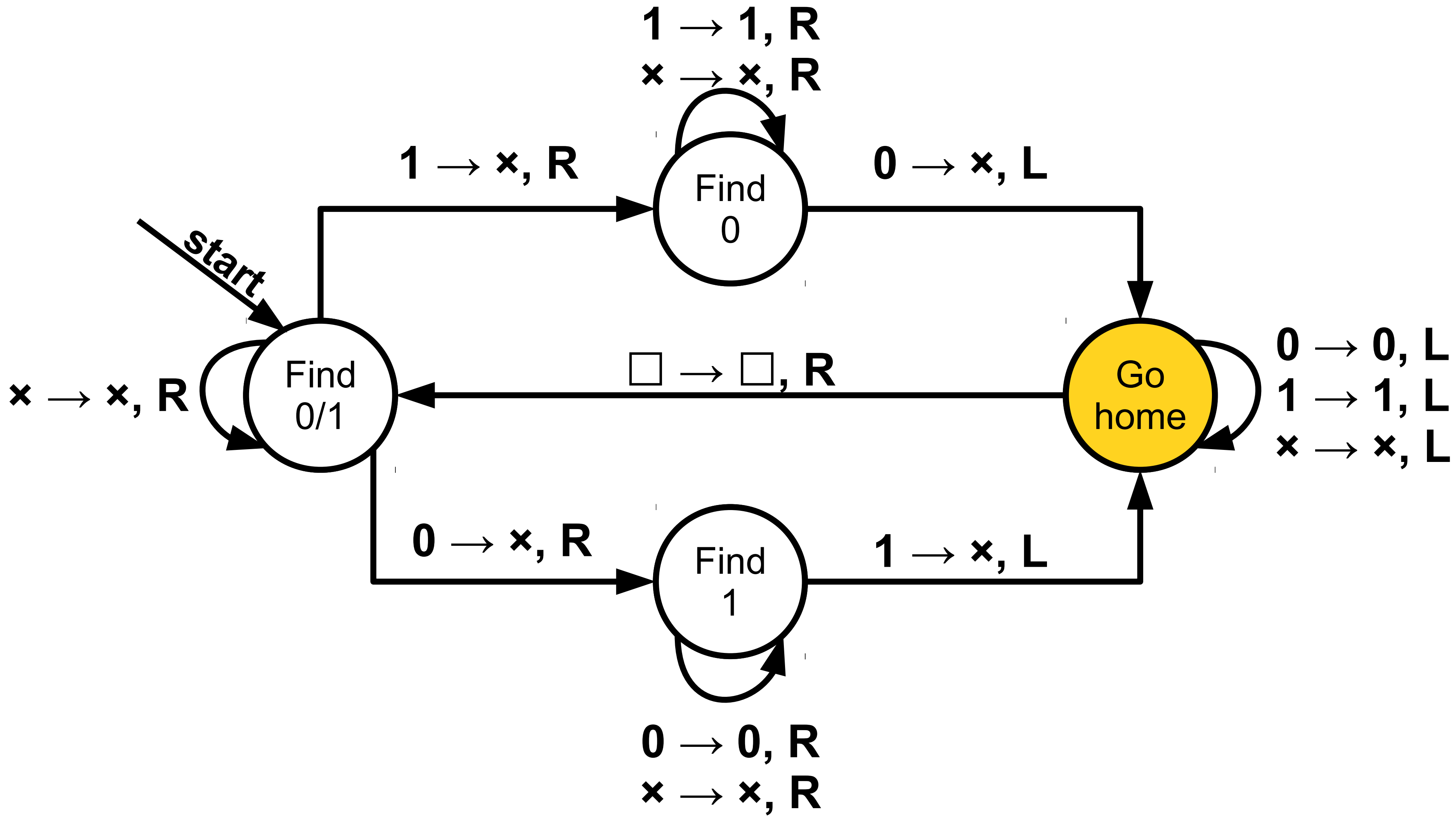

start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
0 → ×, L
Go home
0 → 0, L
1 → 1, L
× → ×, L
□ → □, R
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L

…				×	×	×	×	×	1	×	0		…

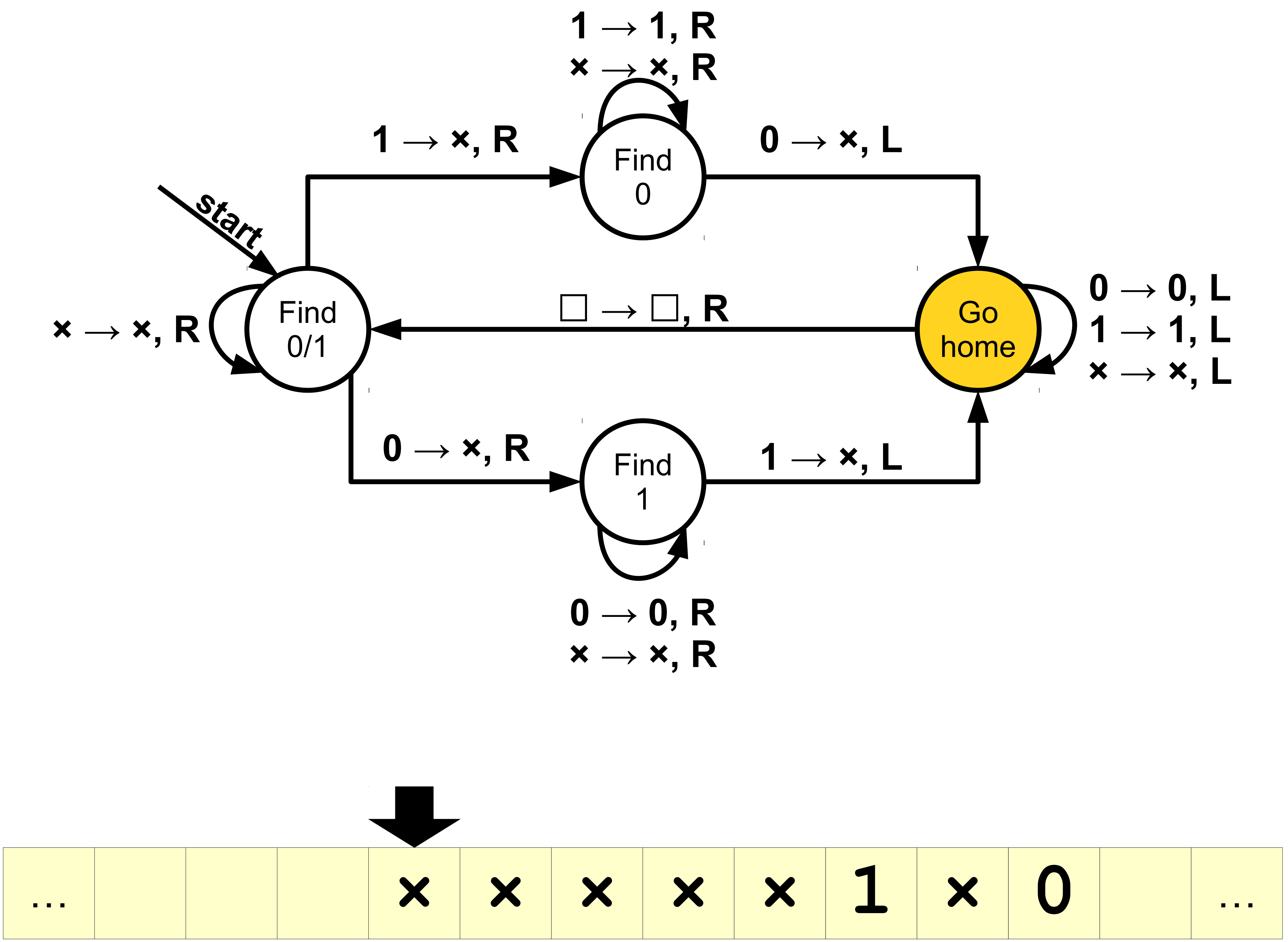

1 → 1, R
× → ×, R
1 → ×, R
0 → ×, L
Find
0
start
Find
0/1
× → ×, R
□ → □, R
Go
home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find
1
1 → ×, L
0 → 0, R
× → ×, R
…
×
×
×
×
×
1
×
0
…


1 → 1, R
× → ×, R
1 → ×, R
0 → ×, L
start
Find 0/1
Find 0
Find 1
Go home
× → ×, R
□ → □, R
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
1 → ×, L
0 → 0, R
× → ×, R

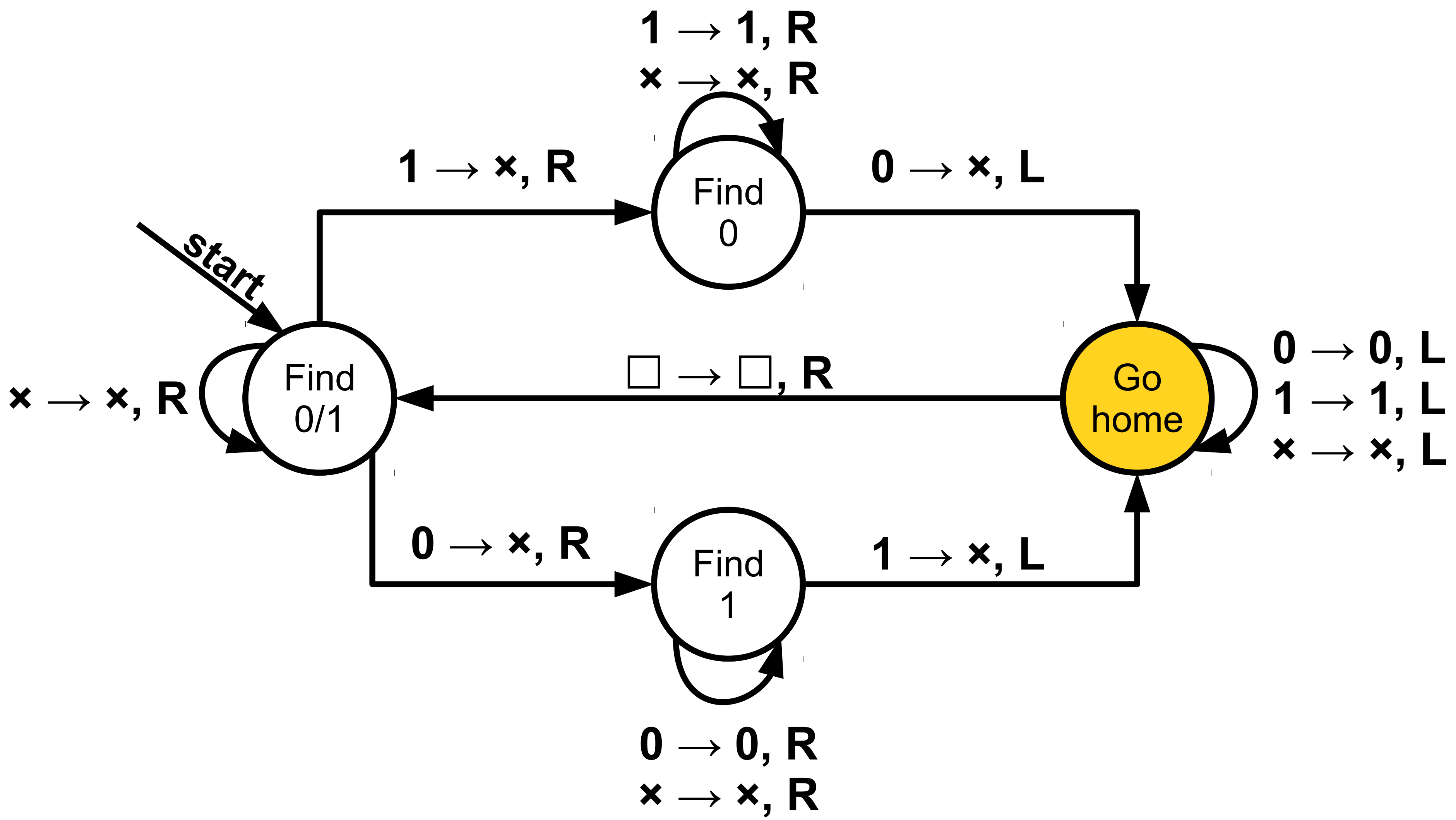
…				×	×	×	×	×	1	×	0		…

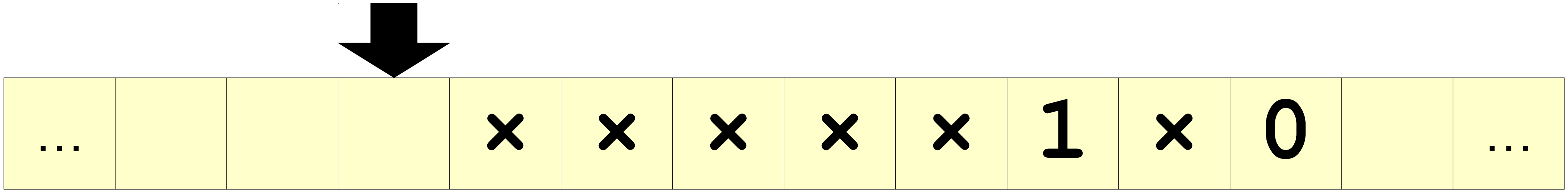

1 → 1, R
× → ×, R
1 → ×, R
Find 0
0 → ×, L
start
× → ×, R
Find 0/1
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R

…				×	×	×	×	×	1	×	0		…

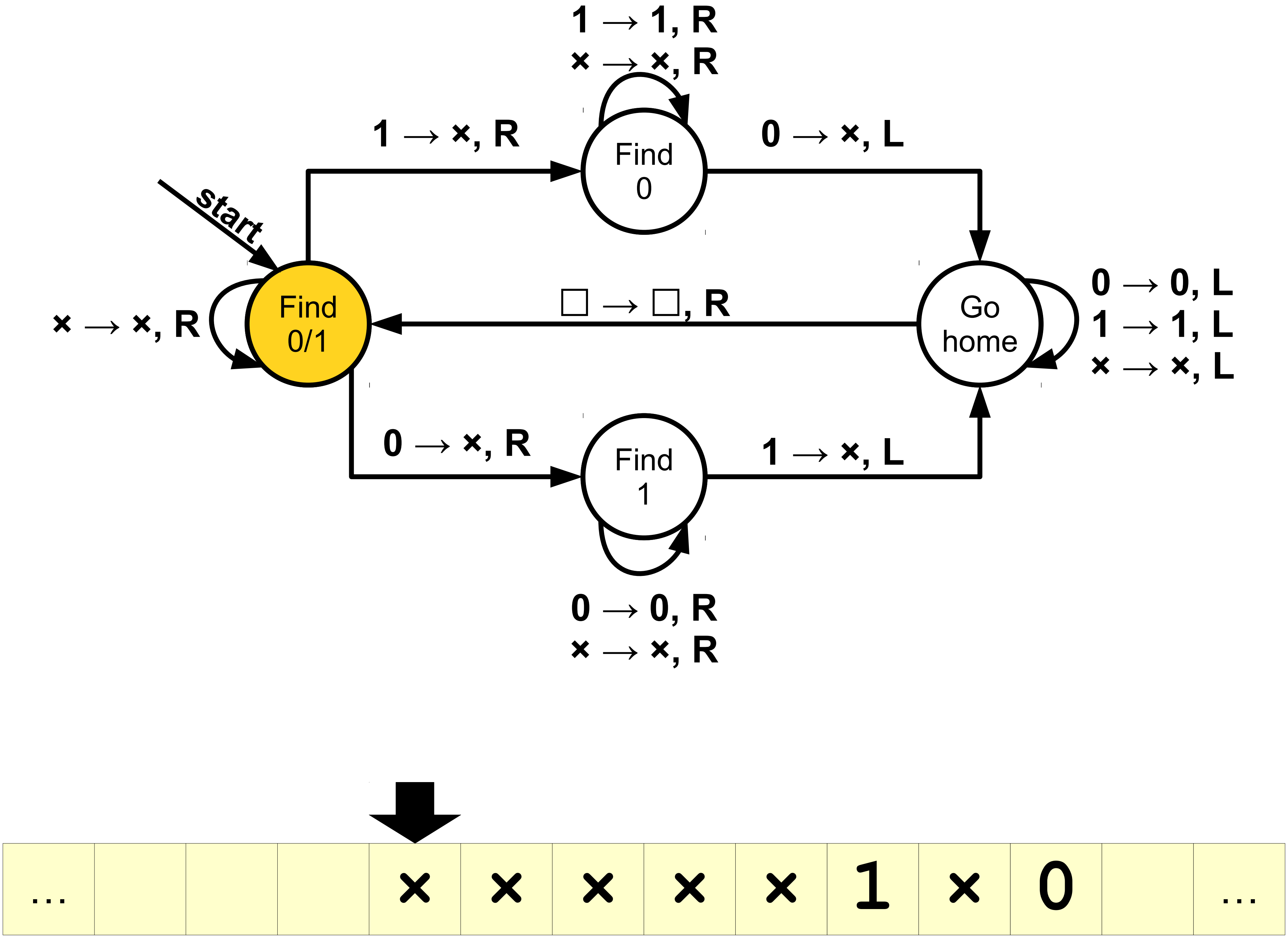

1 → 1, R
× → ×, R
1 → ×, R
Find 0
0 → ×, L
start
× → ×, R
Find 0/1
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R

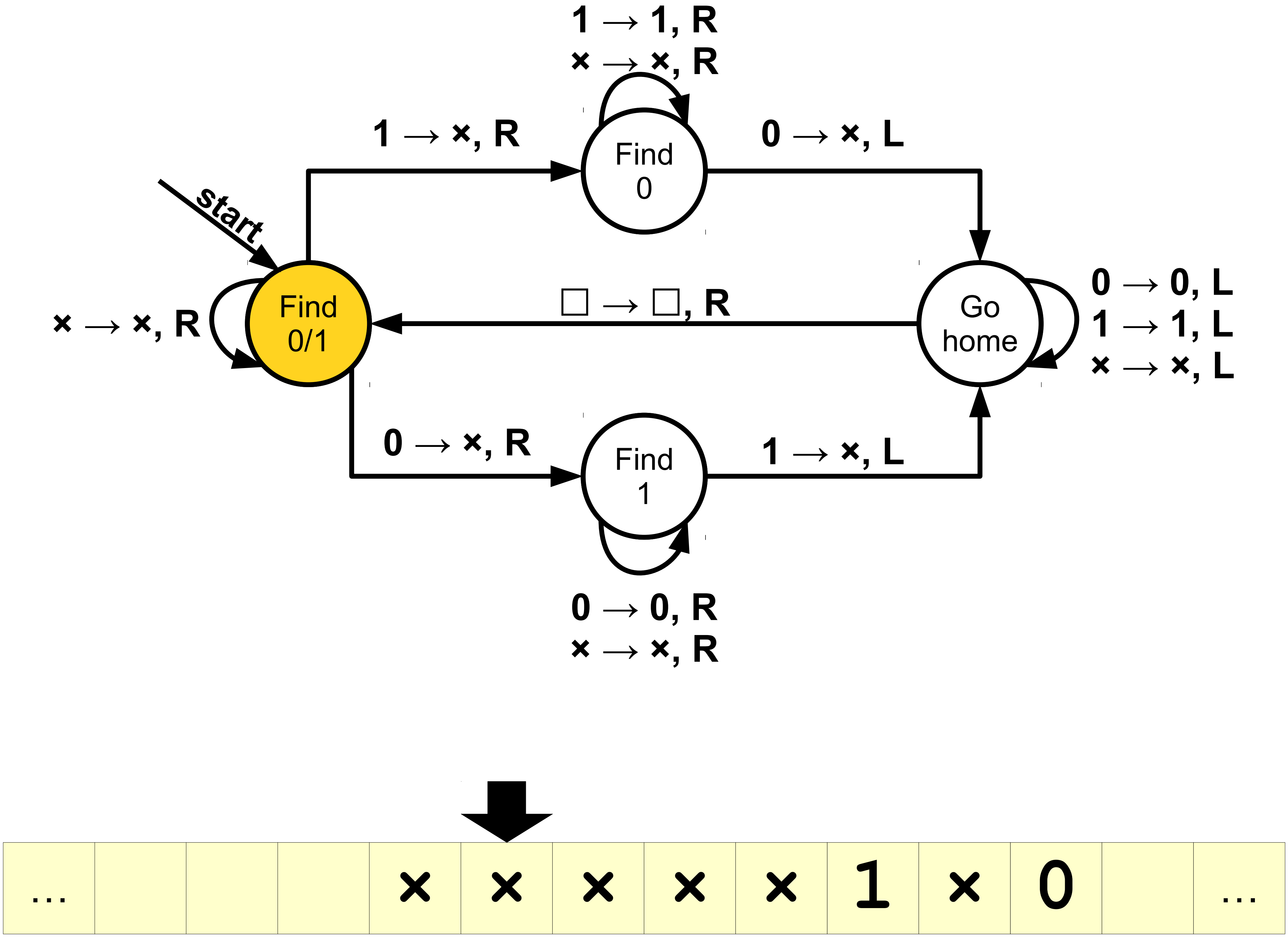
…				×	×	×	×	×	1	×	0		…

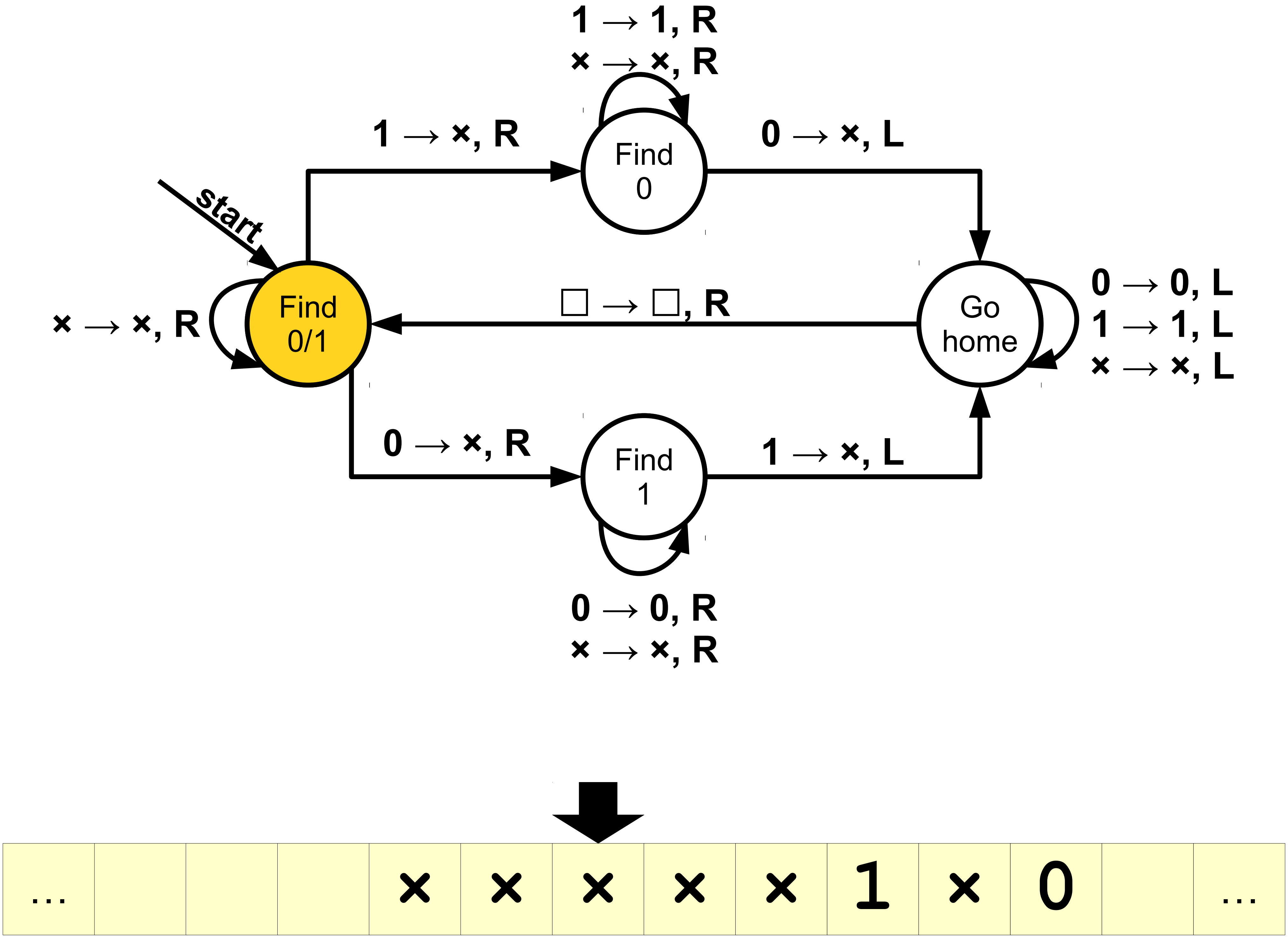

1 → 1, R
× → ×, R
1 → ×, R
Find 0
0 → ×, L
start
Find 0/1
× → ×, R
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R

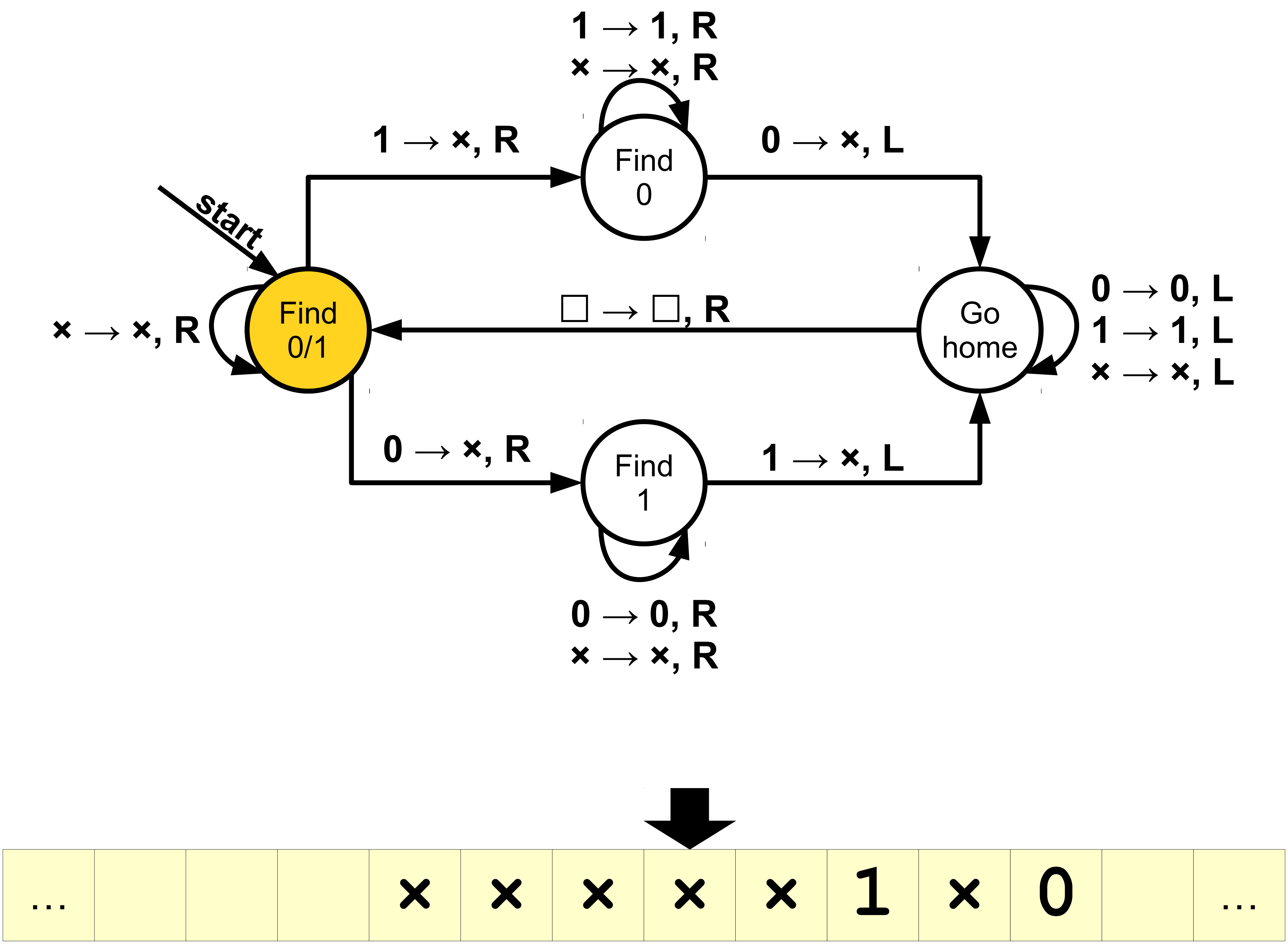


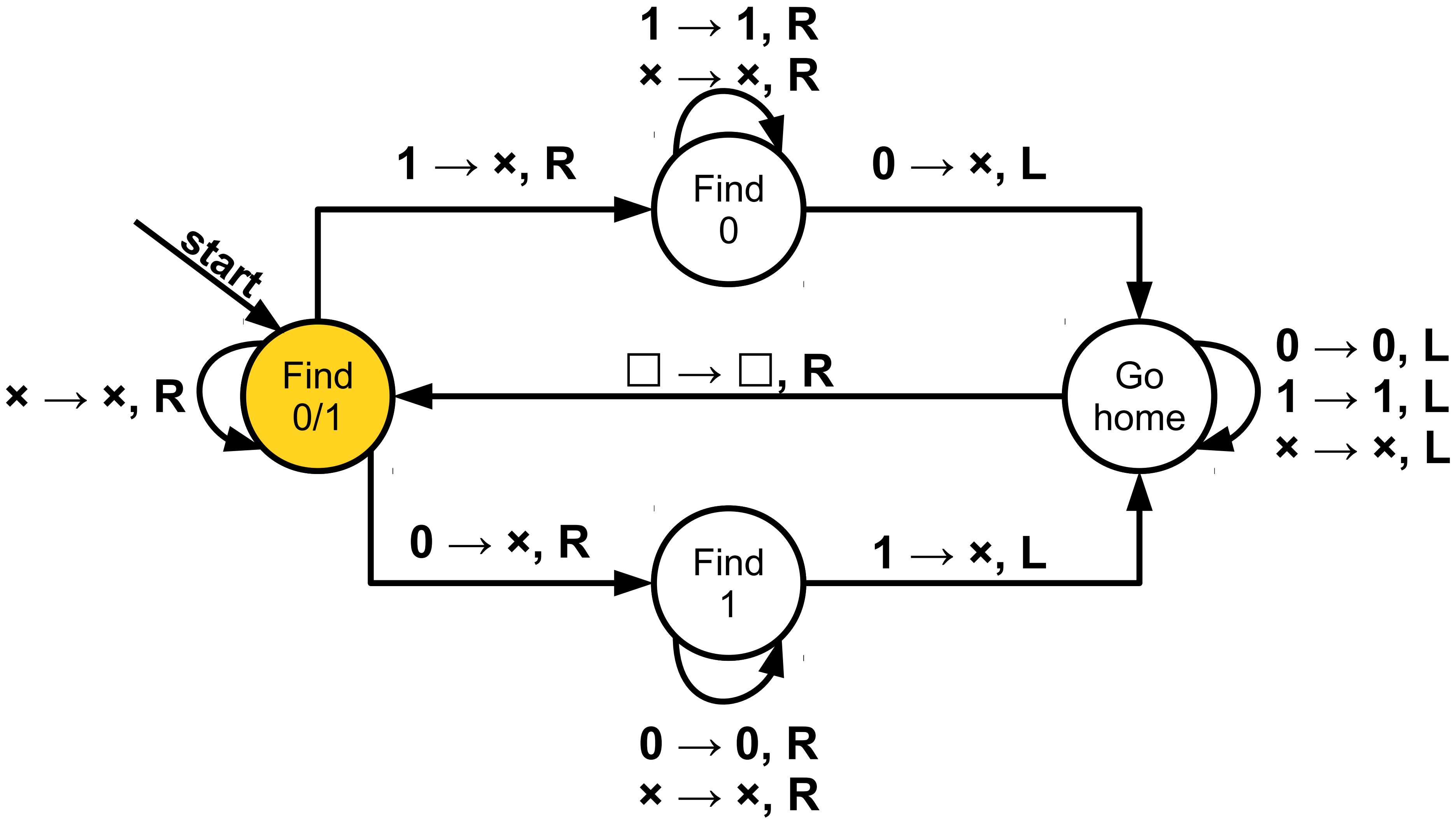
…				×	×	×	×	×	1	×	0		…

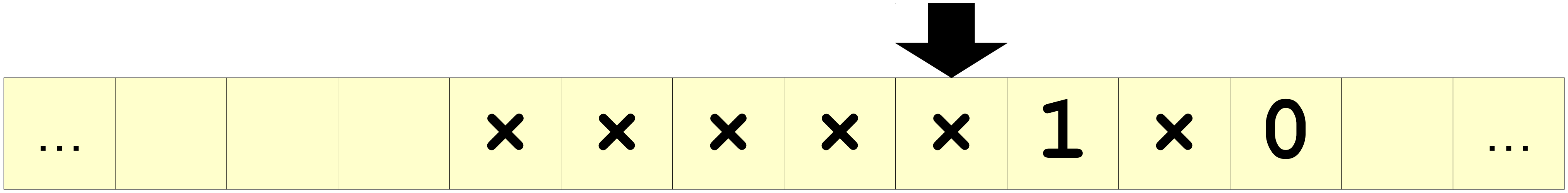

1 → 1, R
× → ×, R
1 → ×, R
Find 0
0 → ×, L
start
× → ×, R
Find 0/1
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R
…
×
×
×
×
×
1
×
0
…


start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
0 → ×, L
Go home
0 → 0, L
1 → 1, L
× → ×, L
□ → □, R
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
…
×
×
×
×
×
1
×
0
…

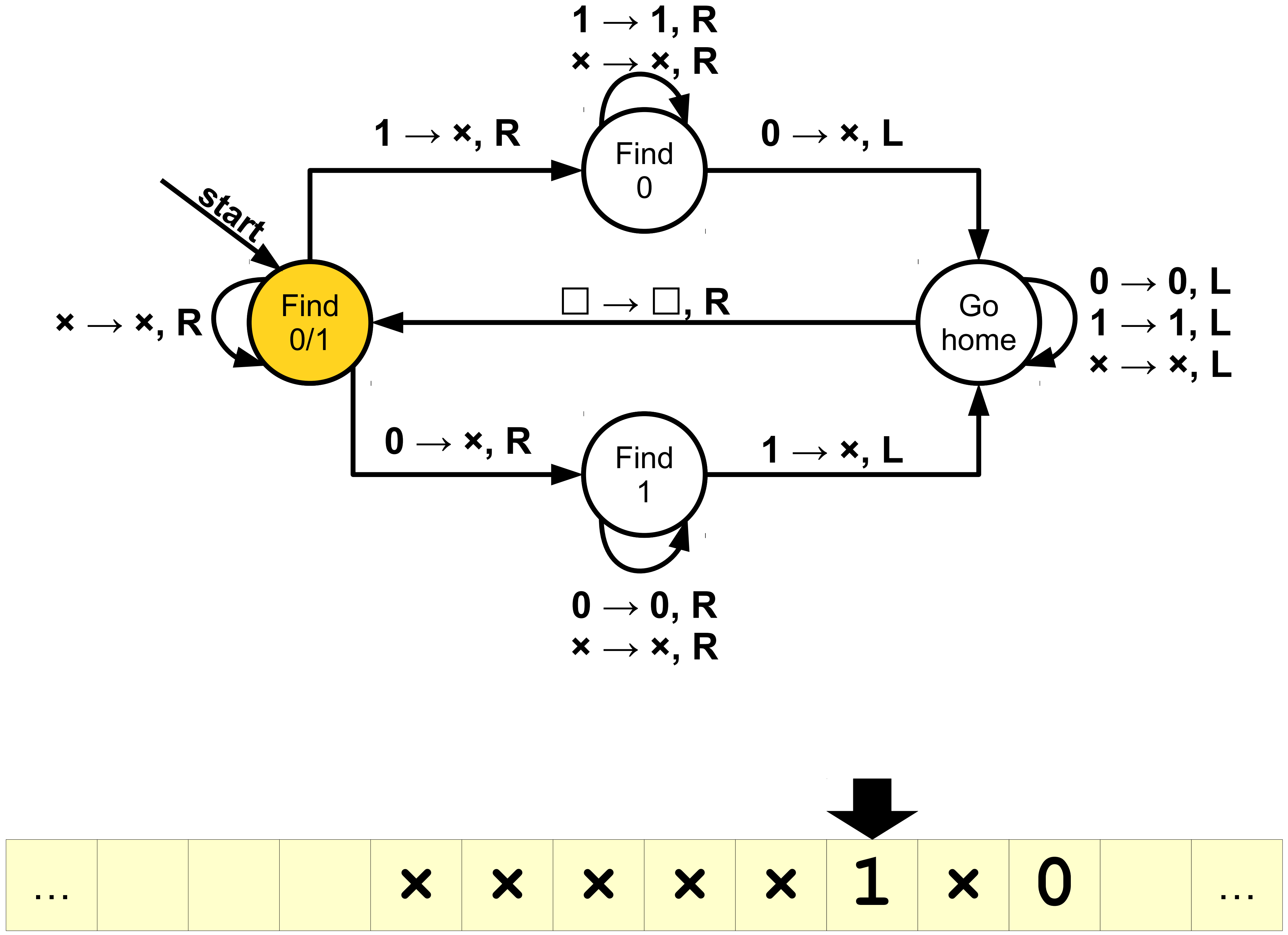

start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
0 → ×, L
Go home
0 → 0, L
1 → 1, L
× → ×, L
□ → □, R
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
…
×
×
×
×
×
1
×
0
…

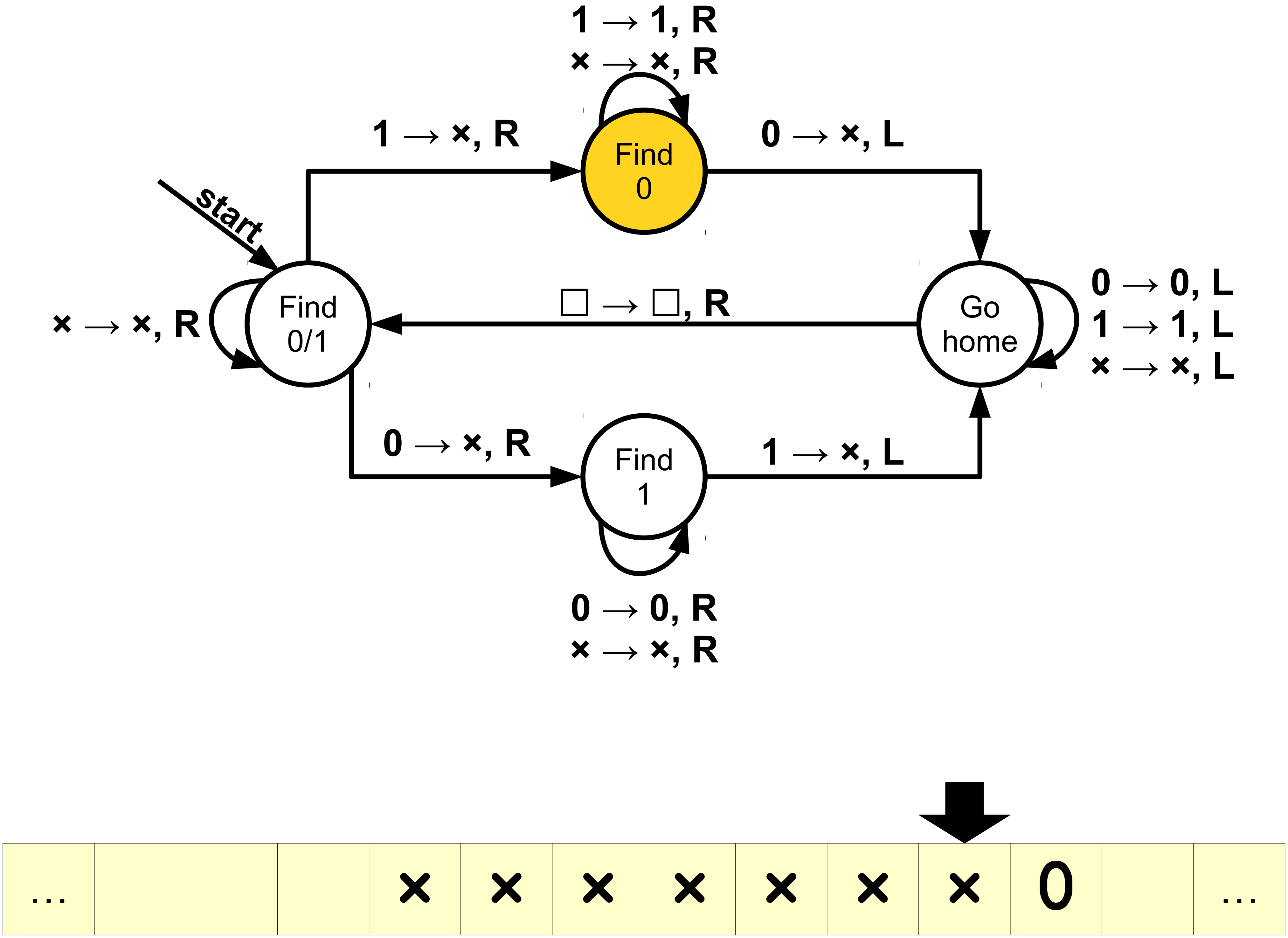

start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
0 → ×, L
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
…
×
×
×
×
×
1
×
0
…

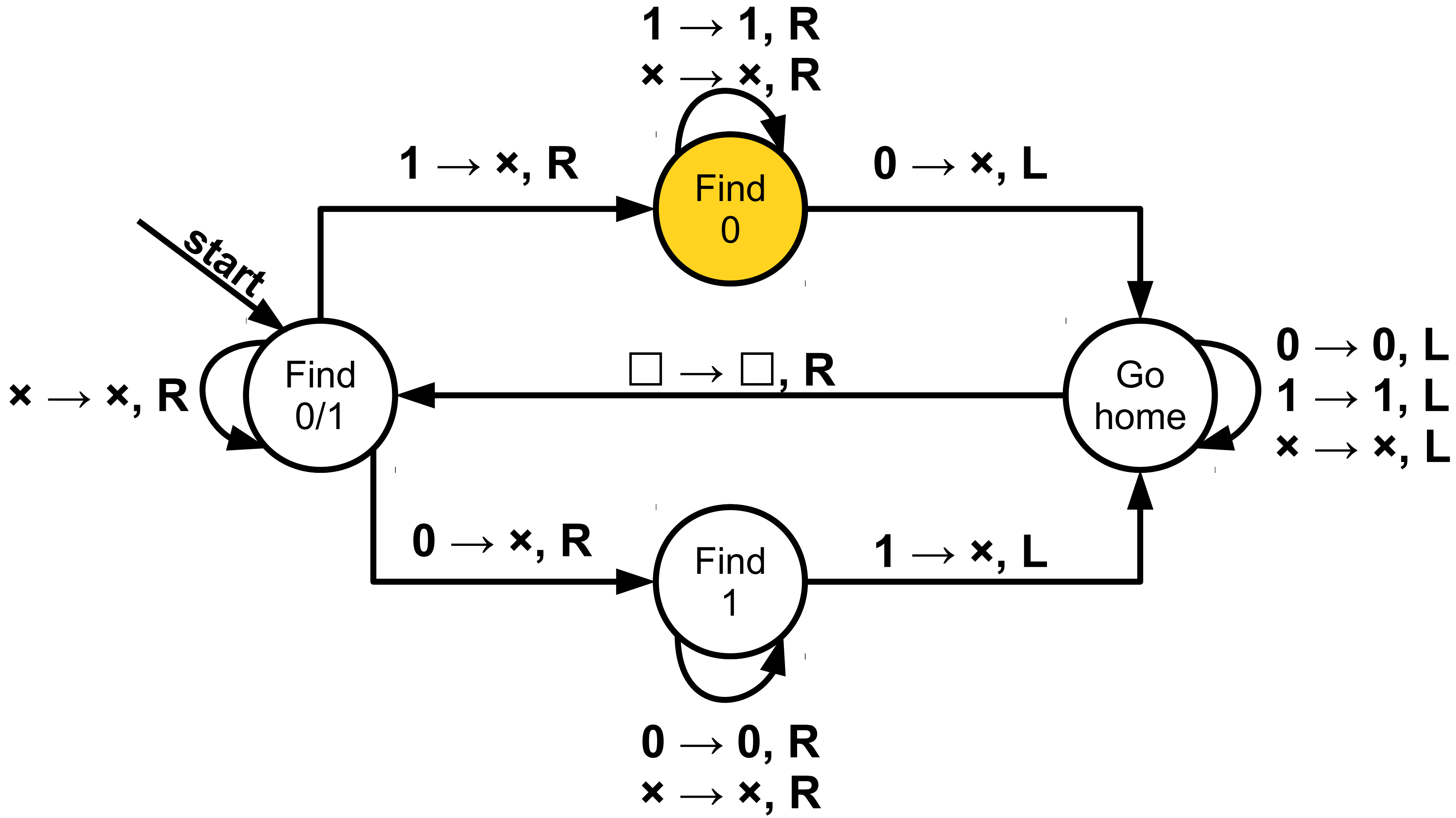

1 → 1, R
× → ×, R
1 → ×, R
0 → ×, L
start
× → ×, R
Find 0/1
Find 0
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R



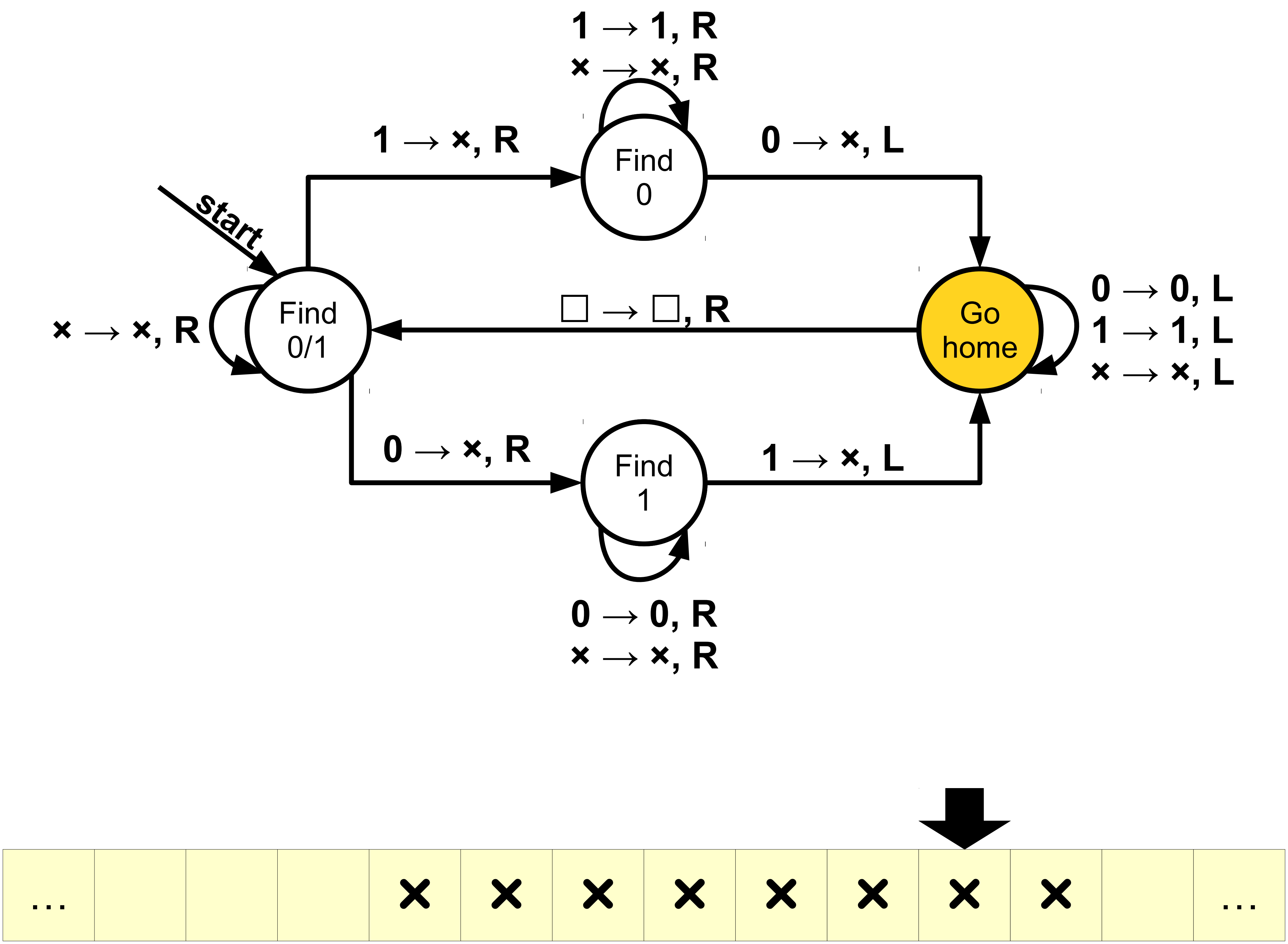
…				×	×	×	×	×	1	×	0		…

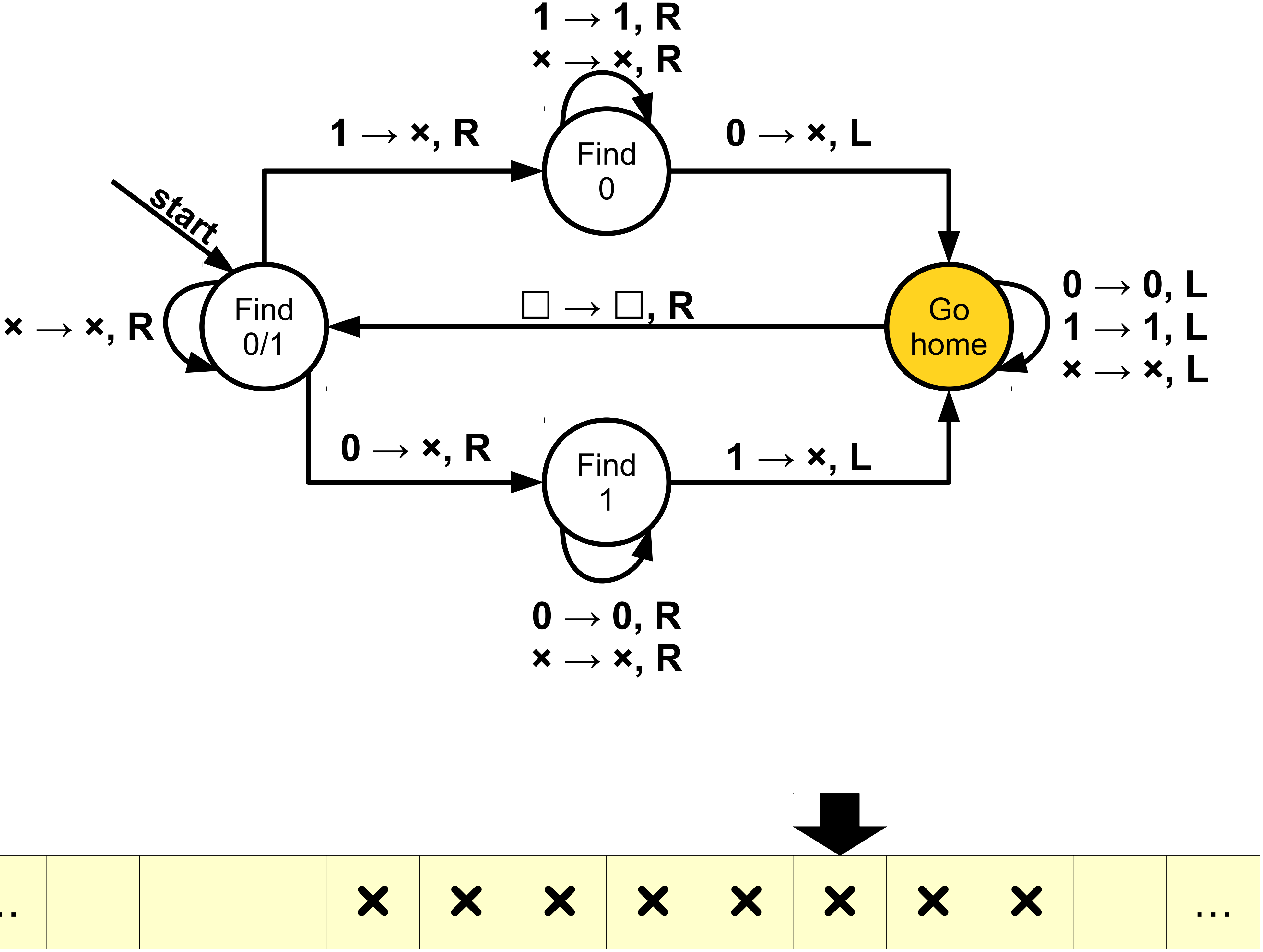

1 → 1, R
× → ×, R
1 → ×, R
0 → ×, L
start
Find
0
× → ×, R
Find
0/1
□ → □, R
Go
home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find
1
1 → ×, L
0 → 0, R
× → ×, R
…
×
×
×
×
×
1
×
0
…

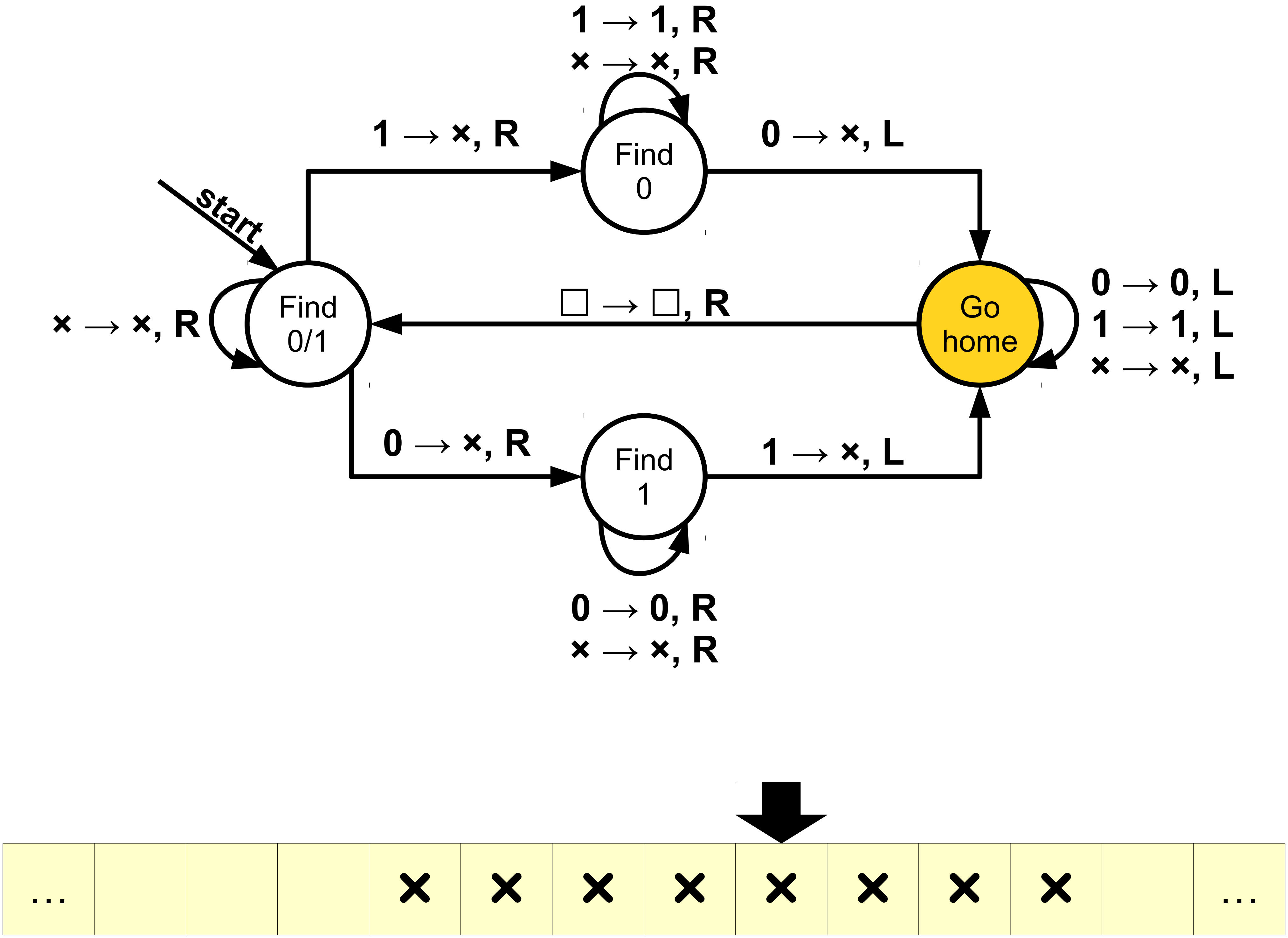

1 → 1, R
× → ×, R
1 → ×, R
Find 0
0 → ×, L
start
× → ×, R
Find 0/1
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R
…
×
×
×
×
×
×
×
0
…

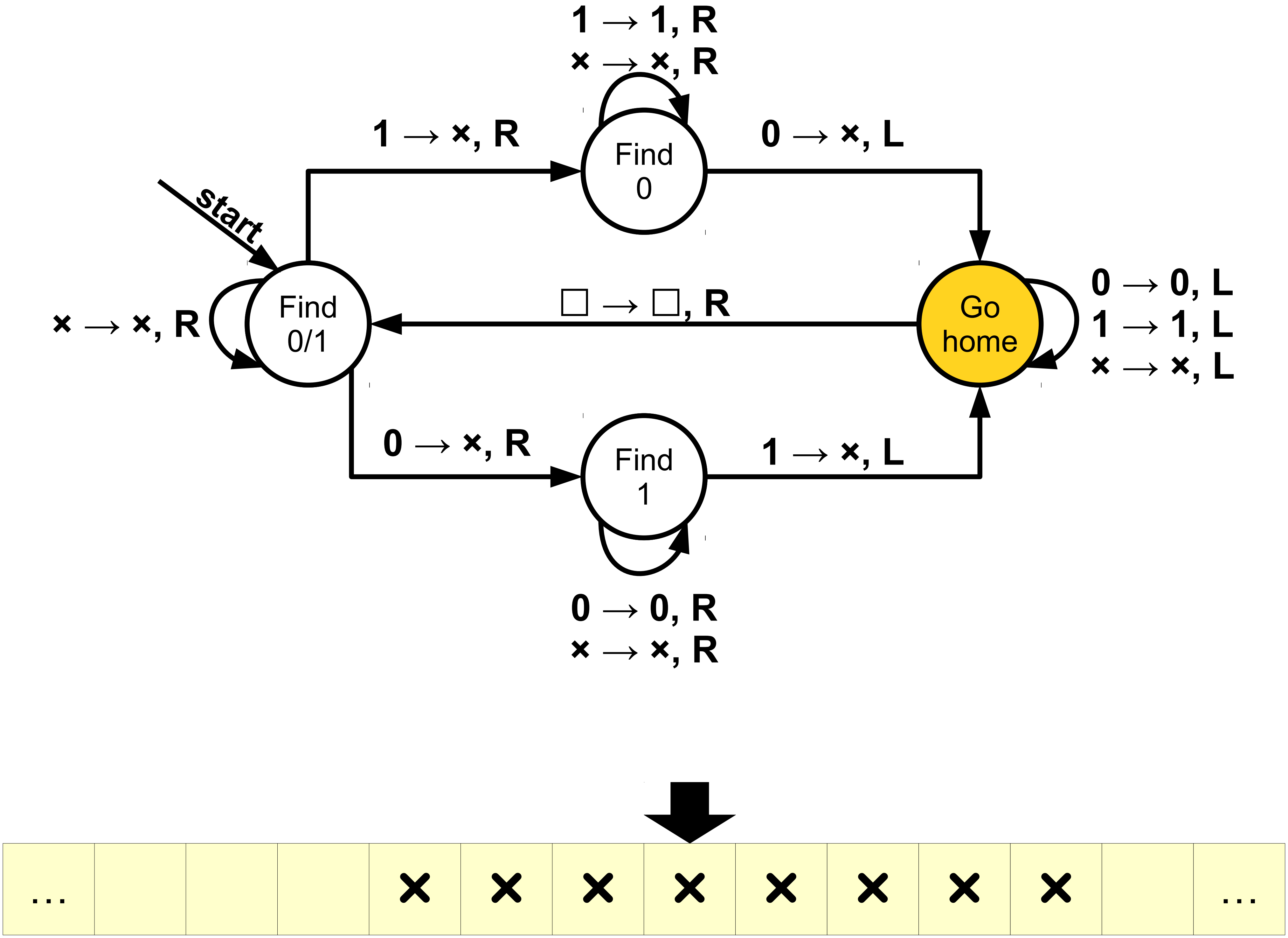

1 → 1, R
× → ×, R
1 → ×, R
Find 0
0 → ×, L
start
× → ×, R
Find 0/1
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R

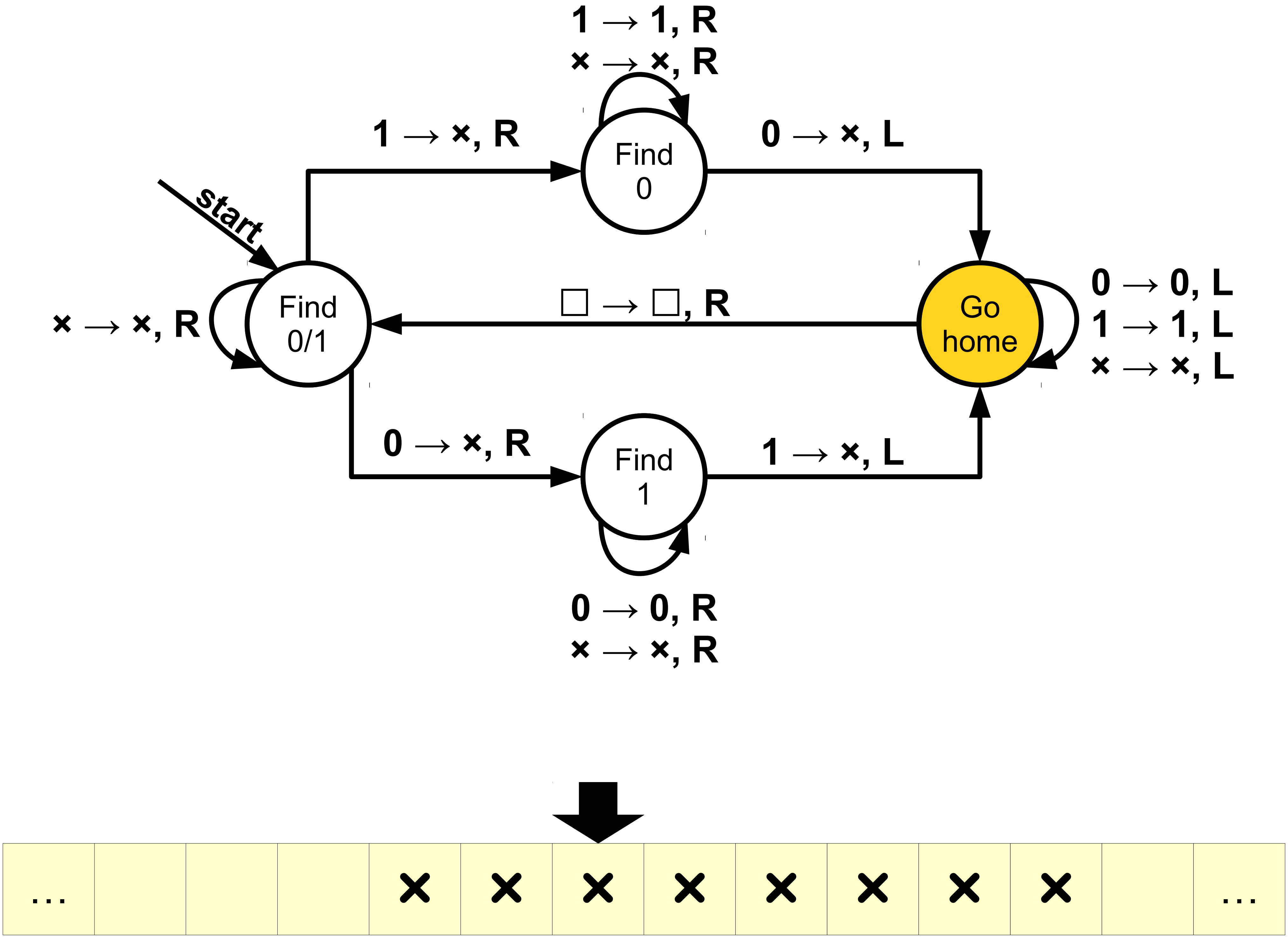
…				×	×	×	×	×	×	×	0		…


start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
0 → ×, L
Go home
0 → 0, L
1 → 1, L
× → ×, L
□ → □, R
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
…
×
×
×
×
×
×
×
×
…


start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
0 → ×, L
Go home
0 → 0, L
1 → 1, L
× → ×, L
□ → □, R
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
…
×
×
×
×
×
×
×
×
…


start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
0 → ×, L
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
…
×
×
×
×
×
×
×
×
…


1 → 1, R
× → ×, R
1 → ×, R
0 → ×, L
Find
0
start
Find
0/1
× → ×, R
□ → □, R
Go
home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find
1
1 → ×, L
0 → 0, R
× → ×, R
…
×
×
×
×
×
×
×
×
…


start
Find 0/1
× → ×, R
1 → ×, R
Find 0
1 → 1, R
× → ×, R
0 → ×, L
0 → ×, R
Find 1
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1 → ×, L
Go home
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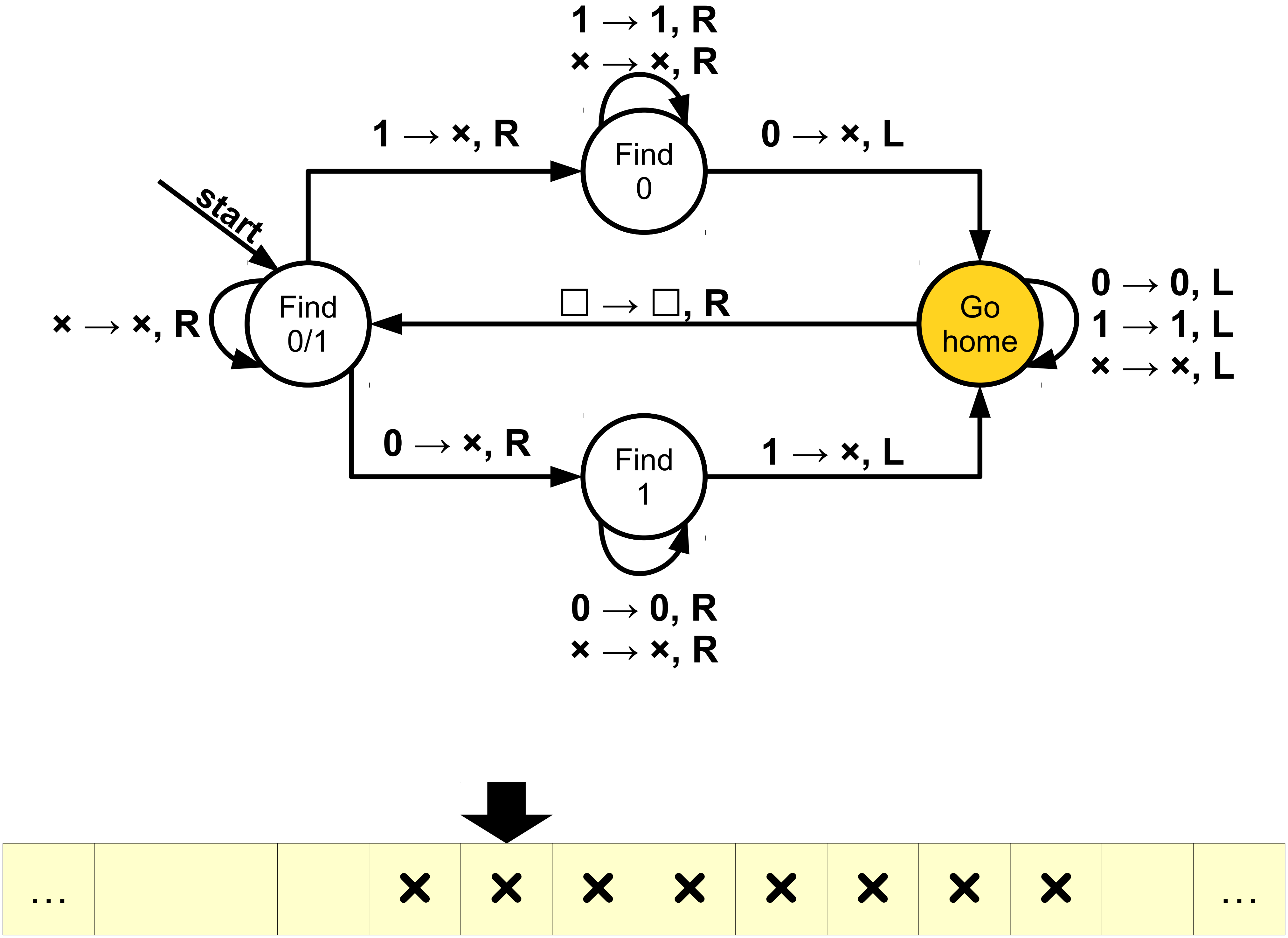
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start
Find 0/1
× → ×, R
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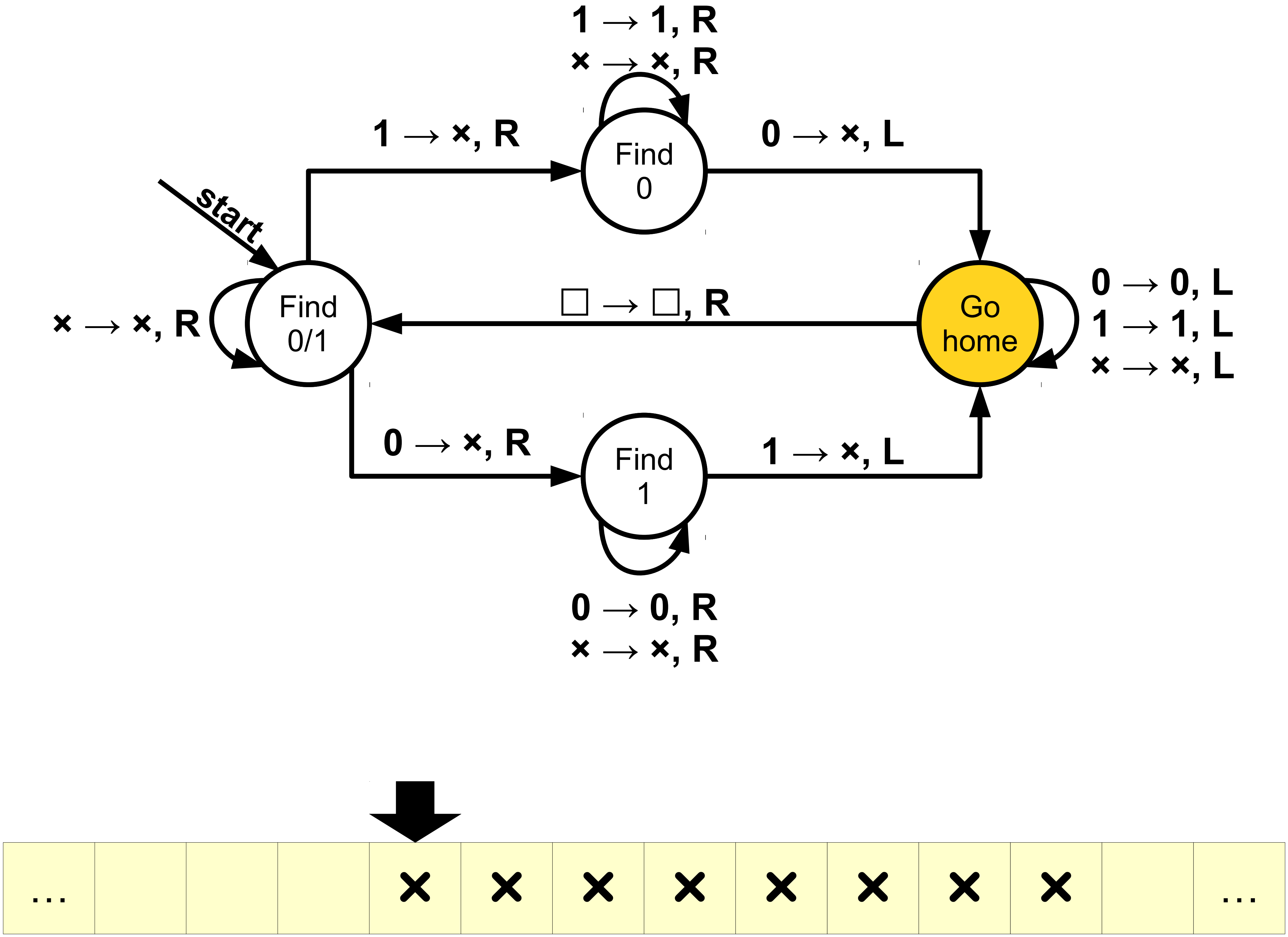
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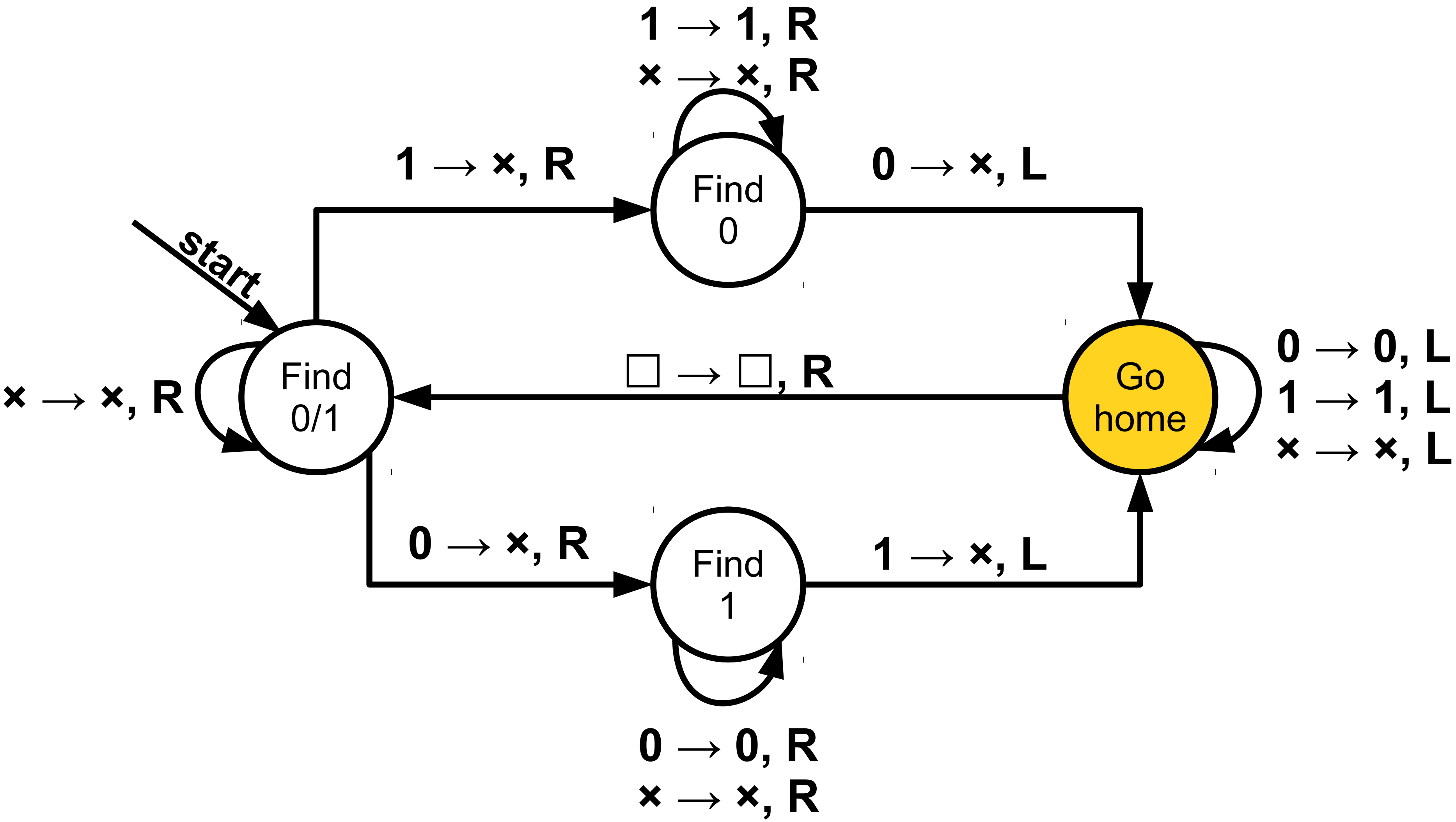
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0 → ×, R
Find 1
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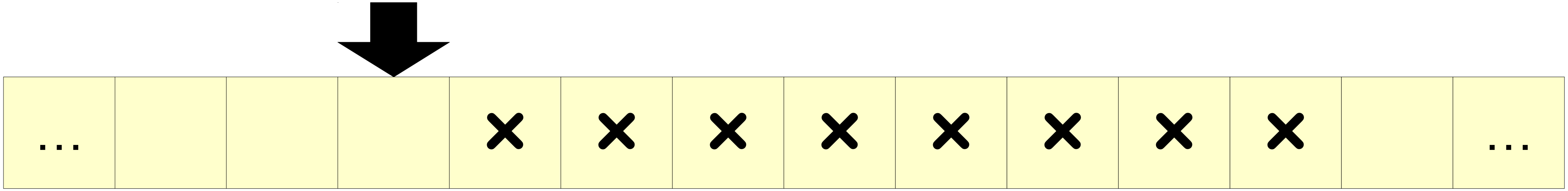
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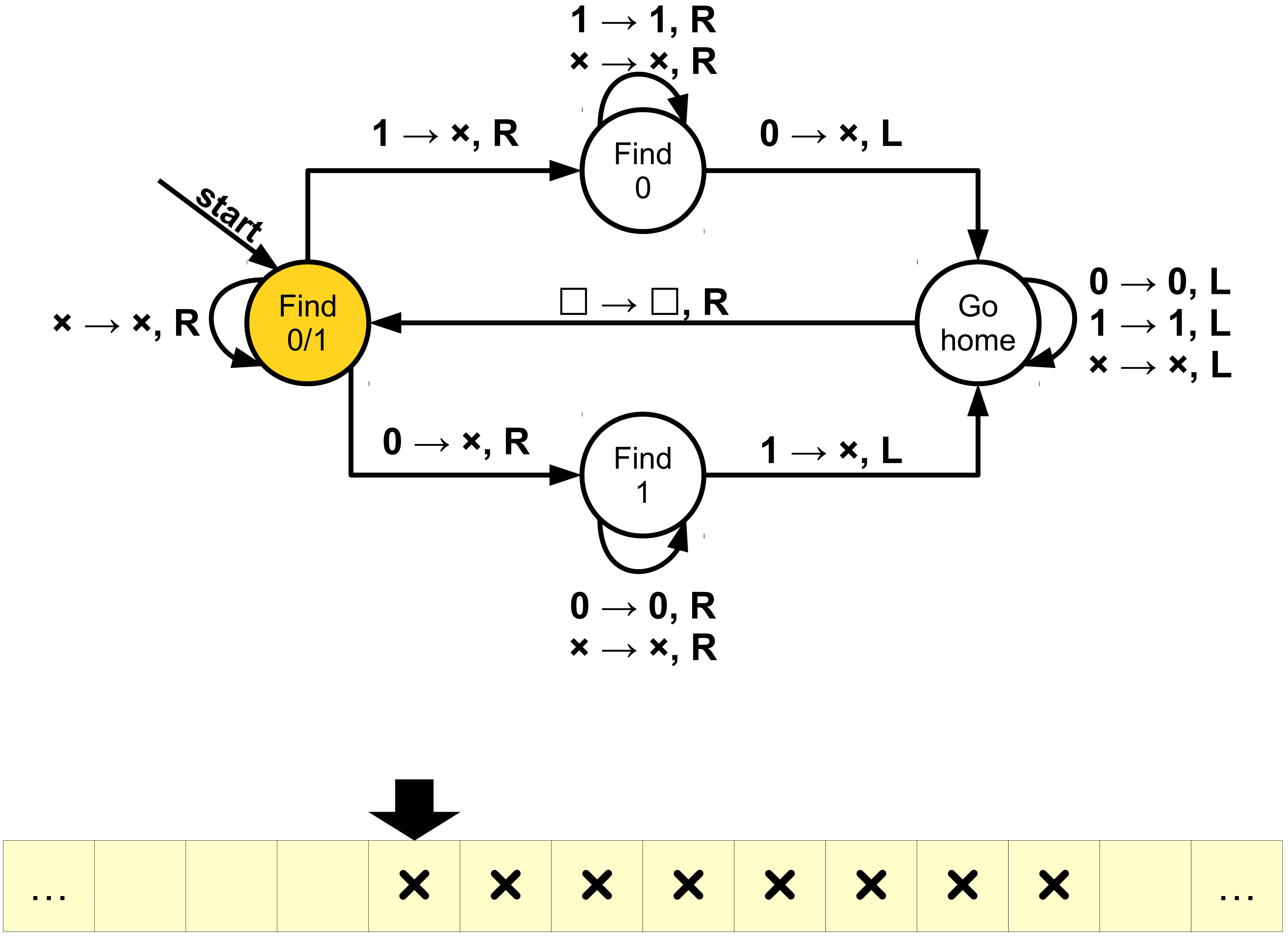
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0 → 0, L
1 → 1, L
× → ×, L
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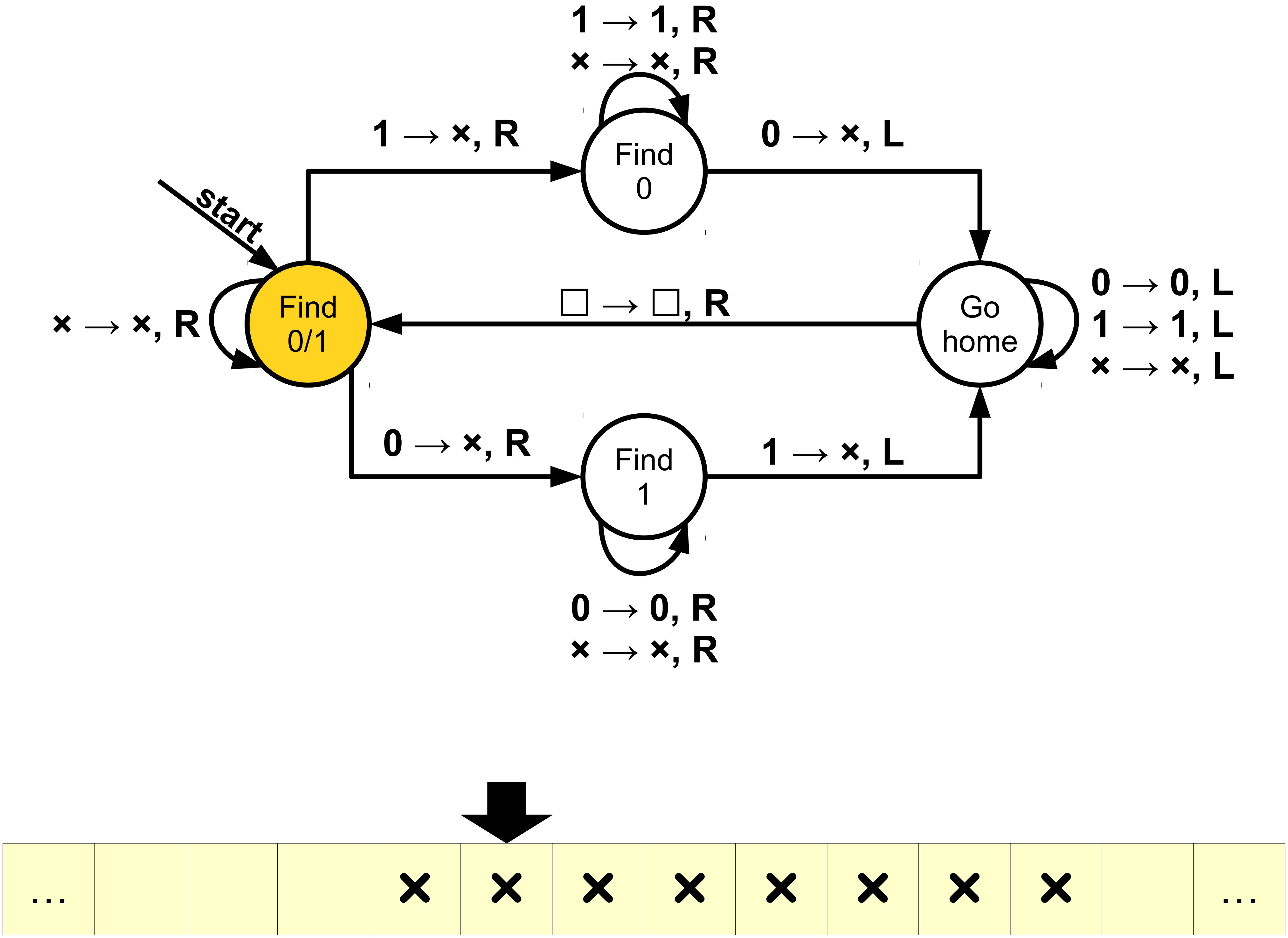
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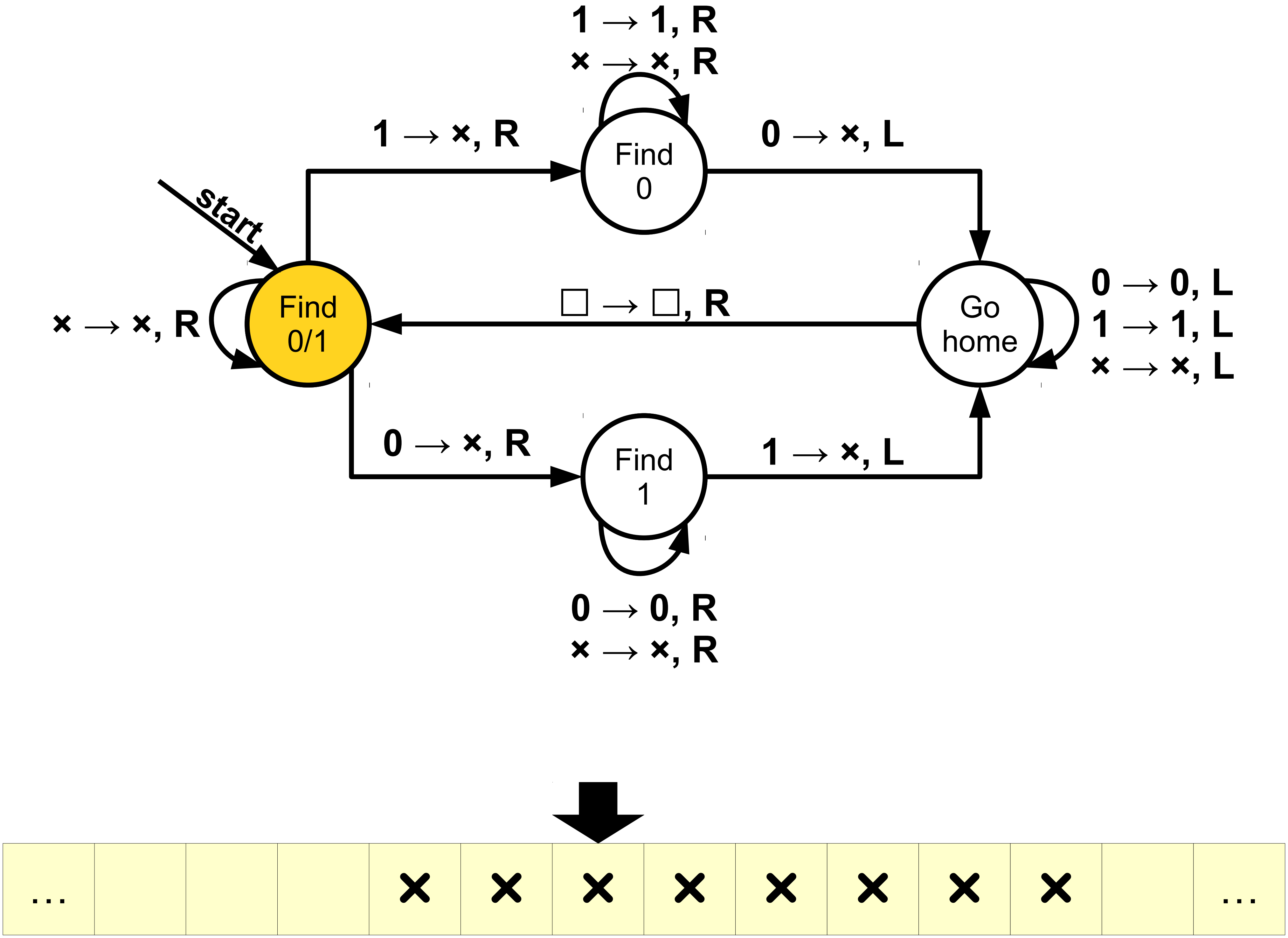
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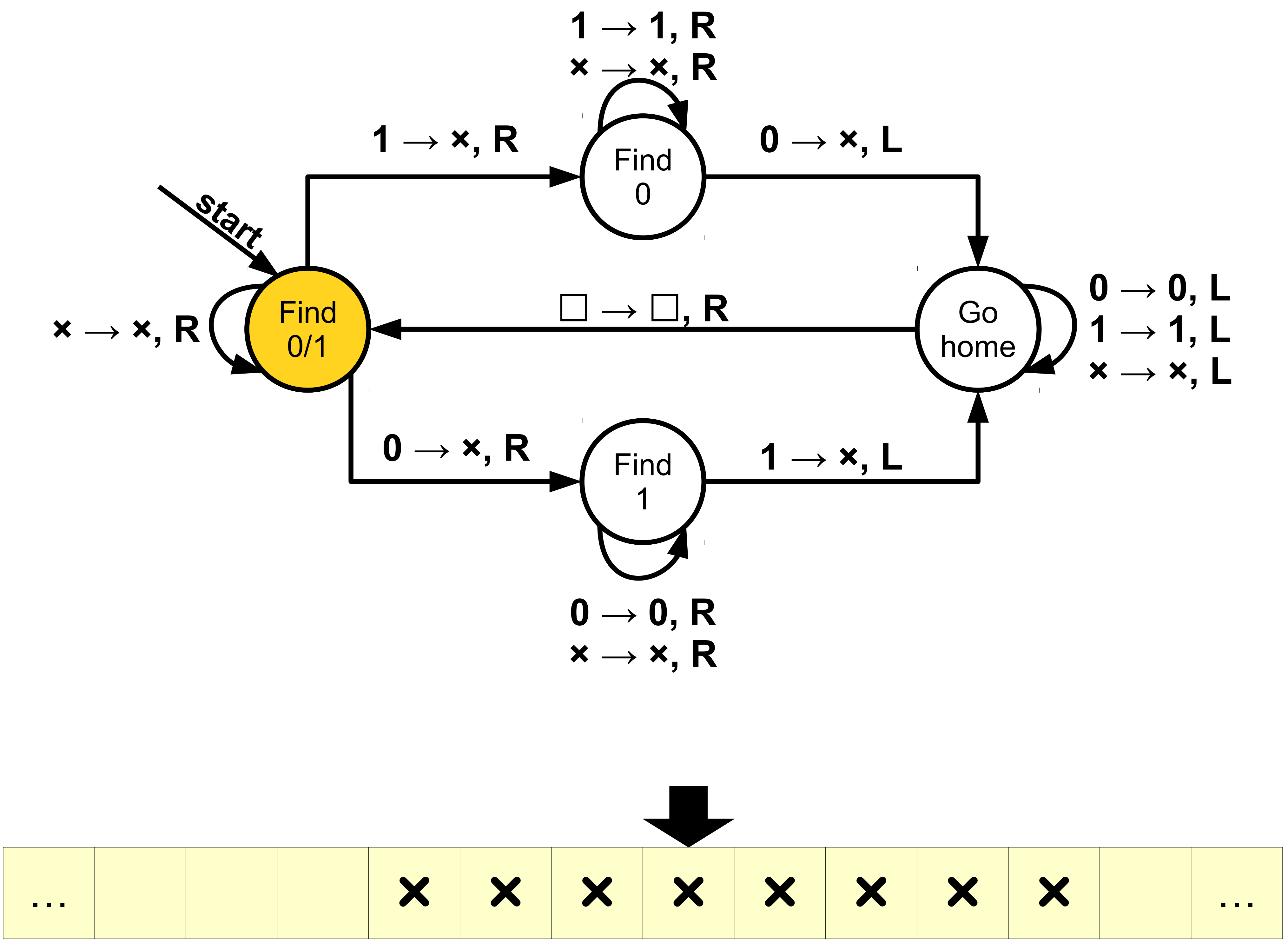
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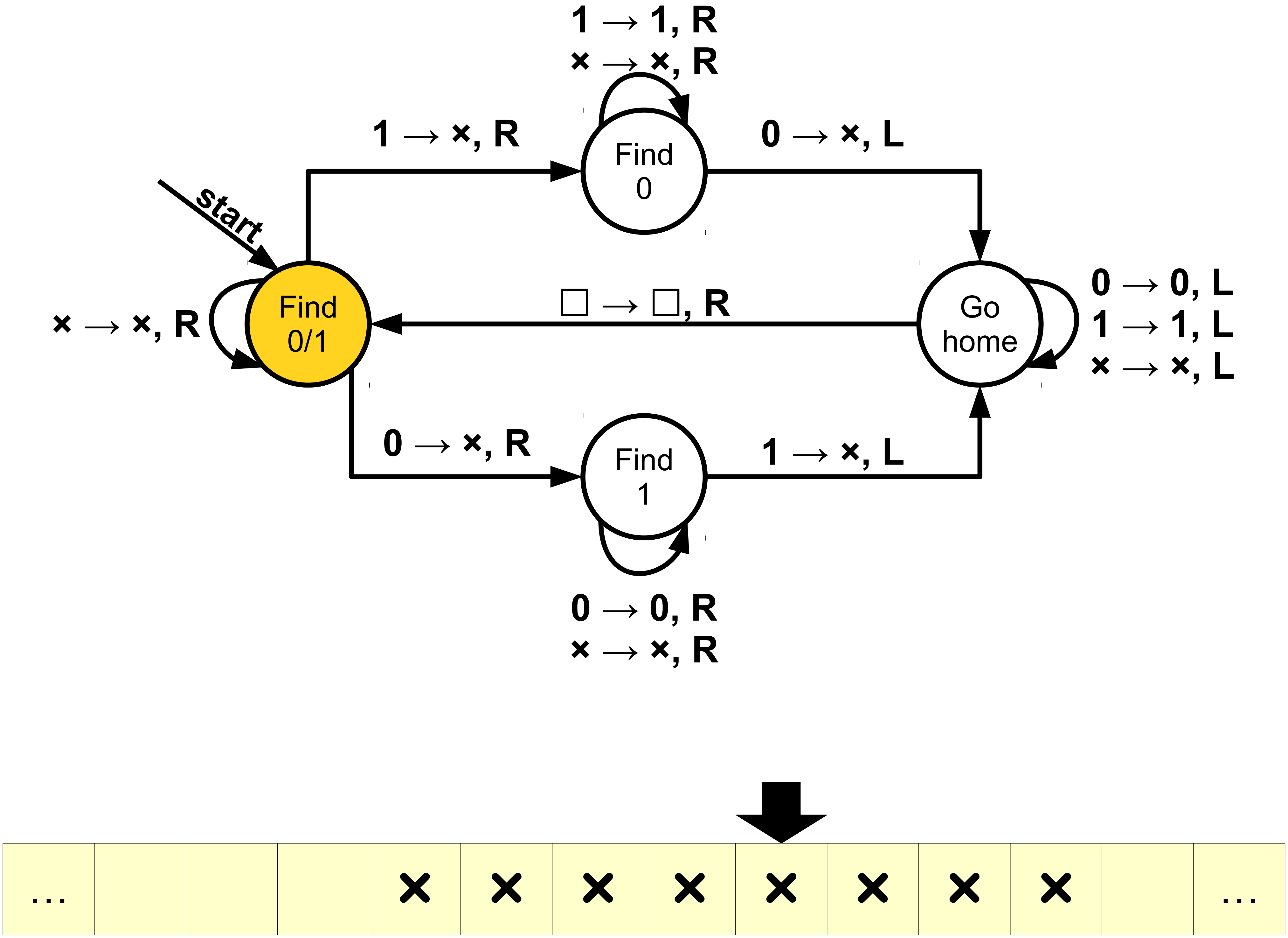
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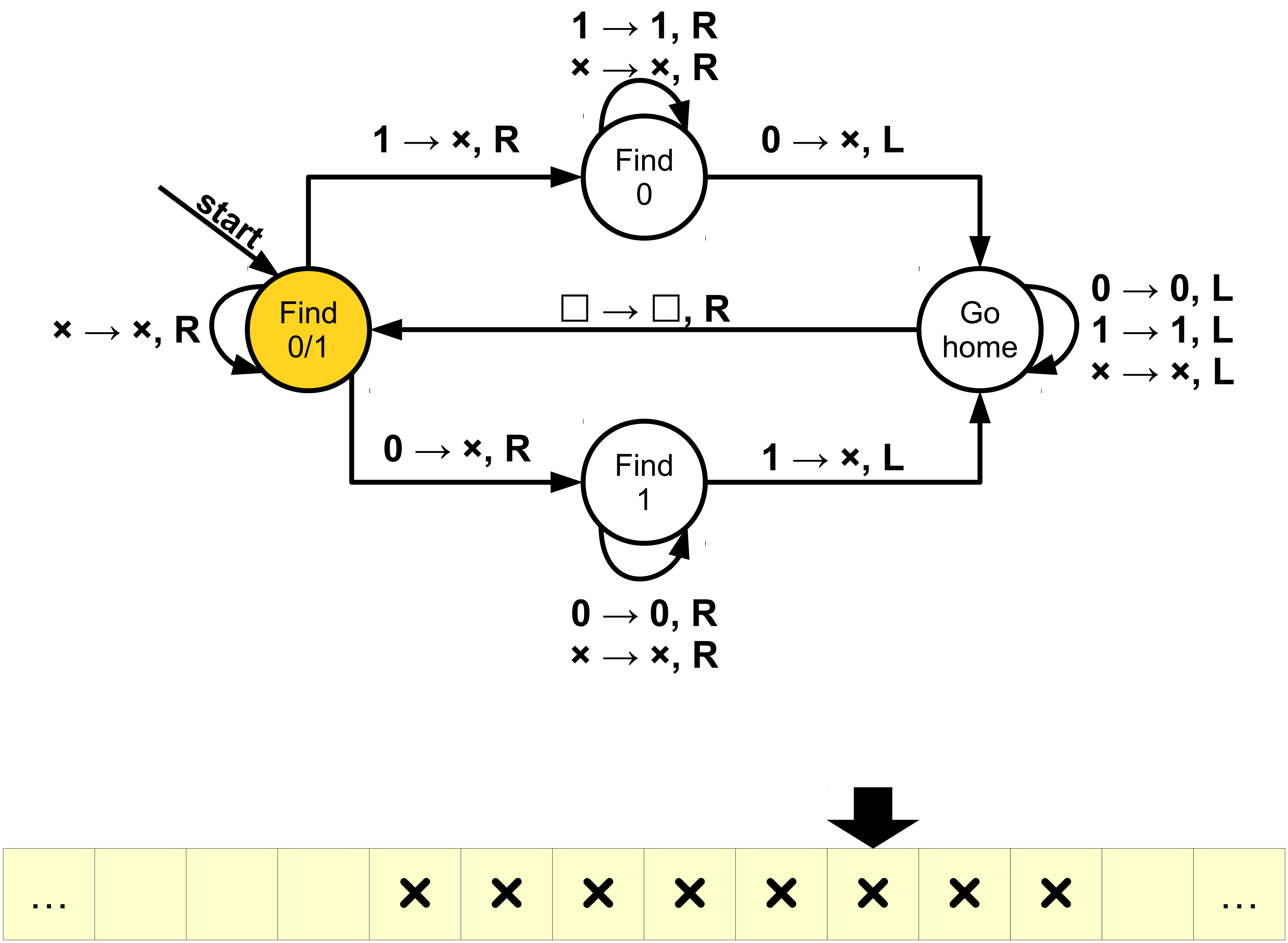
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Find 1
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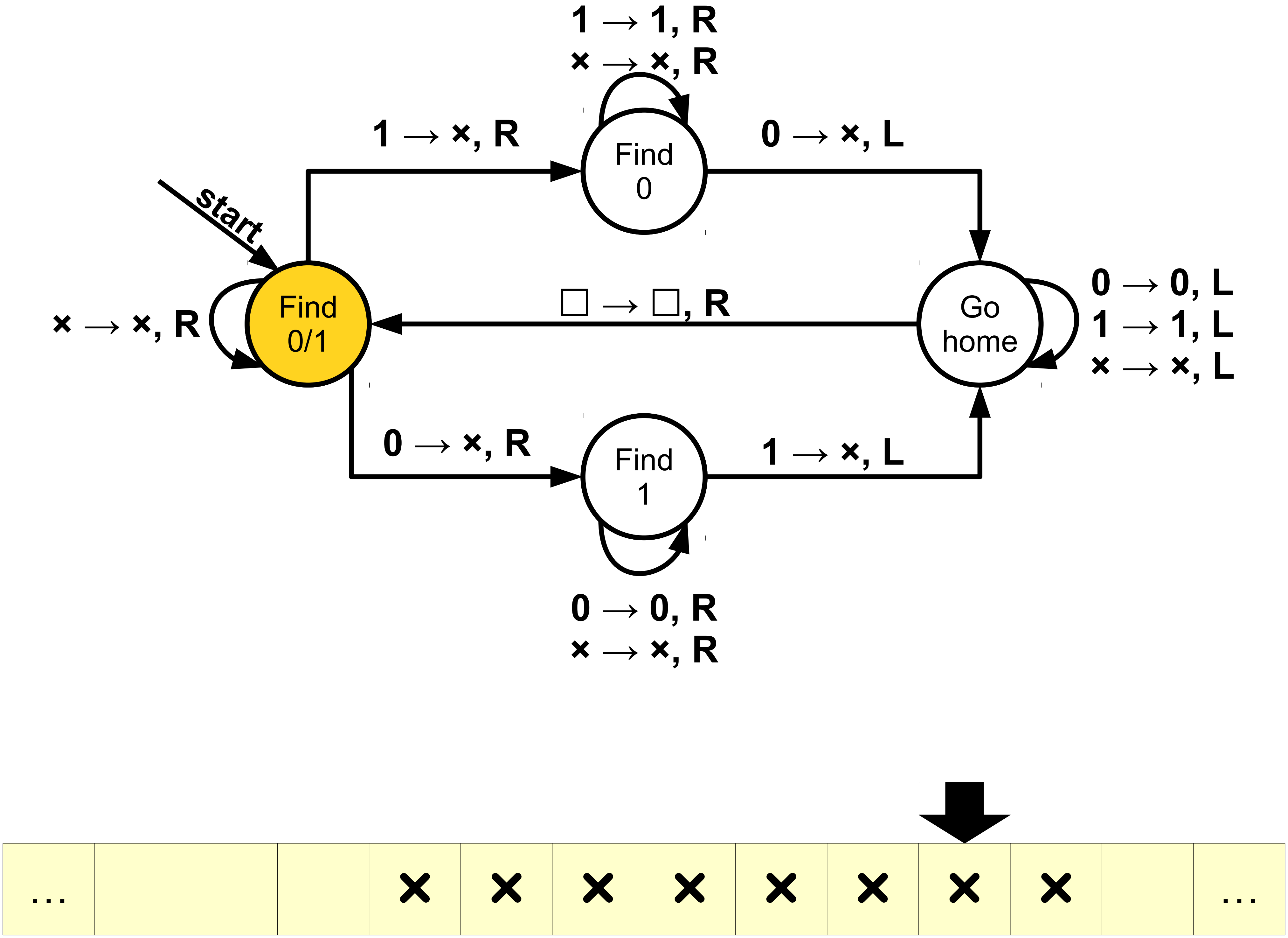
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□ → □, R
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Find 1
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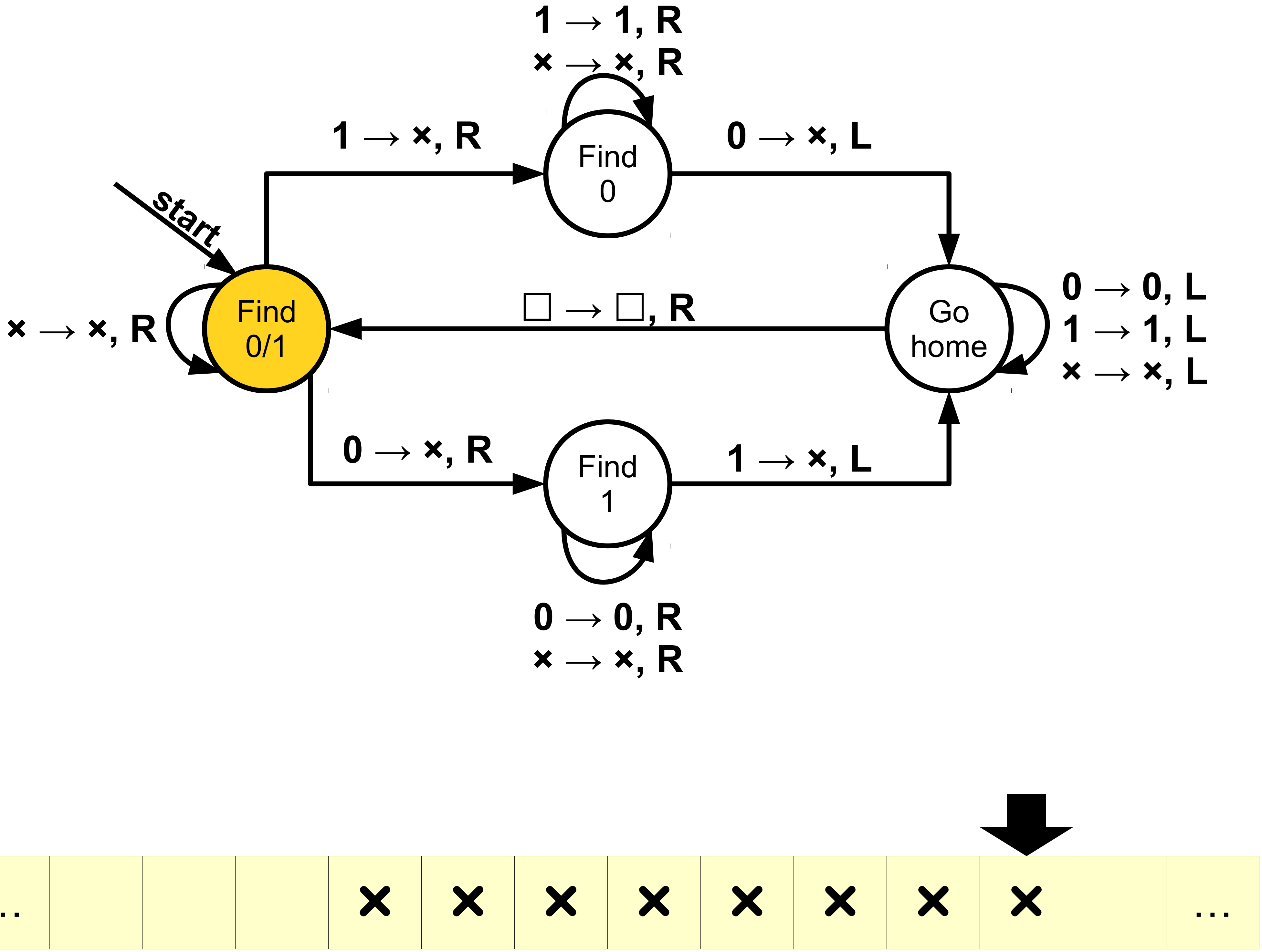
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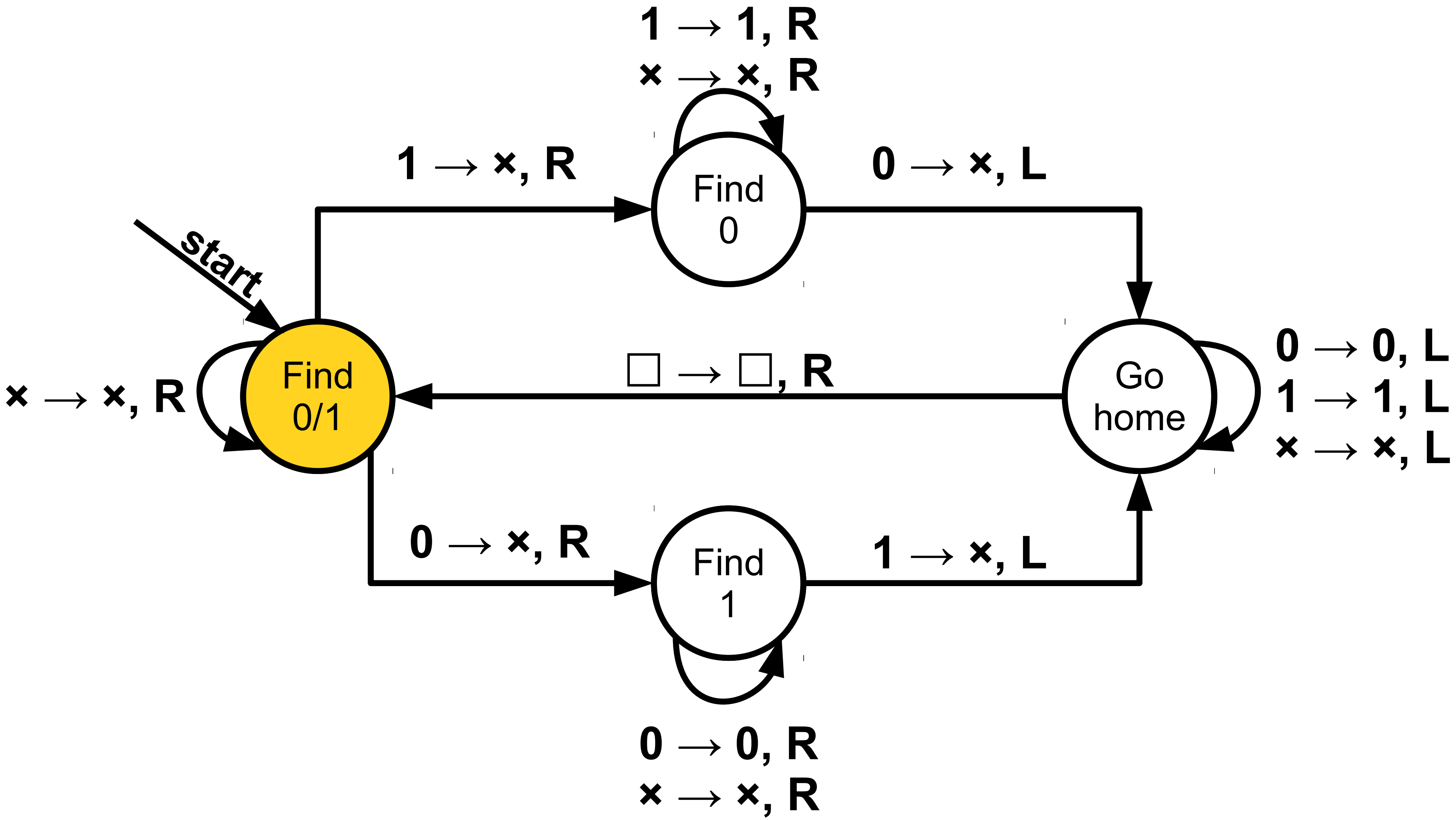
1 → 1, R
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Find 0
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□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
0 → 0, R
× → ×, R

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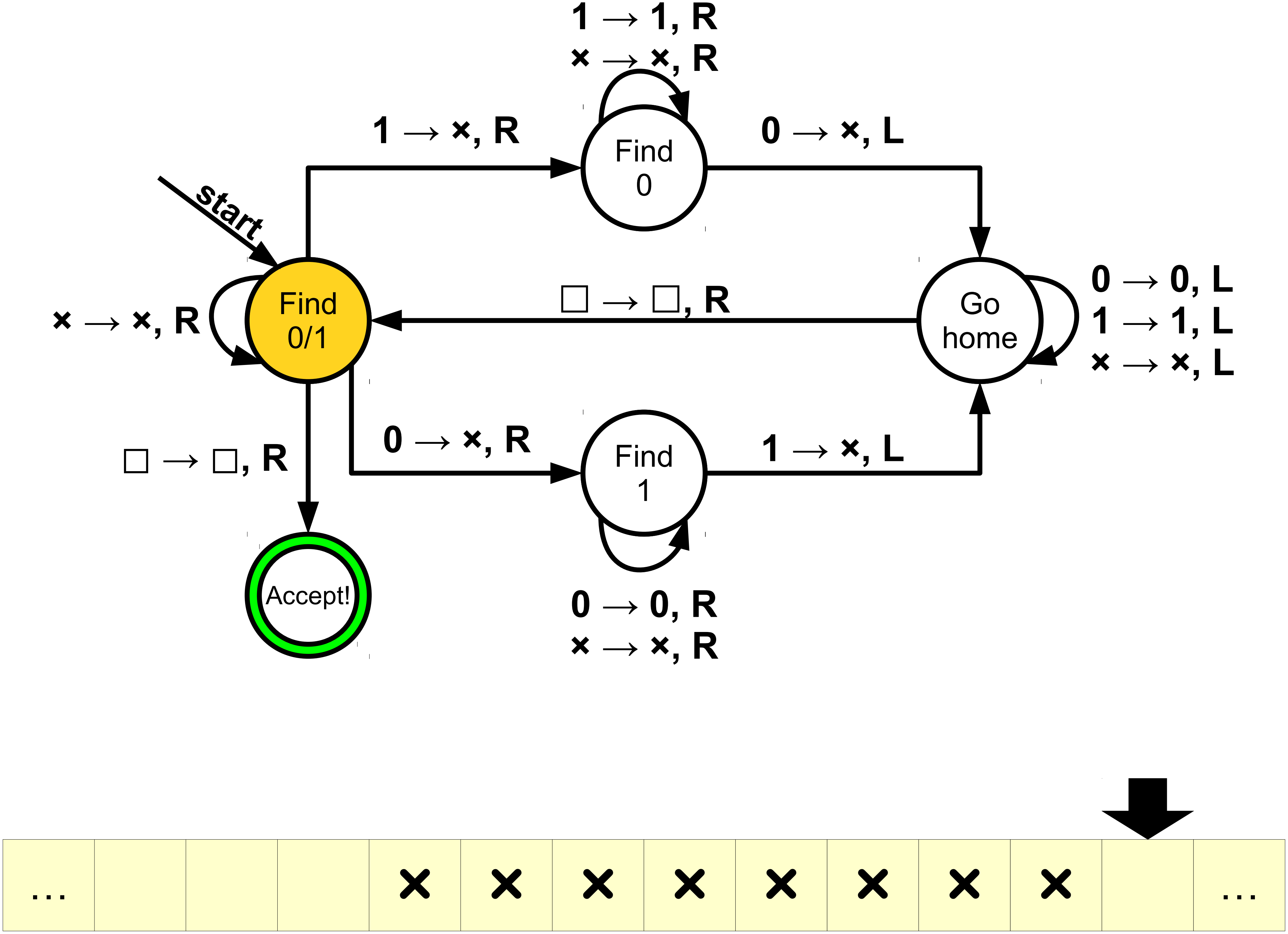
start
Find 0/1
× → ×, R
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Go home
0 → 0, L
1 → 1, L
× → ×, L
□ → □, R
0 → ×, R
Find 1
0 → 0, R
× → ×, R
1 → ×, L
□ → □, R
Accept!
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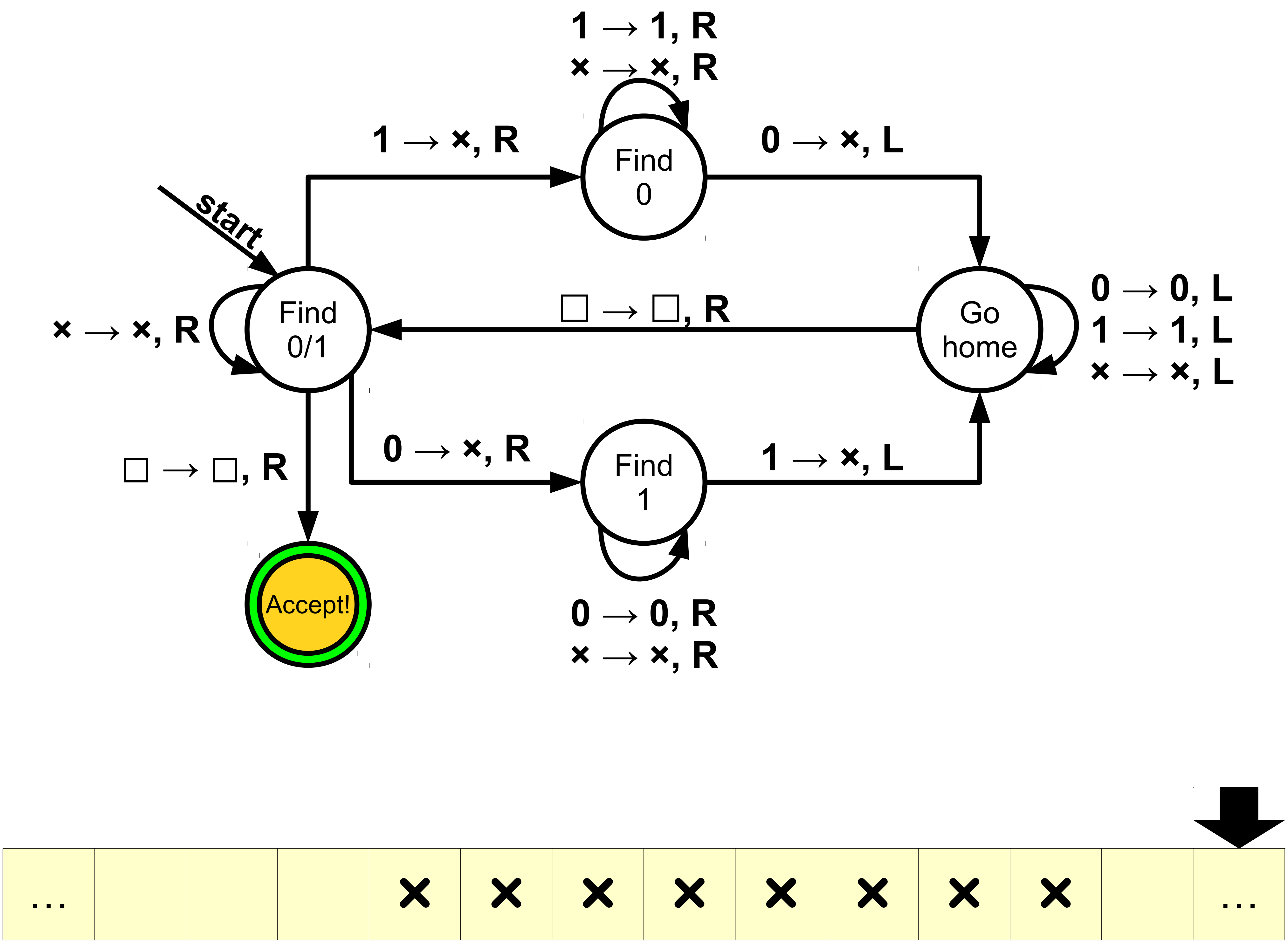
1 → 1, R
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Find 0
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× → ×, L
0 → ×, R
Find 1
1 → ×, L
□ → □, R
Accept!
0 → 0, R
× → ×, R
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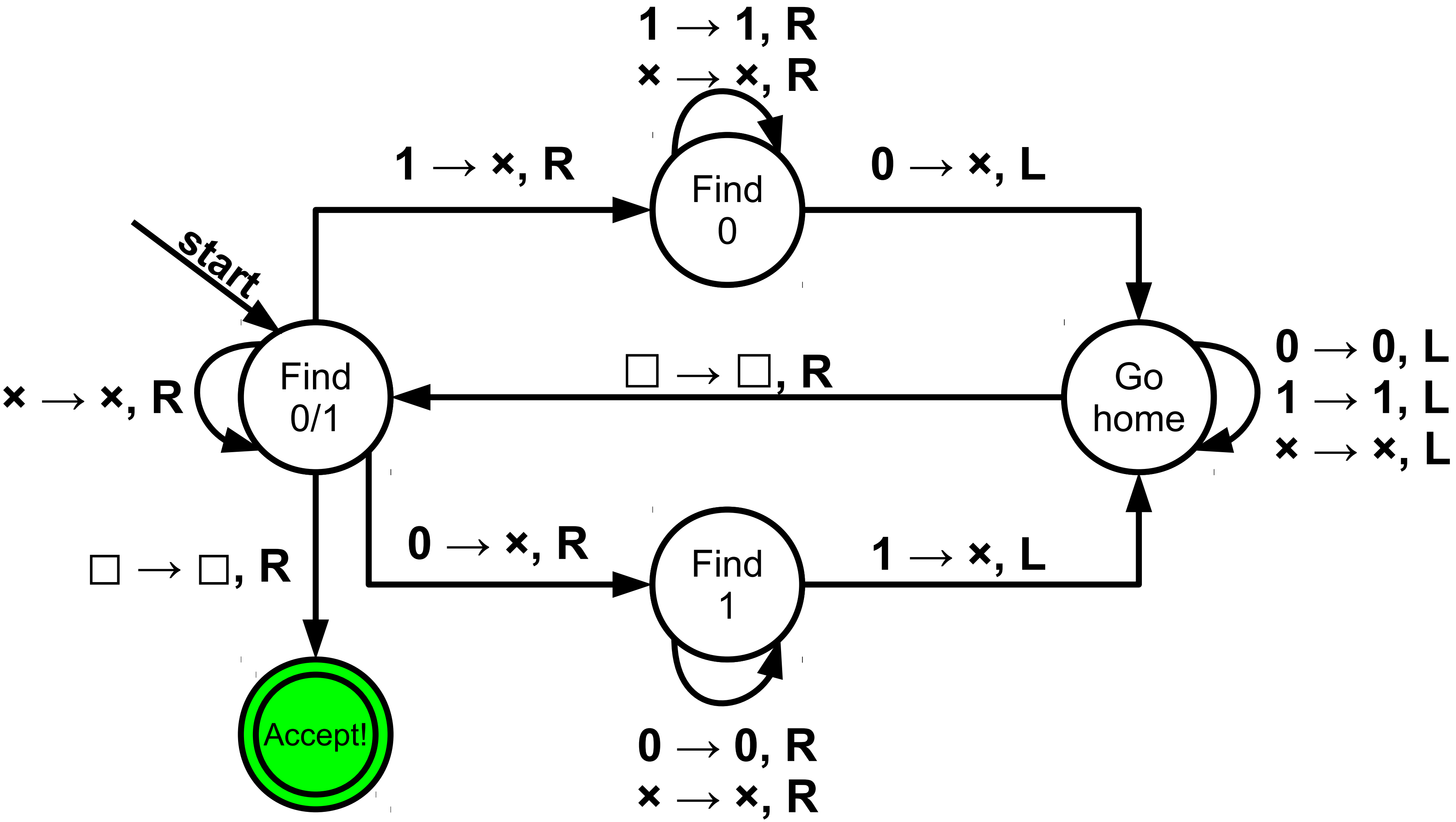
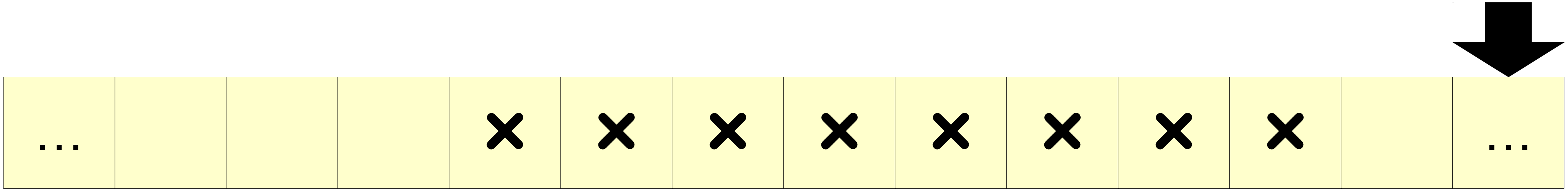

1 → 1, R
× → ×, R
1 → ×, R
0 → ×, L
start
Find 0
Find 0/1
× → ×, R
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
1 → ×, L
Find 1
□ → □, R
Accept!
0 → 0, R
× → ×, R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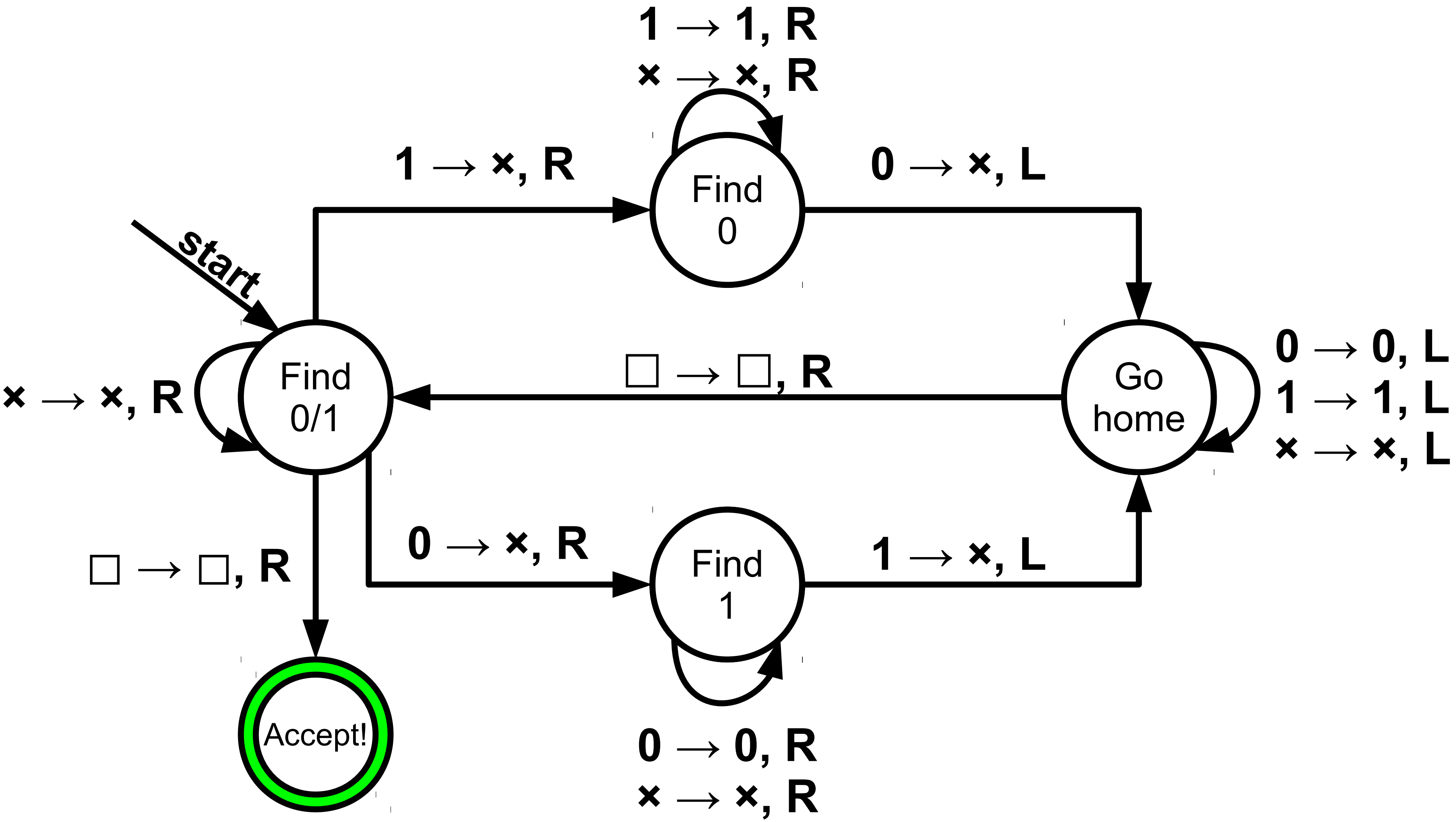
1 → 1, R
× → ×, R
1 → ×, R
Find 0
0 → ×, L
start
Find 0/1
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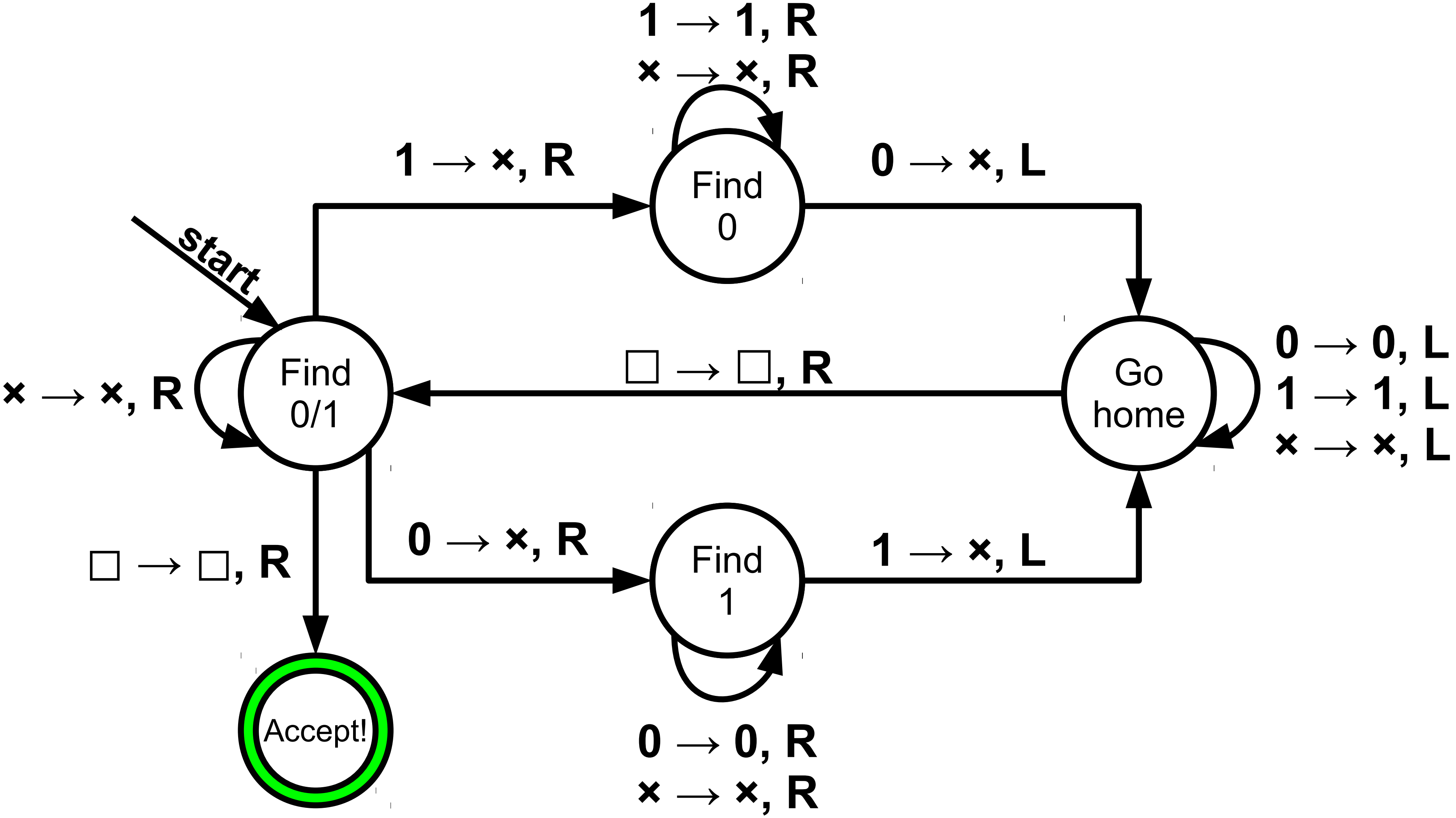
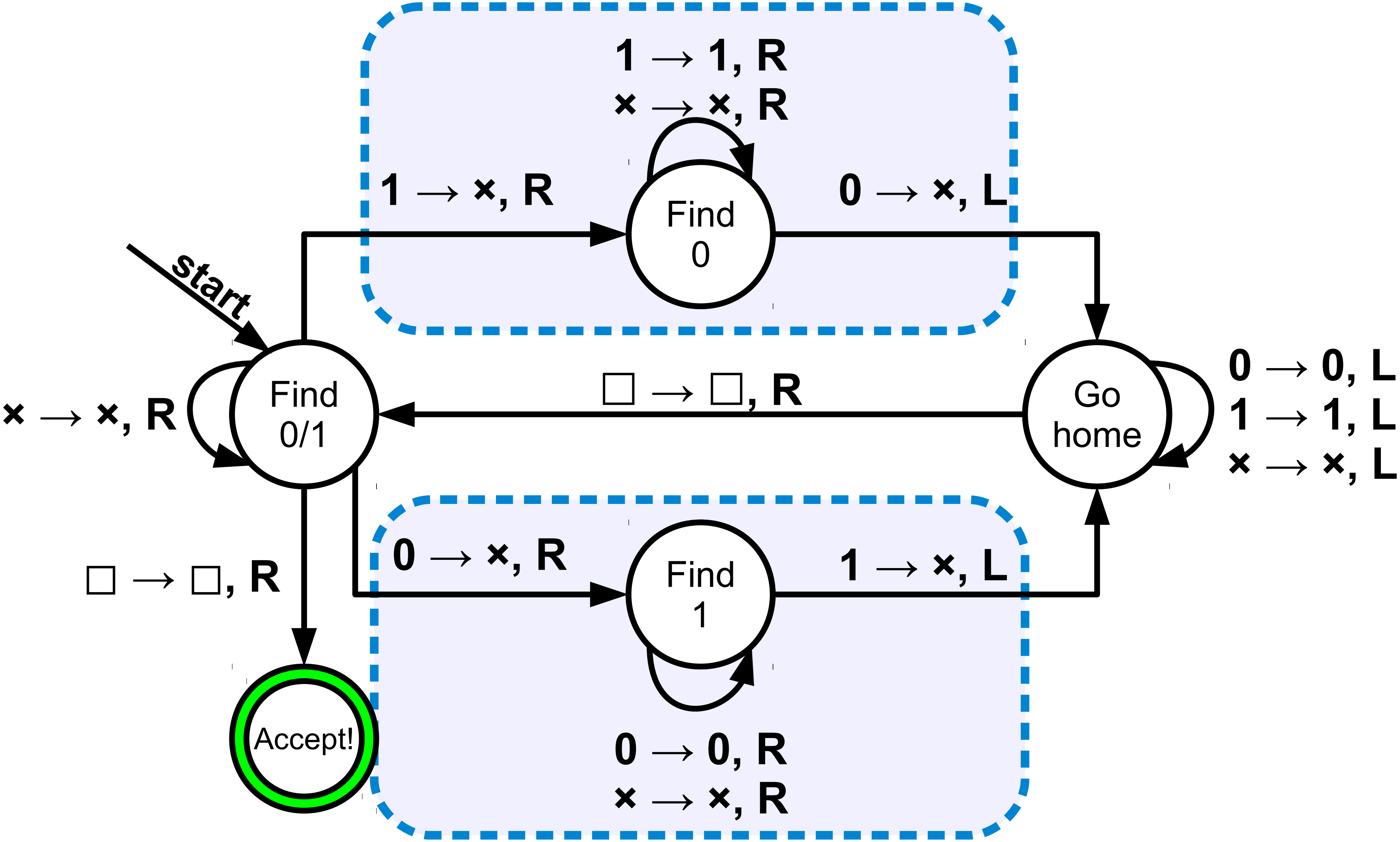
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
0 → ×, R
Find 1
1 → ×, L
□ → □, R
Accept!
0 → 0, R
× → ×, R



Going forward, we'll ignore the missing transitions and pretend they implicitly reject.



1 → 1, R
× → ×, R
1 → ×, R
Find 0
0 → ×, L
start
× → ×, R
Find 0/1
□ → □, R
Go home
0 → 0, L
1 → 1, L
× → ×, L
□ → □, R
0 → ×, R
Find 1
1 → ×, L
Accept!
0 → 0, R
× → ×, R

Constant Storage

- Sometimes, a TM needs to remember some additional information that can't be put on the tape.
- In this case, you can use similar techniques from DFAs and introduce extra states into the TM's finite-state control.
- The finite-state control can only remember one of finitely many things, but that might be all that you need!

Time-Out for Announcements!

Problem Set Six

- Problem Set Five was due at the start of lecture today.
  - Due Tuesday with one late day and Wednesday with two late days.
- Problem Set Six goes out now, is due at the start of next Monday's lecture.
  - Play around with nonregular languages, the Myhill-Nerode theorem, and context-free grammars!
- The second midterm is a week from Thursday. We *do not* recommend using late days on Problem Set Six.

Your Questions

“What do you think about entrepreneurship? Have you ever considered becoming an entrepreneur? Why or why not?”

I had a brilliant idea for a startup in my freshman year, but then Google did it. ☺

It's a mixed bag! I think the entrepreneurial spirit is great in that it challenges people to just go fix the problems they see. I think it's a bit unhealthy in that people feel pressured to make startups when they honestly should just keep studying and learning more about the world.

"How are you working towards making CS a factor in making the lives of the less fortunate better when all it seems that CS, outside of academia, can do is solve problems for the rich?"

I guarantee you I'm not doing enough. I can talk about some of the things that I'm currently doing / hoping to do.

Computing gives people a chance to climb up the economic ladder and can empower the weak and vulnerable if used correctly. I hope that I'm giving people the tools to help make this happen.

"If I did poorly on the midterm (failed) and well on the problem sets, what is my standing in the class? Am i at risk of failing?"

Here's full disclosure on how I compute grades!

1. I compute raw scores weighted by the amounts I said I was going to weight everything by (each problem set has a weight printed on the front, the midterms are 15% each, and the final is 30%.

2. I compute a grading curve. I never curve down: a 90% is always an A−, an 80% is always a B−, etc. I usually put the median as the cutoff between B/B+ and usually put the 25th percentile as the C+/B− cutoff. The B=/A− cutoff fluctuates a bit, but it's usually around the 60th percentile mark. I always do a follow-up check to make sure that I can explain all the grades I'm giving. I also leave out extra credit when designing the curve, but leave it in when assigning letter grades.

You can definitely pass the class if you failed the first exam – you can pass even if you didn't take it! Just try to avoid having two bad exams – that will really hurt your grade.

Back to CS103!

Another TM Design

- Consider the following language over $\Sigma = \{\texttt{0}, \texttt{1}\}$:

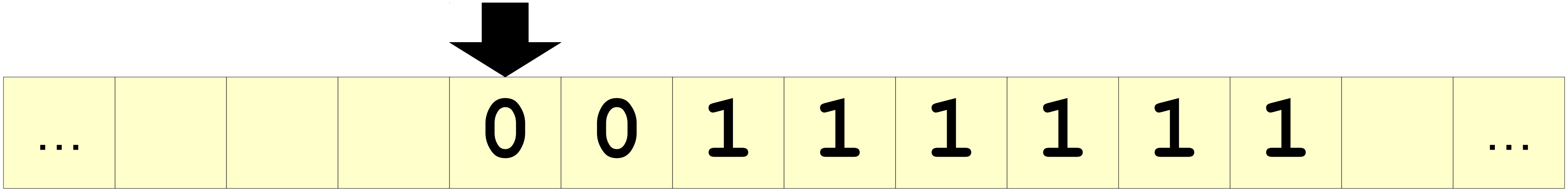
$$L = \{ \texttt{0}^n\texttt{1}^m \mid n, m \in \mathbb{N} \text{ and } m \text{ is a multiple of } n \}$$

- Is this language regular?
- How might we design a TM for this language?

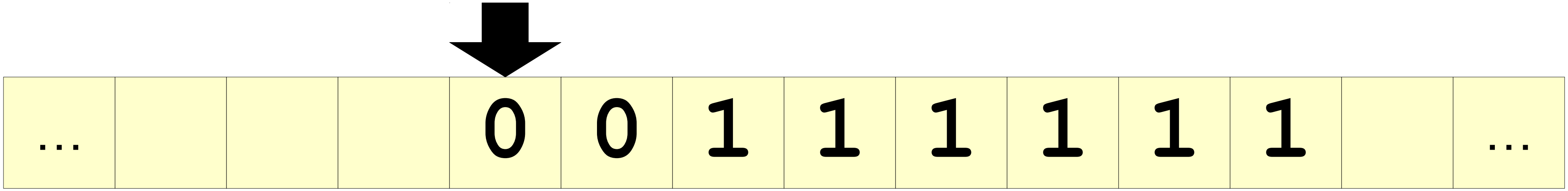
An Observation

- We can recursively describe when one number *m* is a multiple of *n*:
  - If $m = 0$, then *m* is a multiple of *n*.
  - Otherwise, *m* is a multiple of *n* iff $m - n$ is a multiple of *n*.
- **Idea:** Repeatedly subtract *n* from *m* until *m* becomes zero (good!) or drops below zero (bad!)

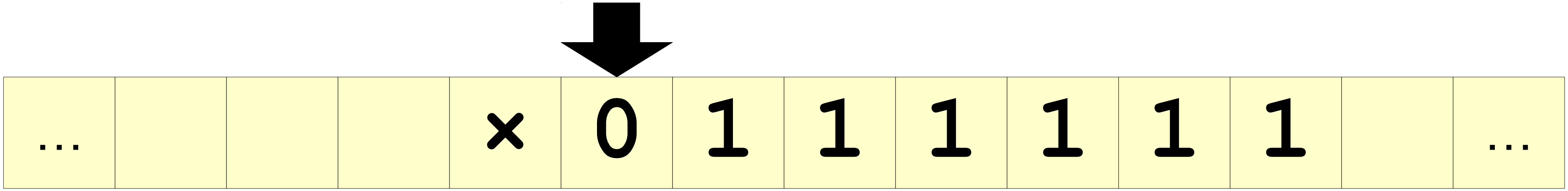
The Challenge



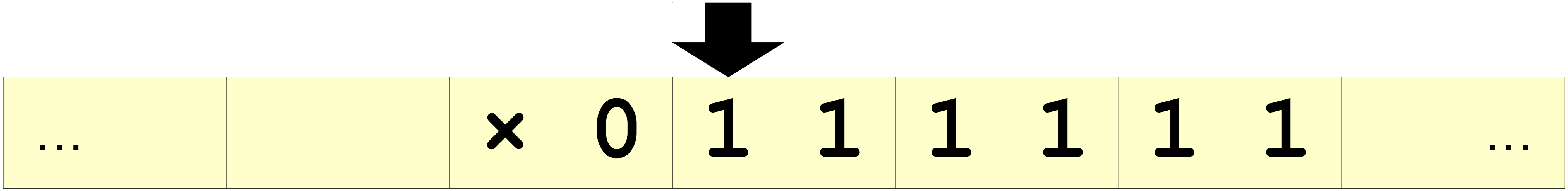
One Solution



One Solution



One Solution



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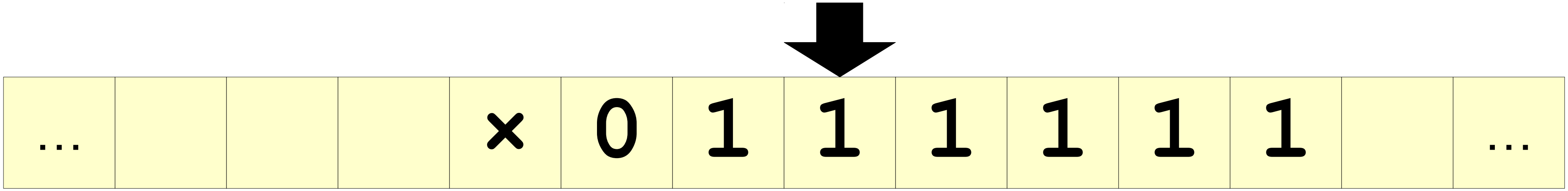
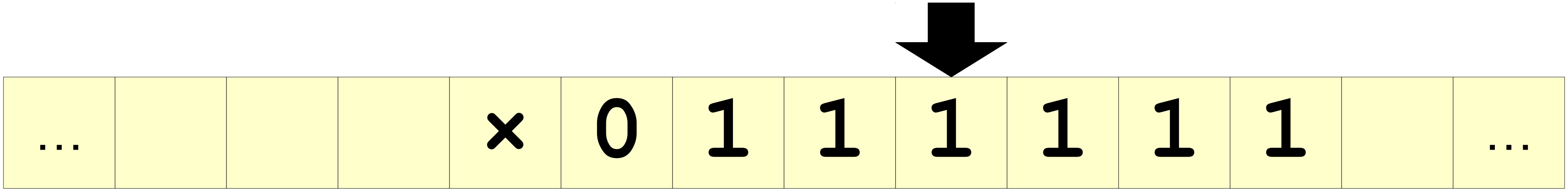
One Solution



One Solution



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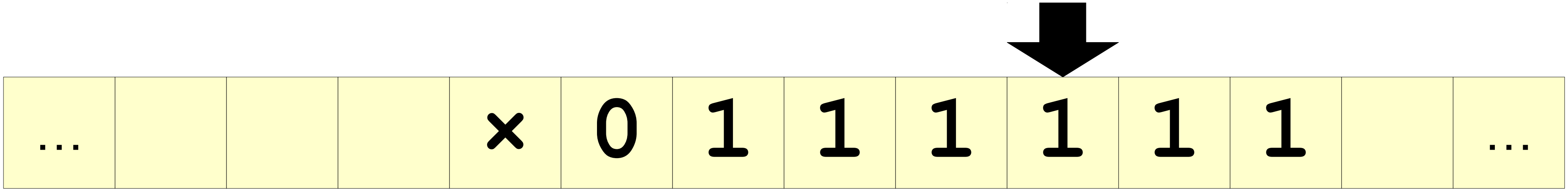
One Solution



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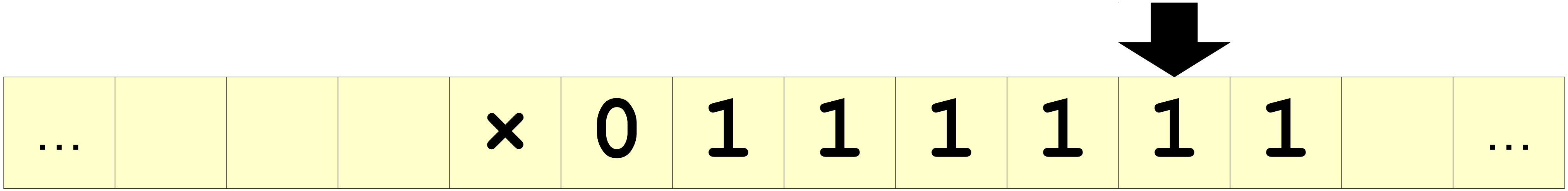

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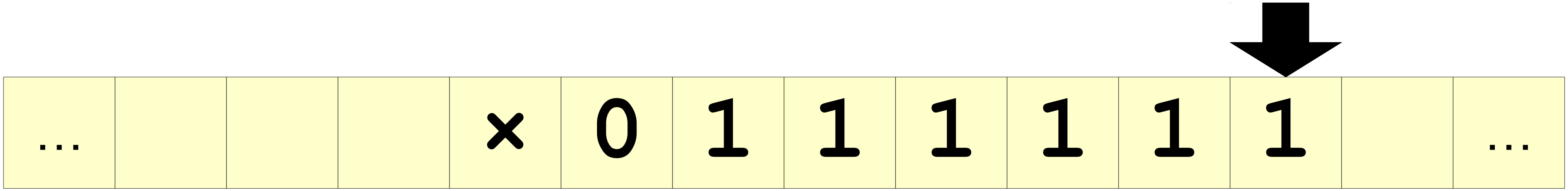
One Solution



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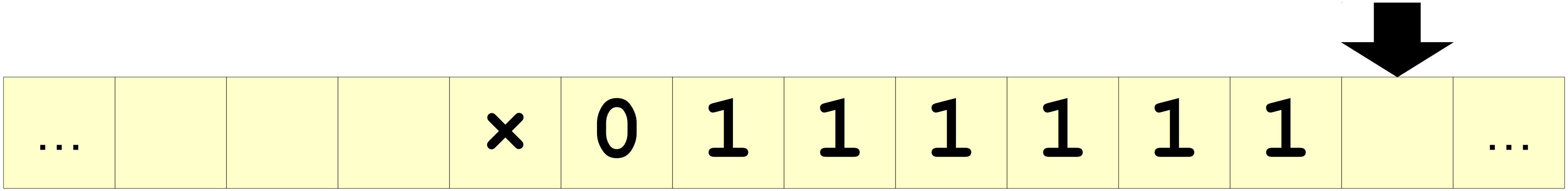
One Solution



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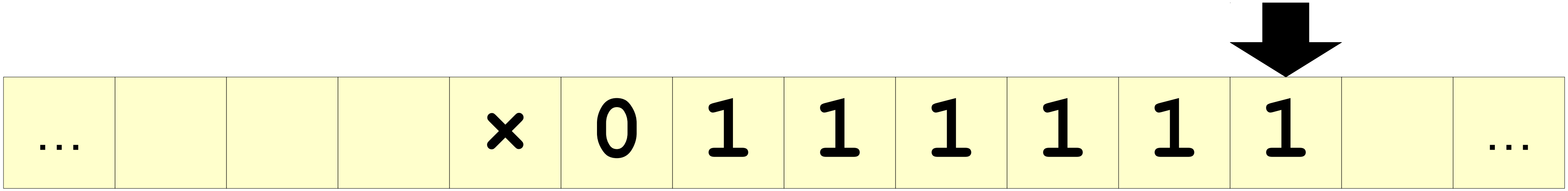

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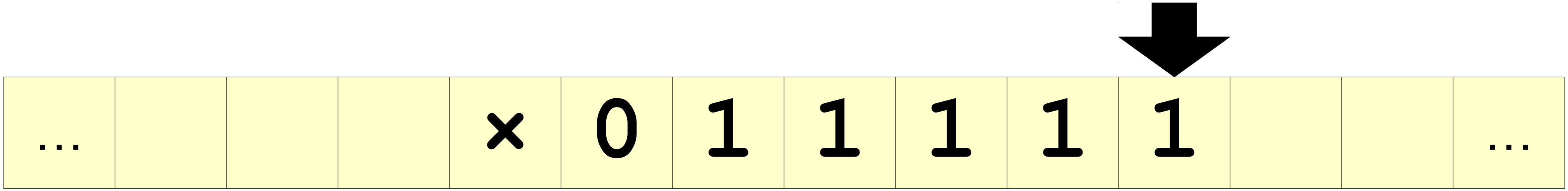

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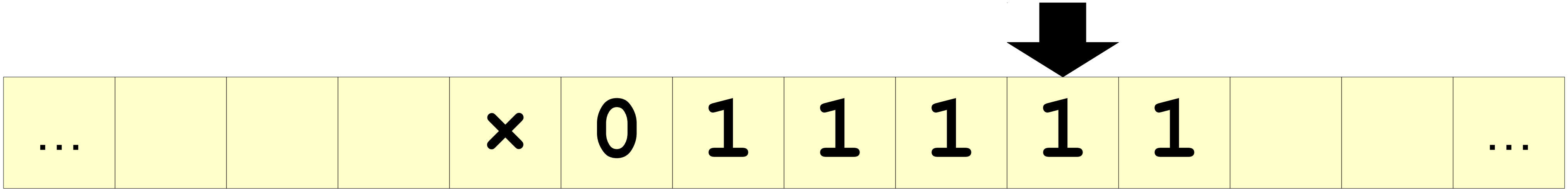

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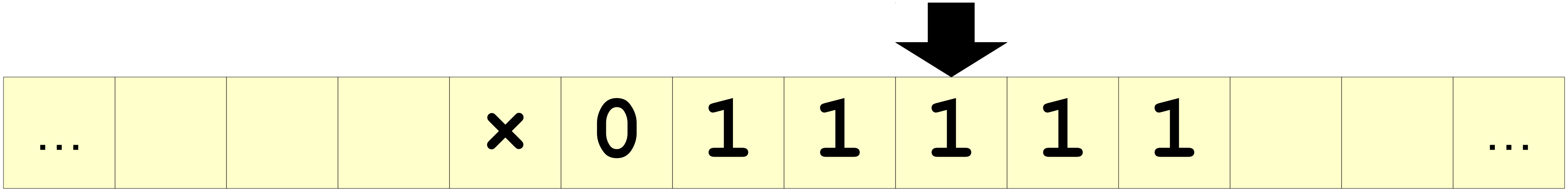

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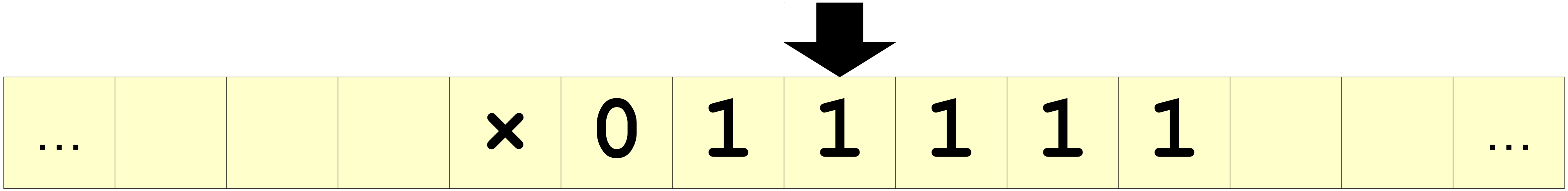

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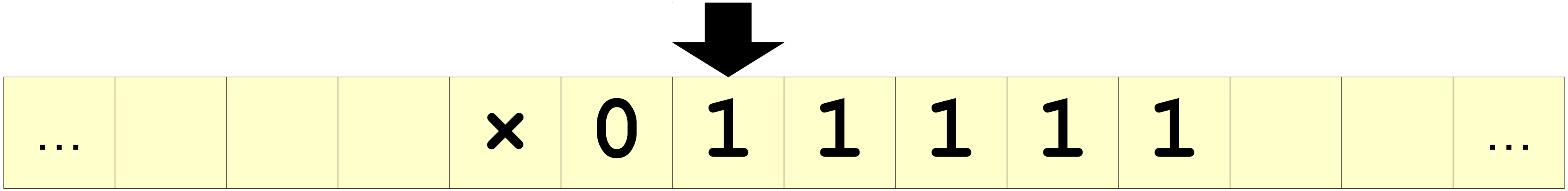

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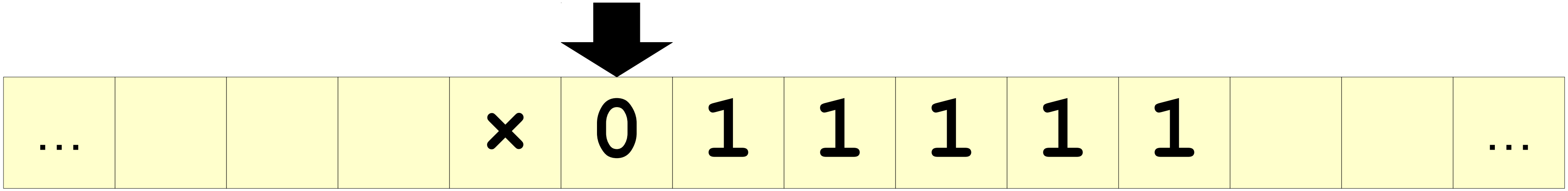

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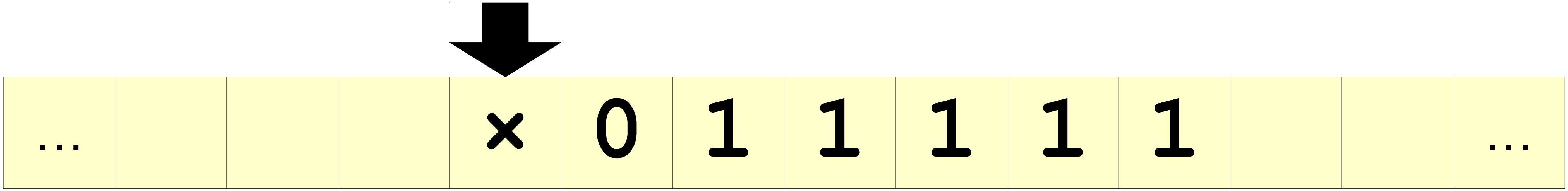

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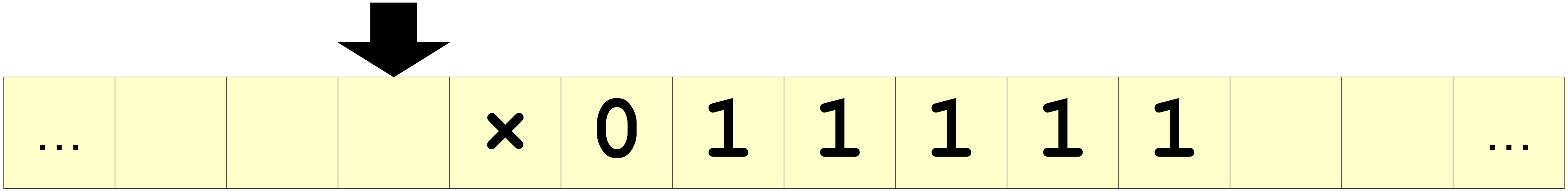

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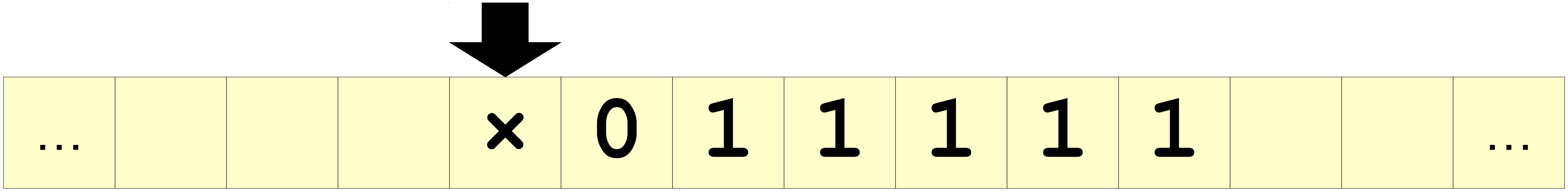

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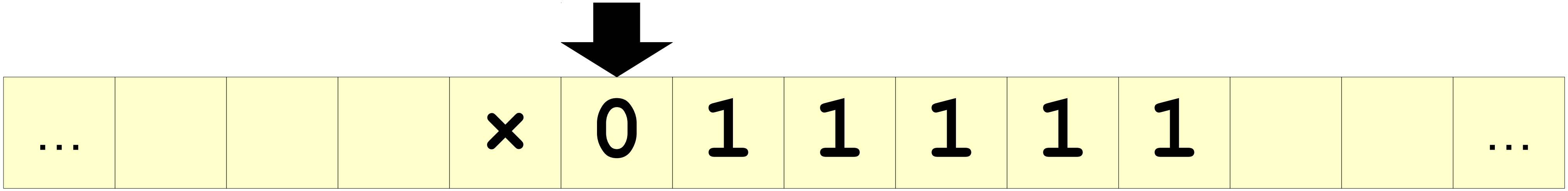

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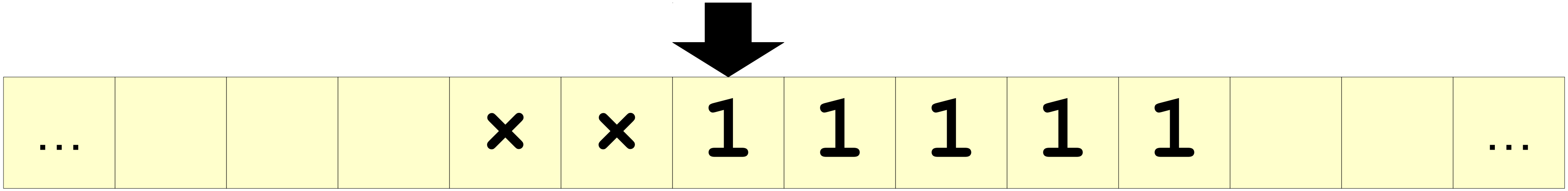
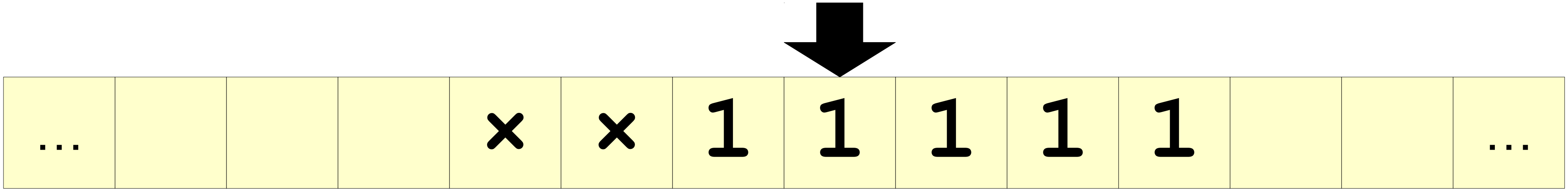
One Solution

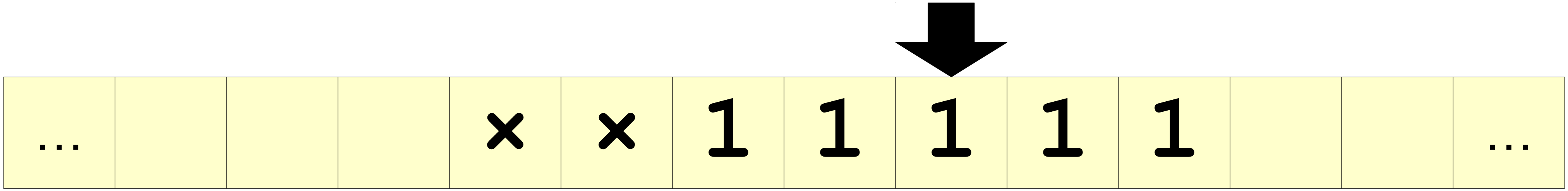


…				×	×	1	1	1	1	1			…

One Solution

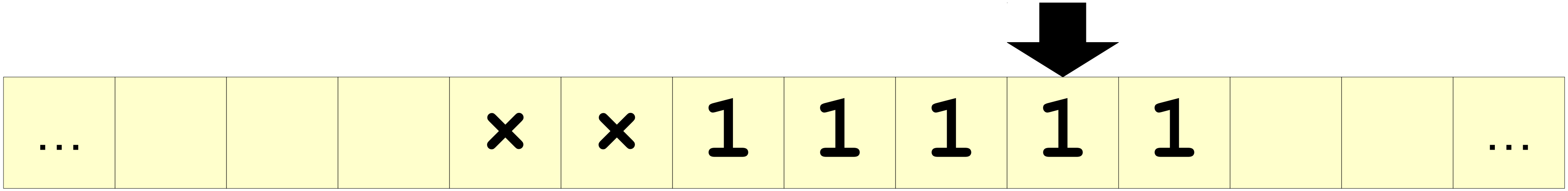


One Solution



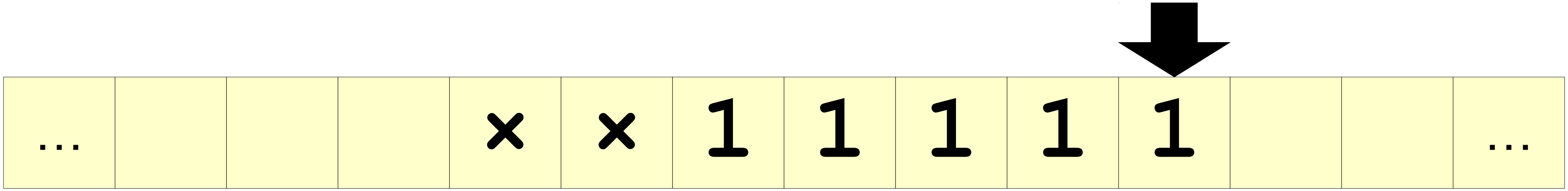
…				×	×	1	1	1	1	1			…

One Solution



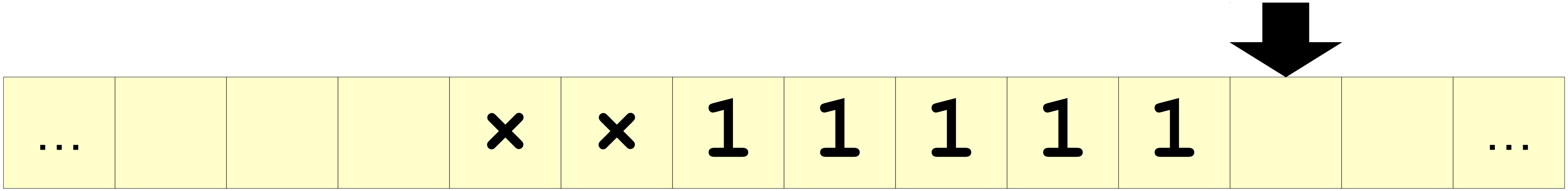
…				×	×	1	1	1	1	1			…

One Solution



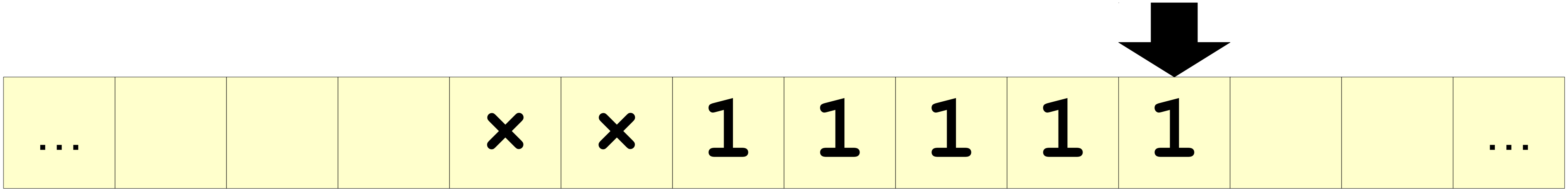
…				×	×	1	1	1	1	1			…

One Solution



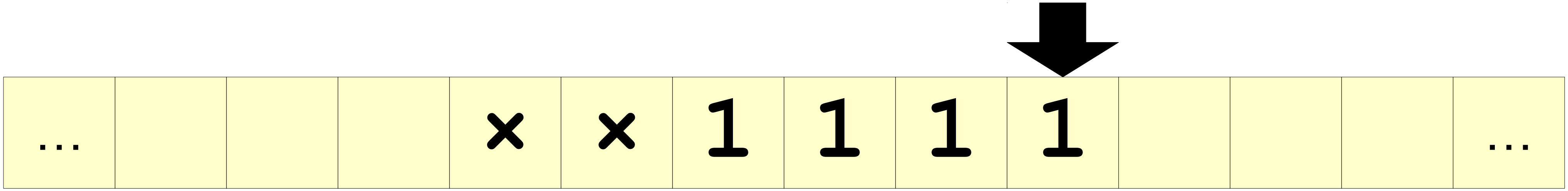
…				×	×	1	1	1	1	1			…

One Solution

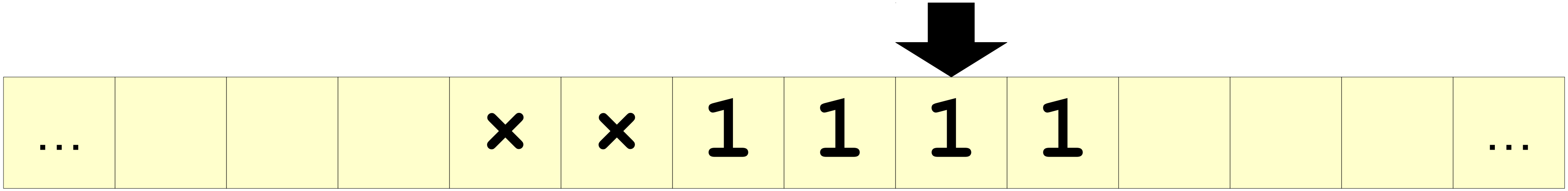


…				×	×	1	1	1	1	1			…

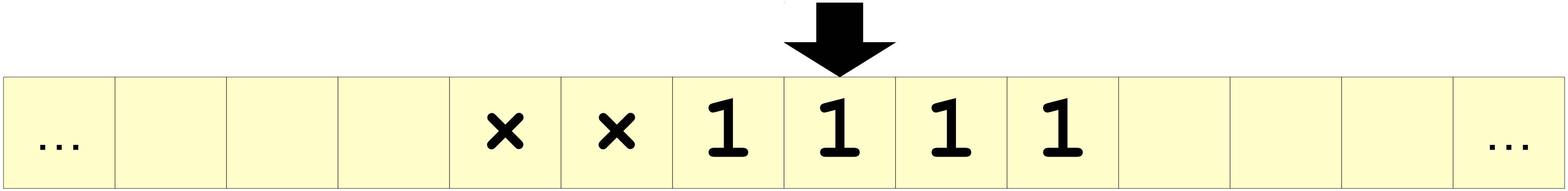
One Solution



One Solution

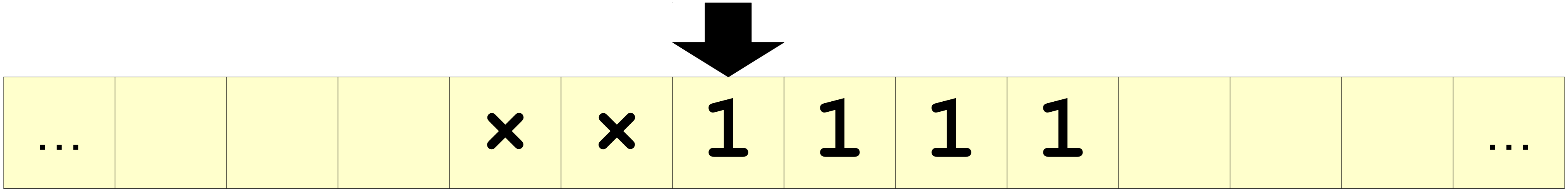


One Solution



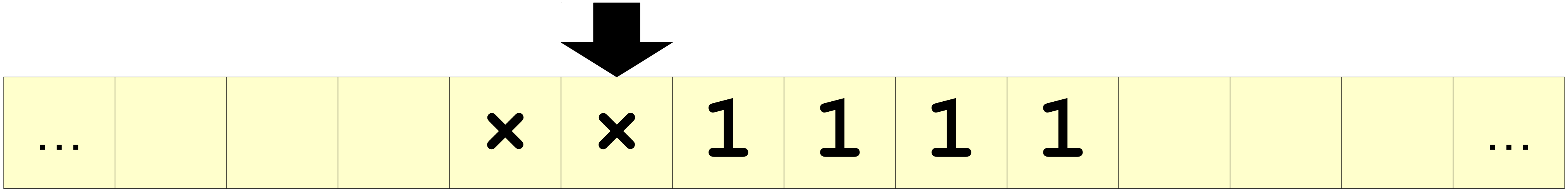
…				×	×	1	1	1	1				…

One Solution

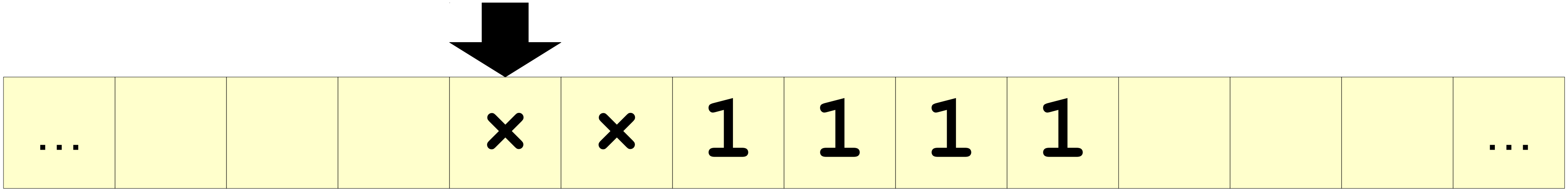


…				×	×	1	1	1	1				…

One Solution

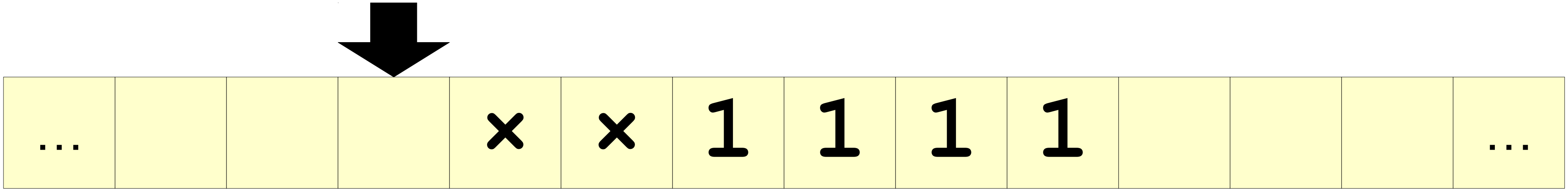


One Solution



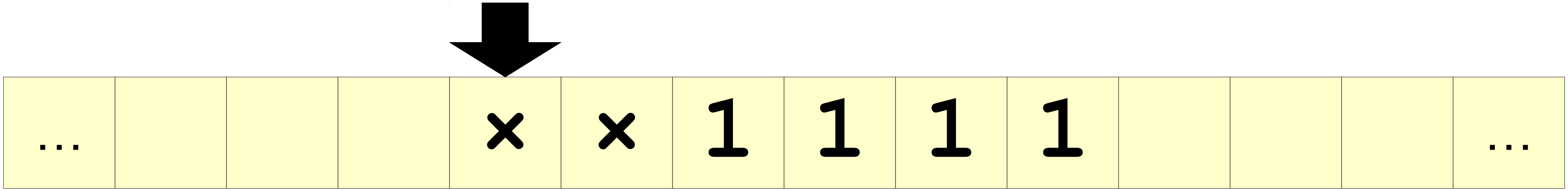
… × × 1 1 1 1 …

One Solution

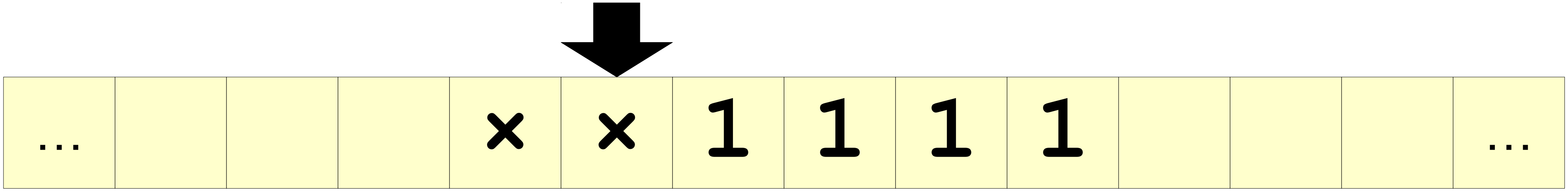


…				×	×	1	1	1	1				…

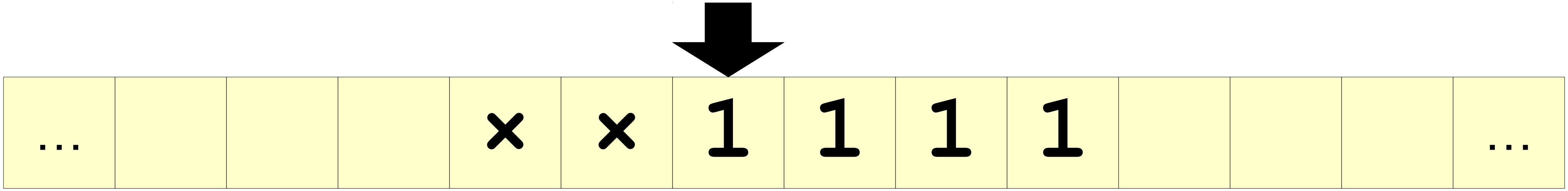
One Solution



One Solution

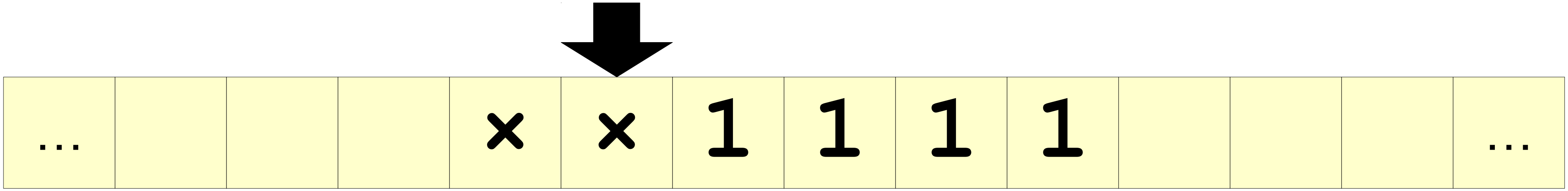


One Solution

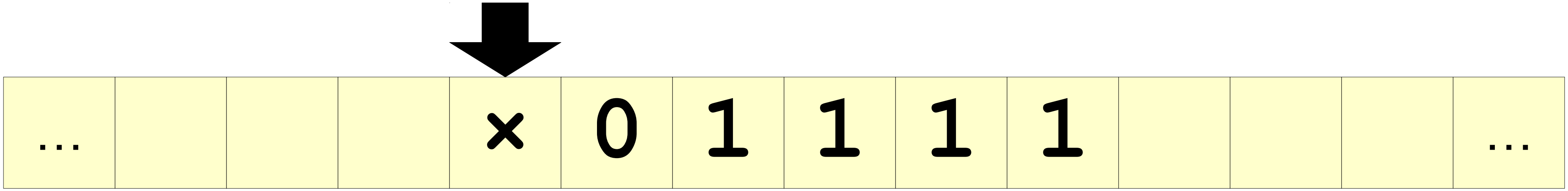


… × × 1 1 1 1 …

One Solution

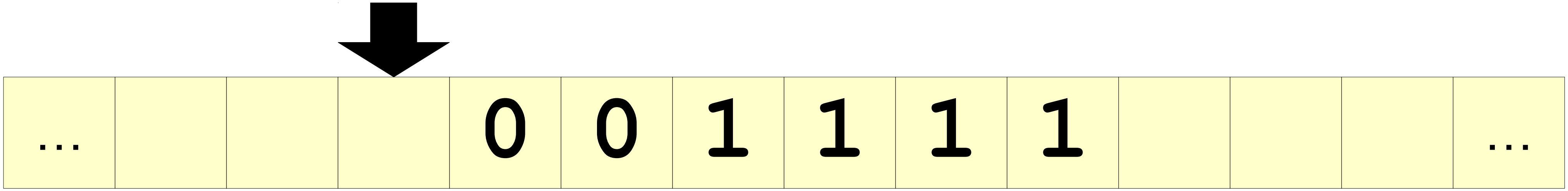


One Solution



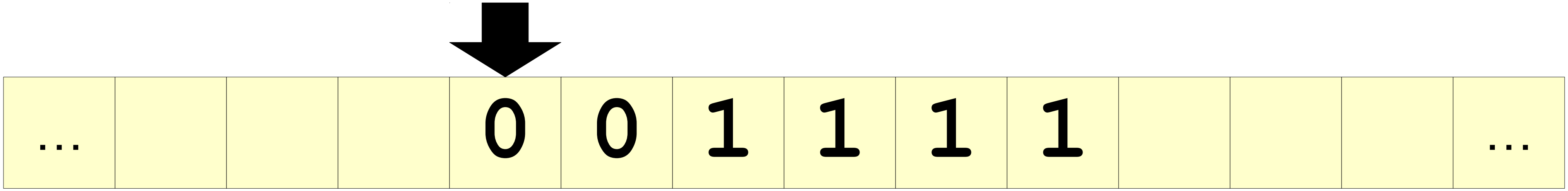
…				×	0	1	1	1	1				…

One Solution

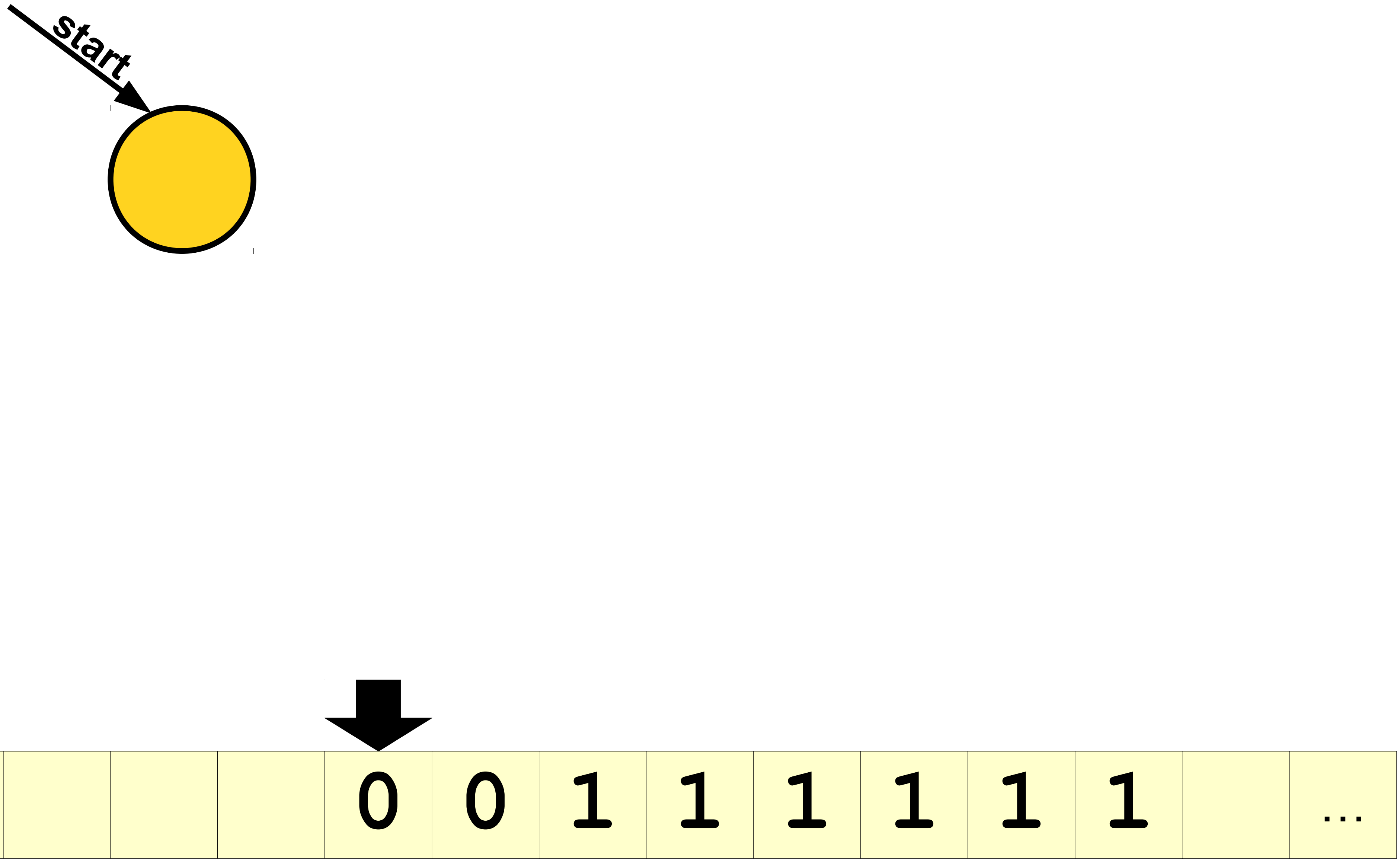


…				0	0	1	1	1	1				…

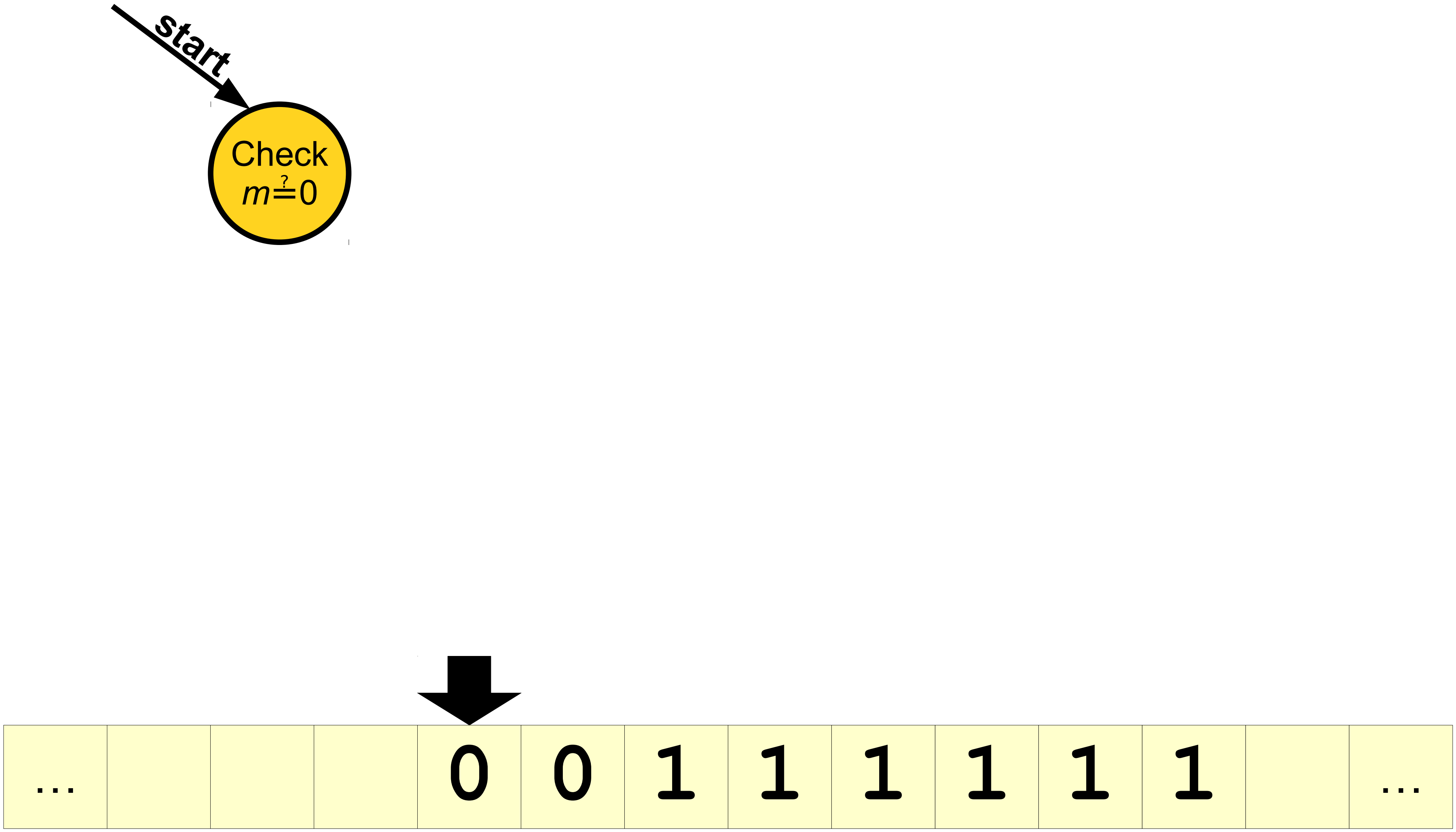
One Solution

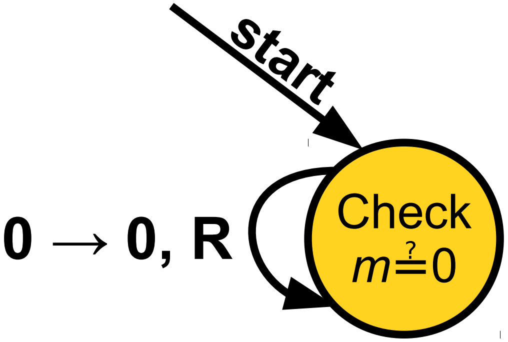


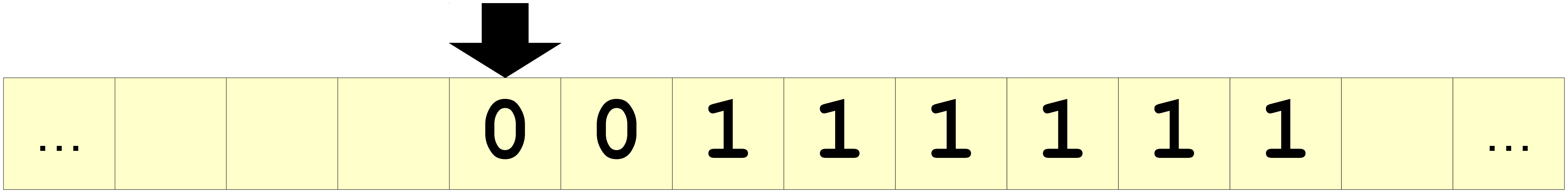
…				0	0	1	1	1	1				…



…				0	0	1	1	1	1	1	1		…


start
Check
$m \overset{?}{=} 0$
…
0
0
1
1
1
1
1
1
…


start
0 → 0, R
Check
m ≟ 0


…
0
0
1
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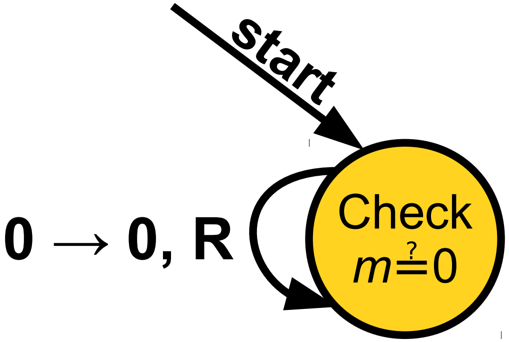
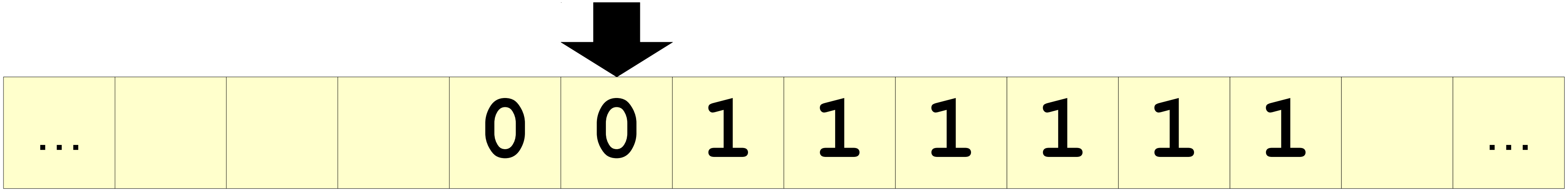
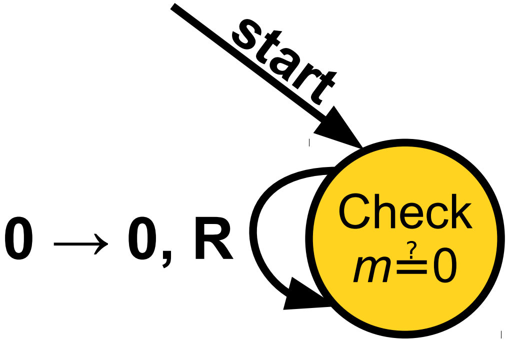
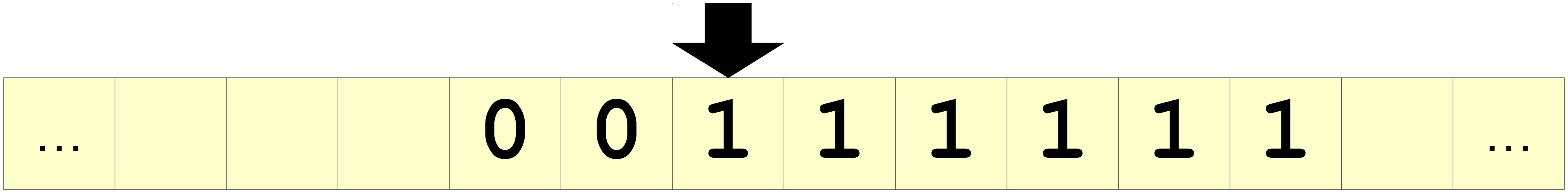
1
1
1
…



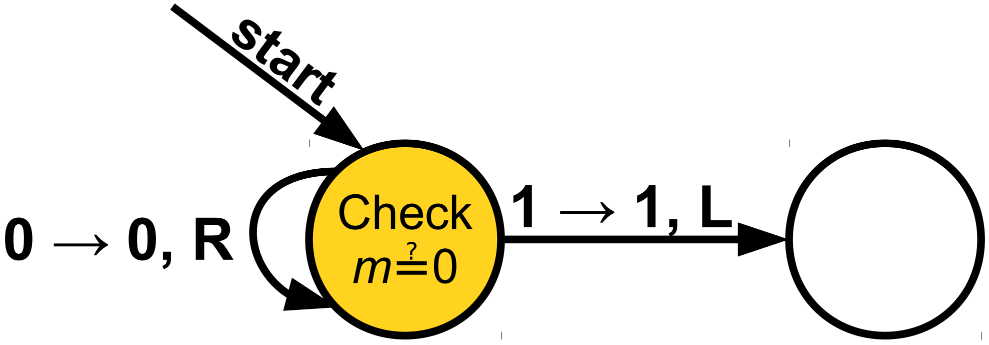


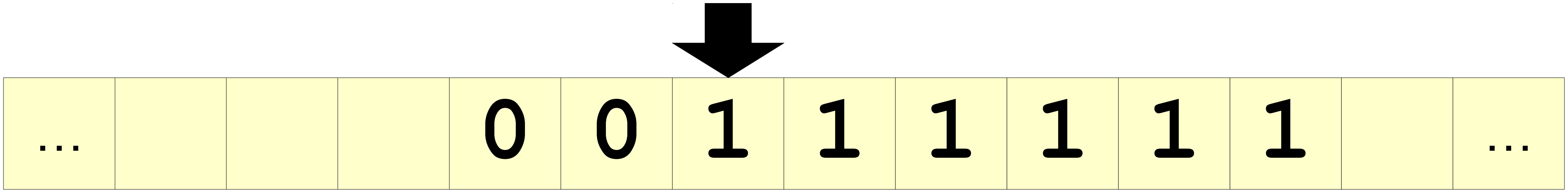
…				0	0	1	1	1	1	1	1		…





…				0	0	1	1	1	1	1	1		…


start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L


…
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1
1
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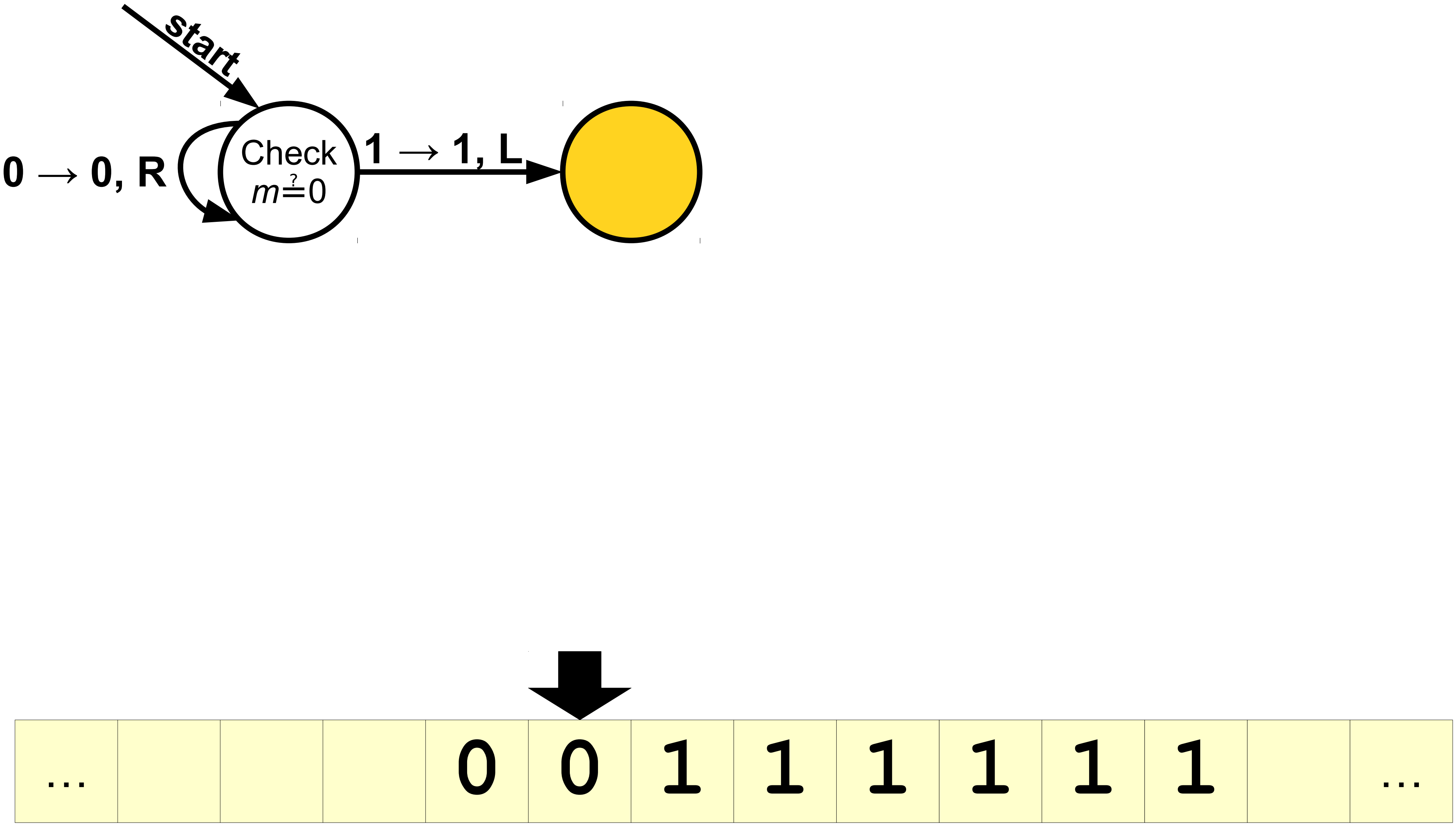
1
1
…


start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
…
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0
1
1
1
1
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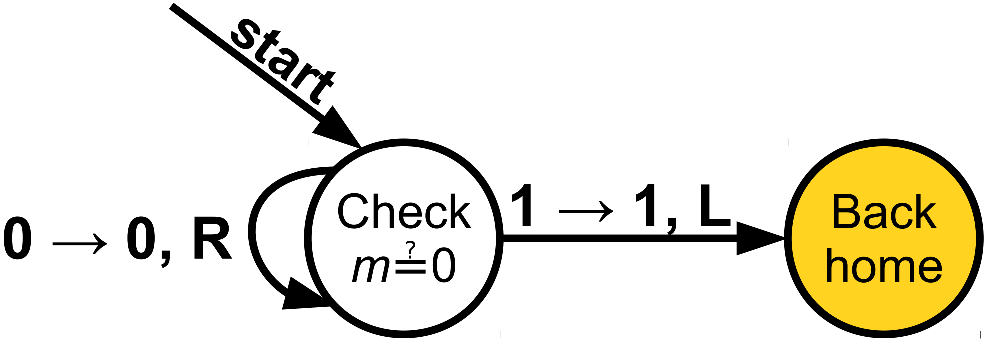
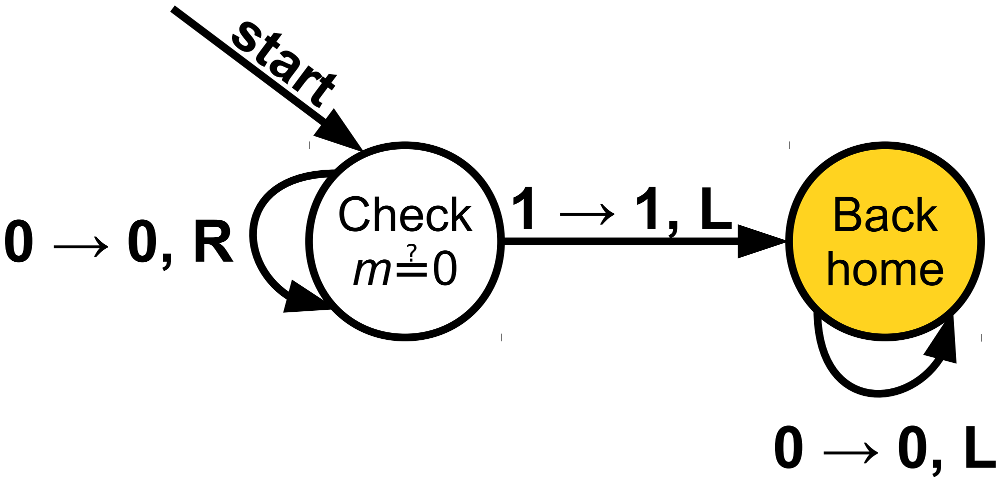
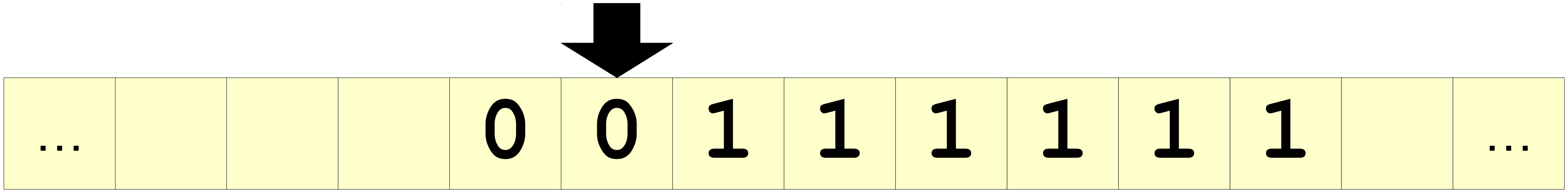
1
…

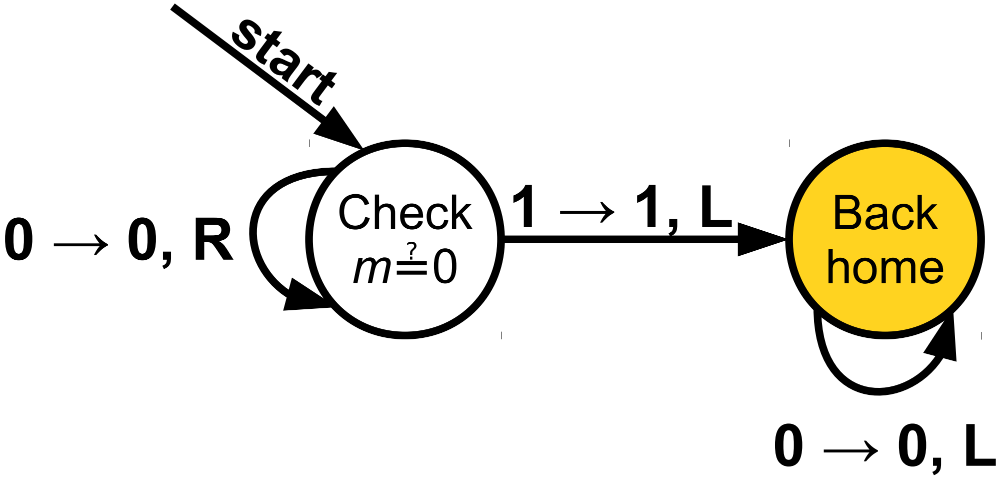


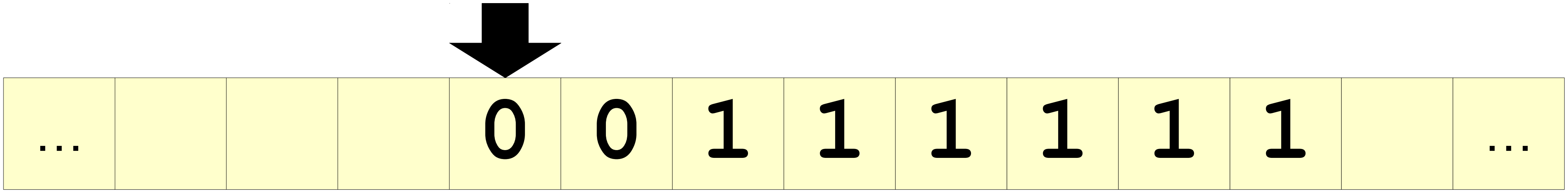
…				0	0	1	1	1	1	1	1		…



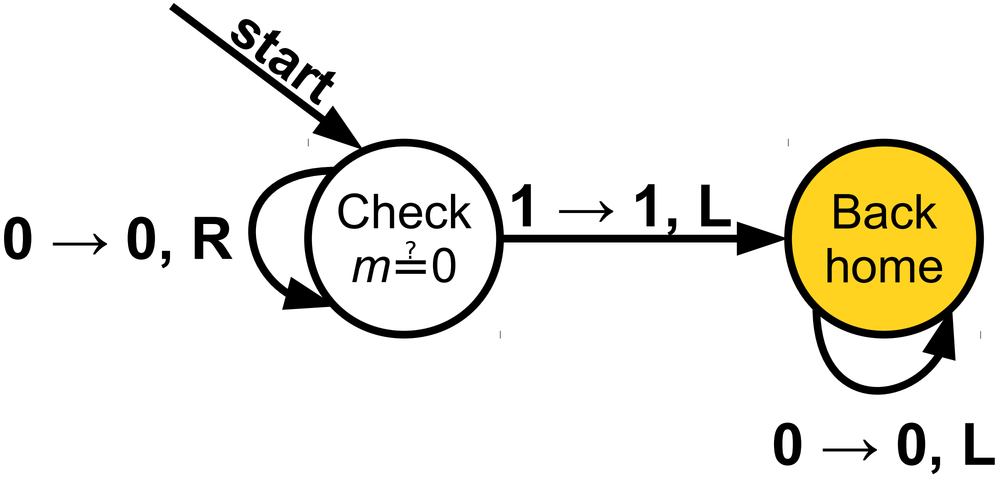


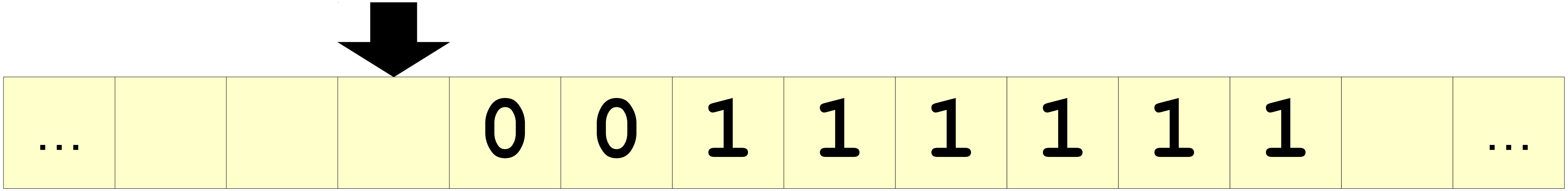
…				0	0	1	1	1	1	1	1		…



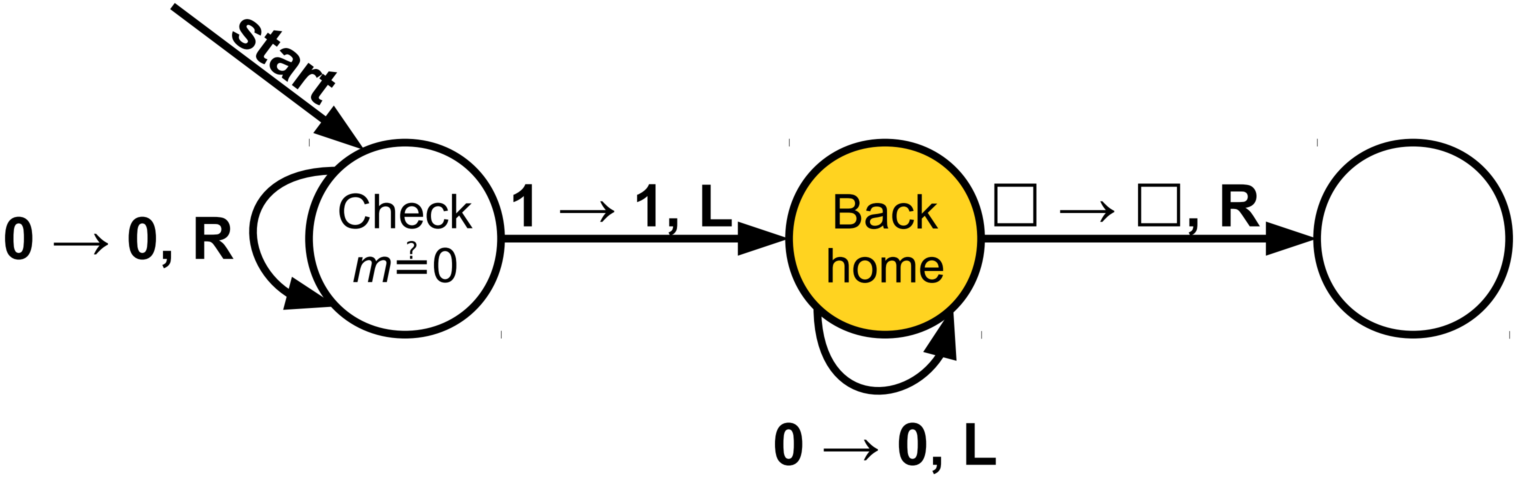


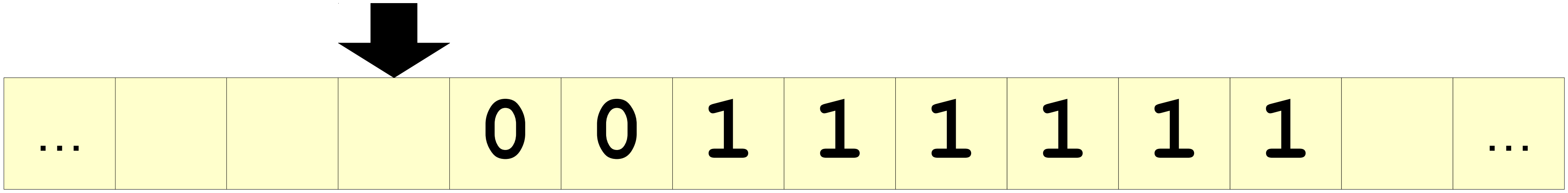
…				0	0	1	1	1	1	1	1		…



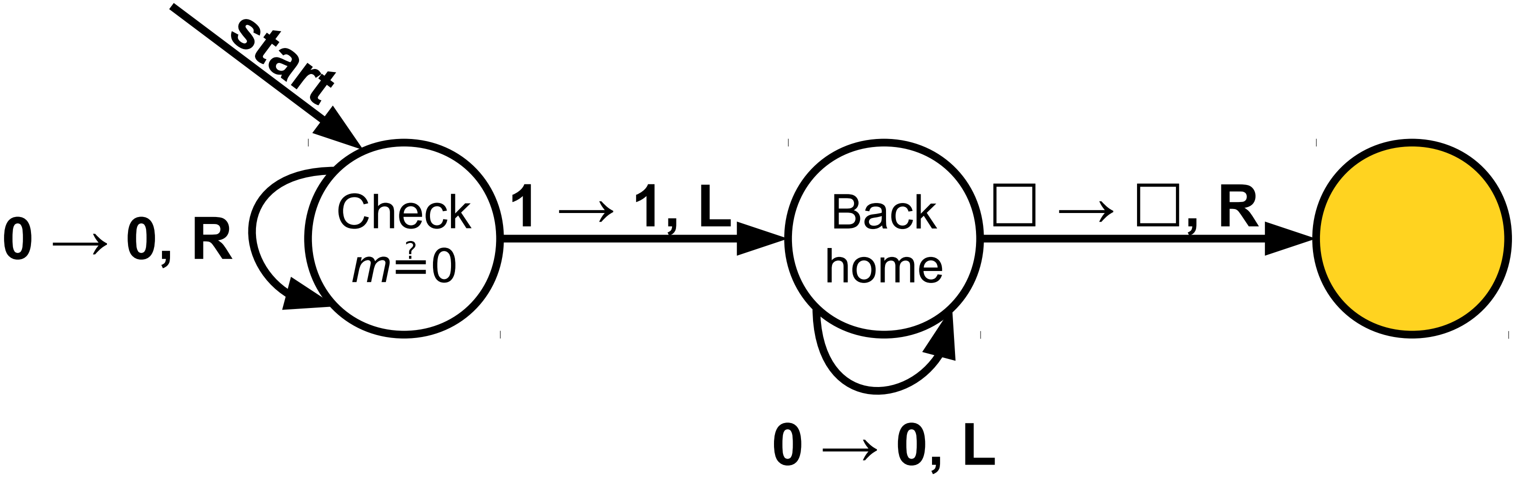


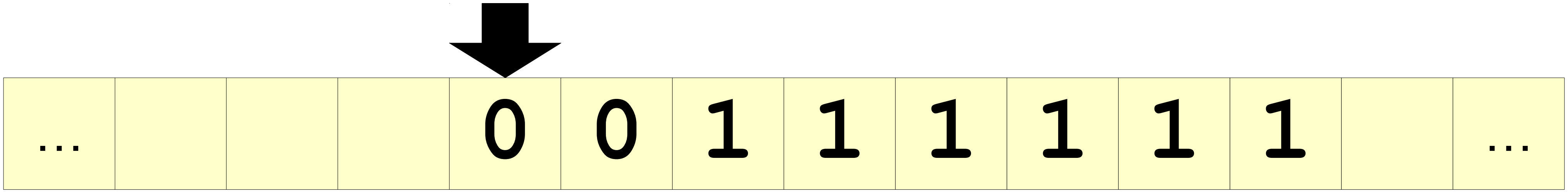
…				0	0	1	1	1	1	1	1		…



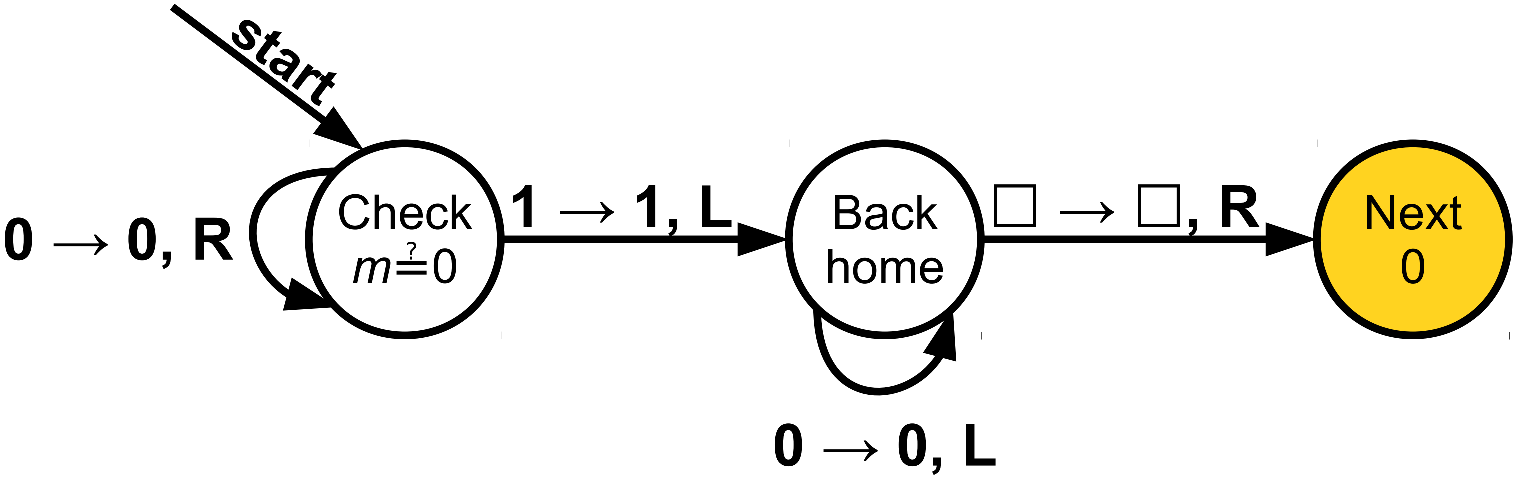


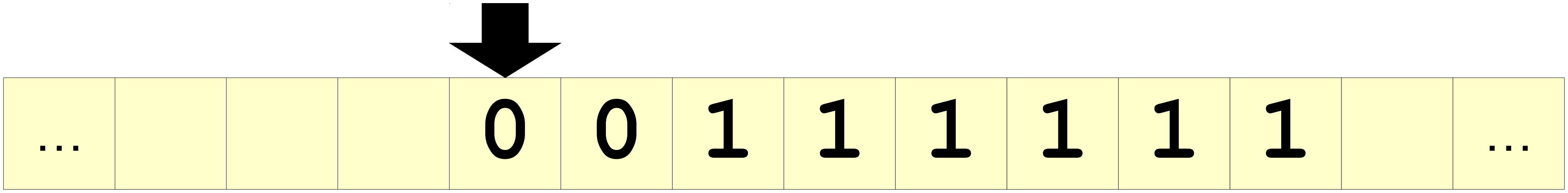
…				0	0	1	1	1	1	1	1		…



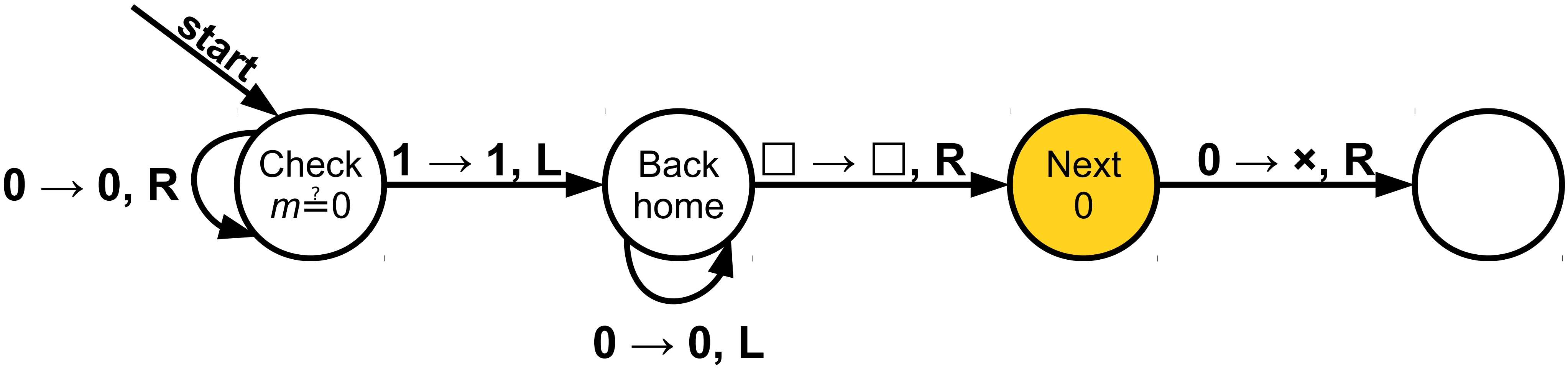


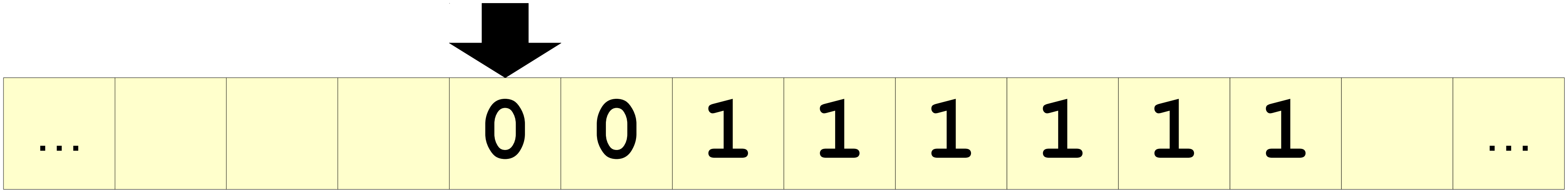
…				0	0	1	1	1	1	1	1		…



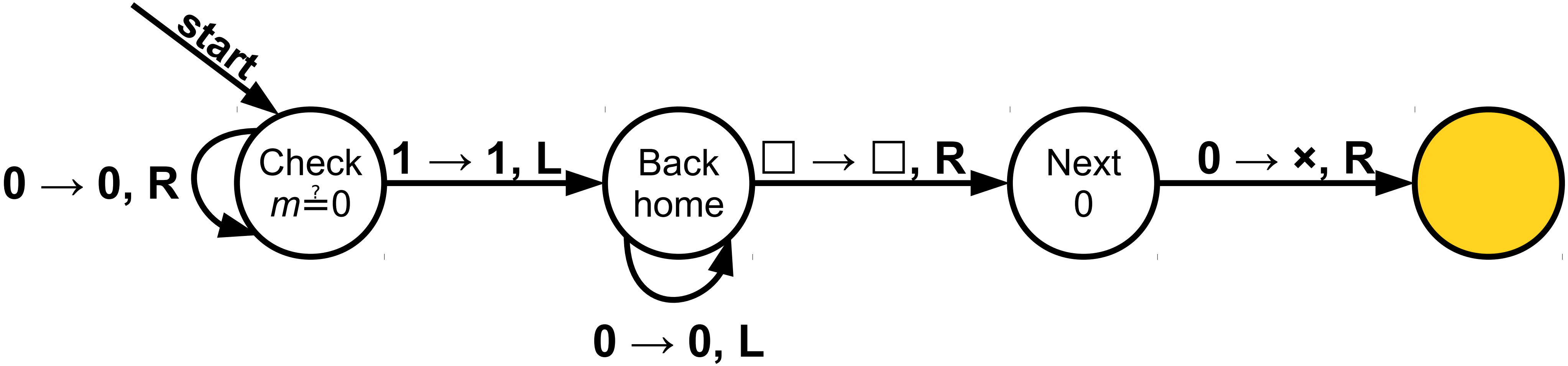


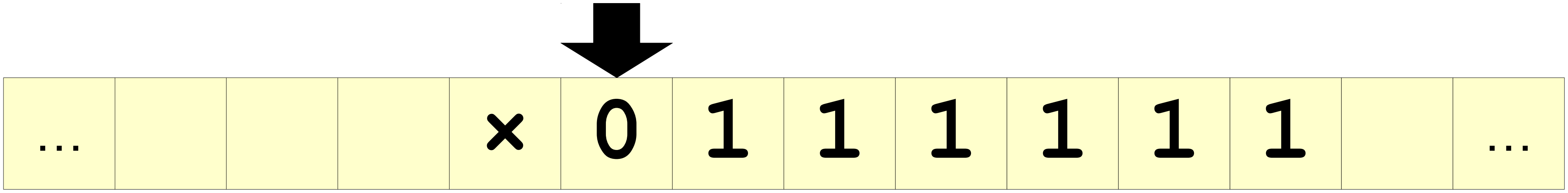
…				0	0	1	1	1	1	1	1		…



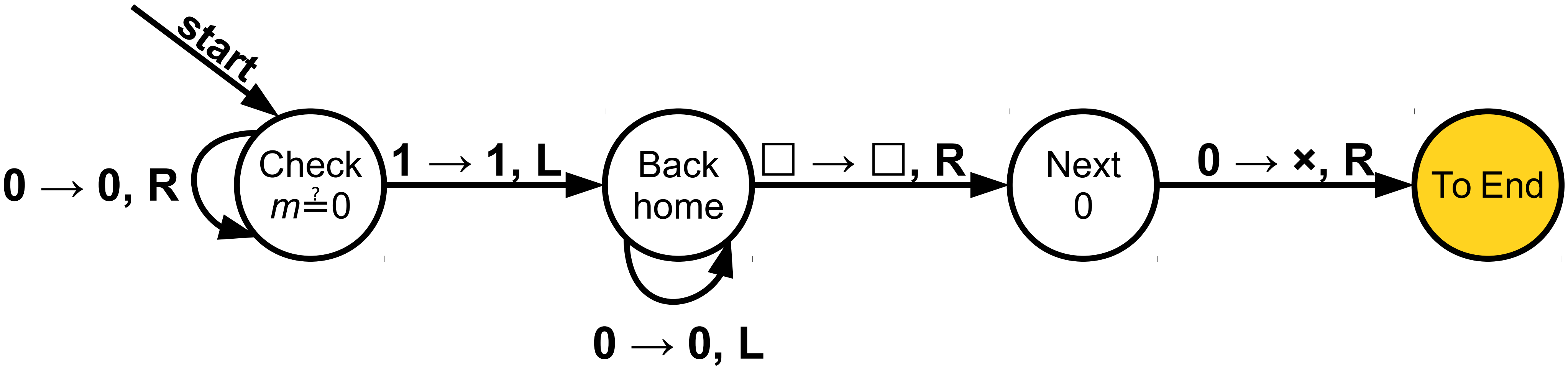


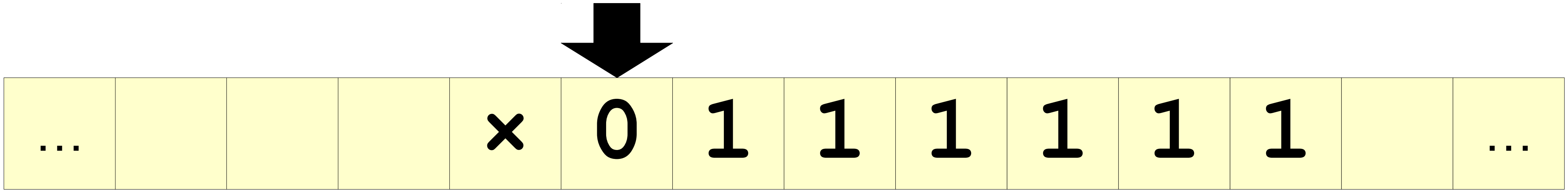
…				0	0	1	1	1	1	1	1		…



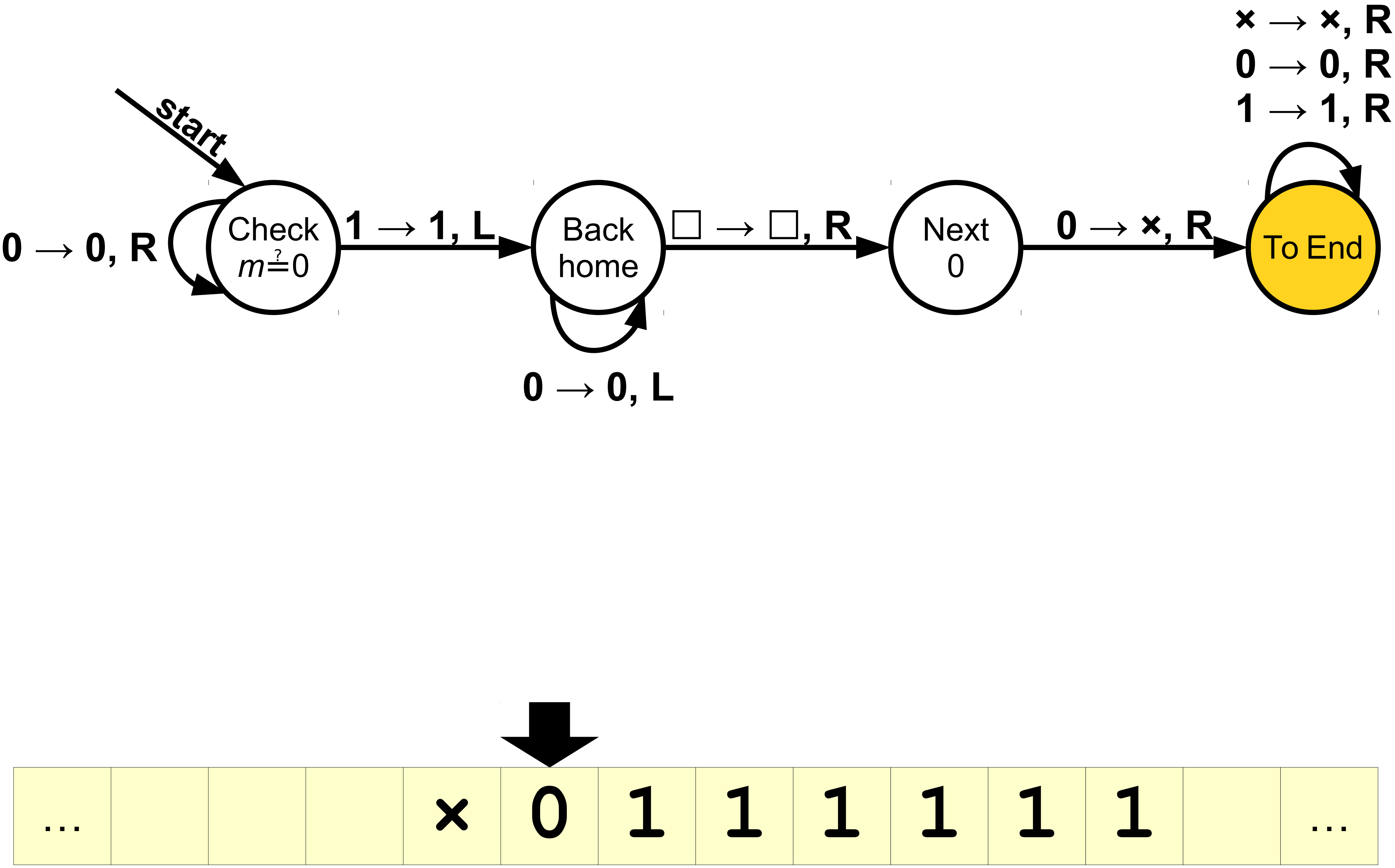


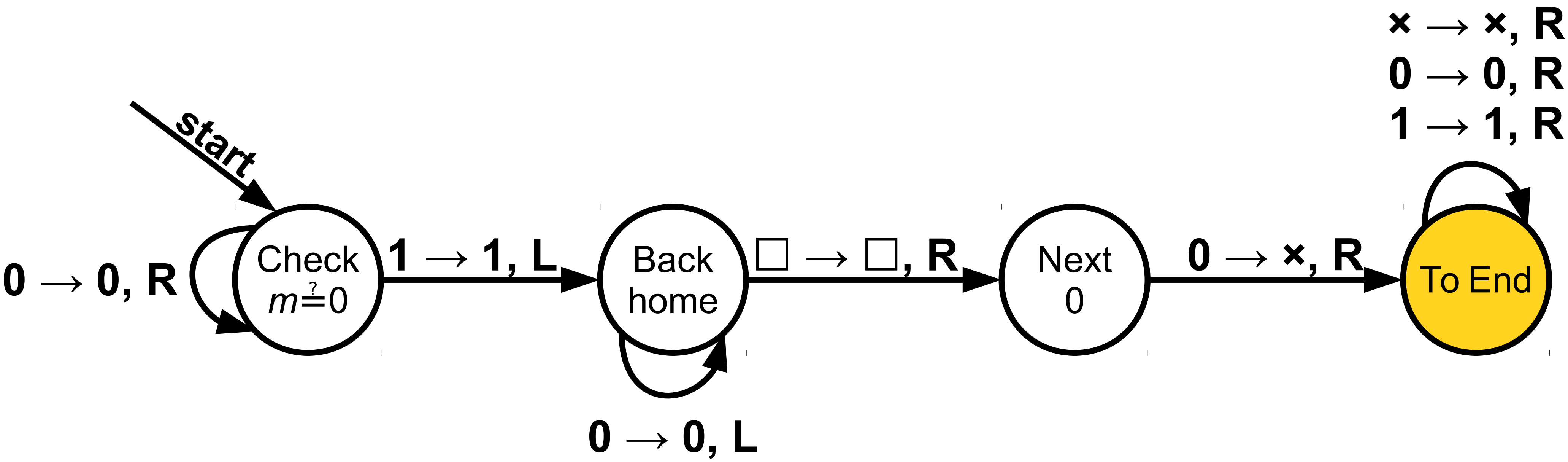
…				×	0	1	1	1	1	1	1		…

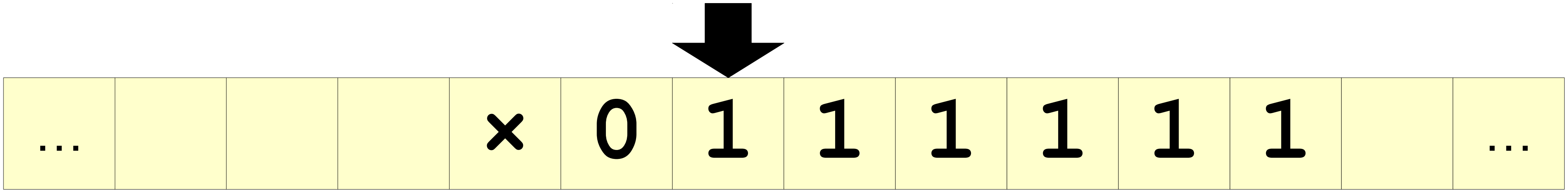




…				×	0	1	1	1	1	1	1		…


start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
…
×
0
1
1
1
1
1
1
…


start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R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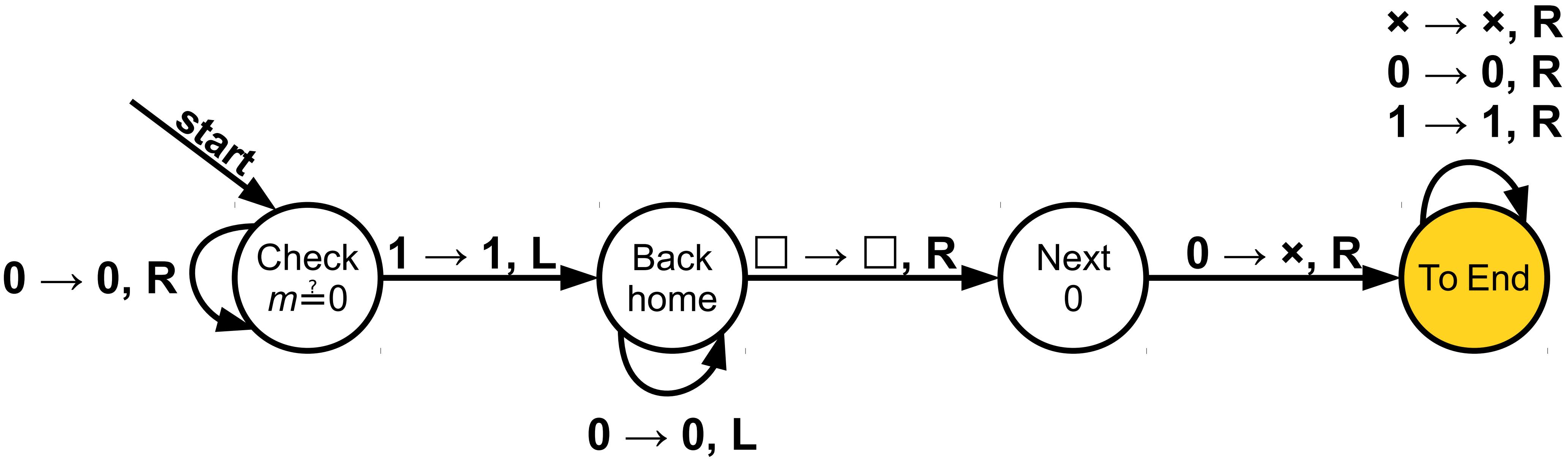
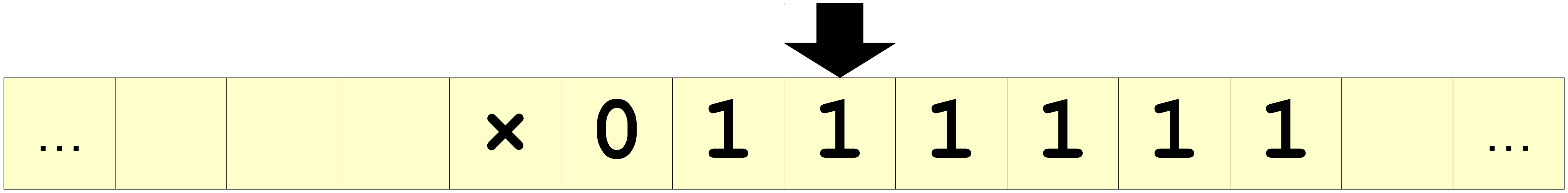
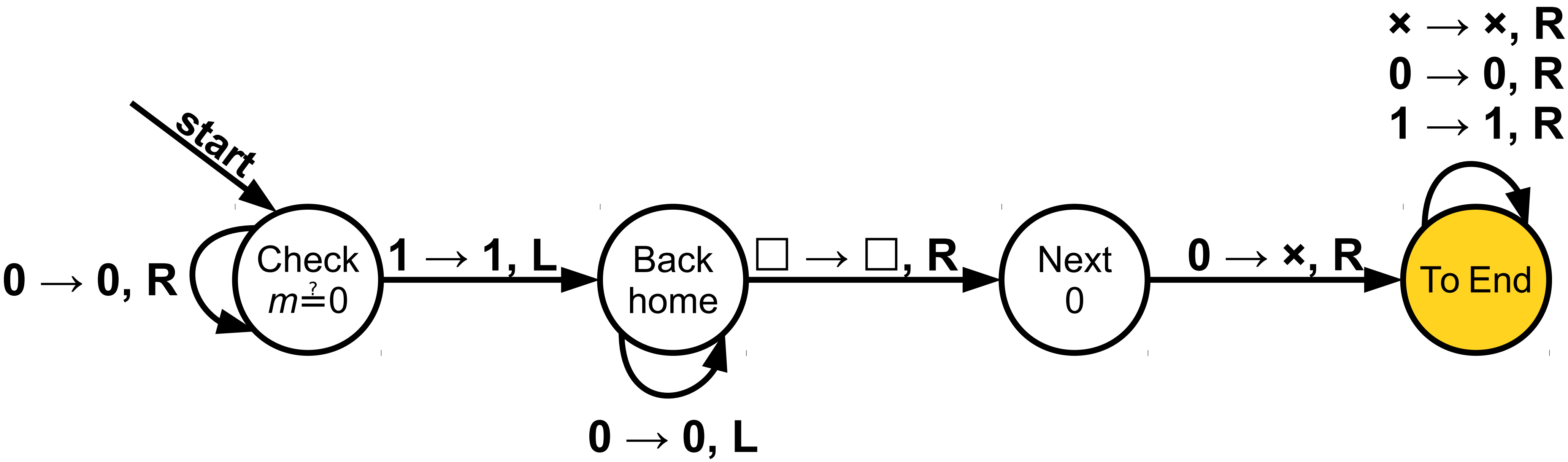

start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R



…				×	0	1	1	1	1	1	1		…


start
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
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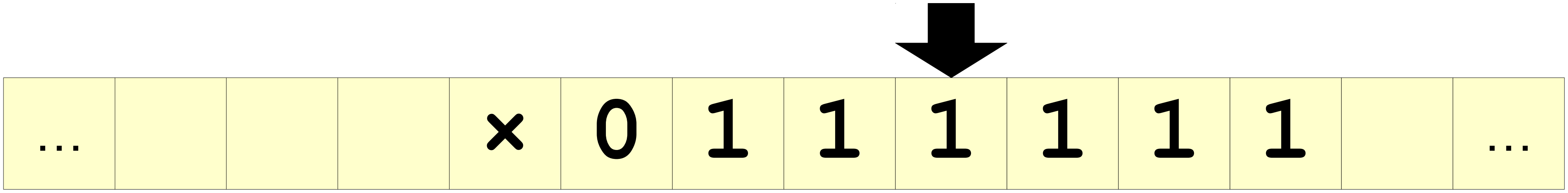
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R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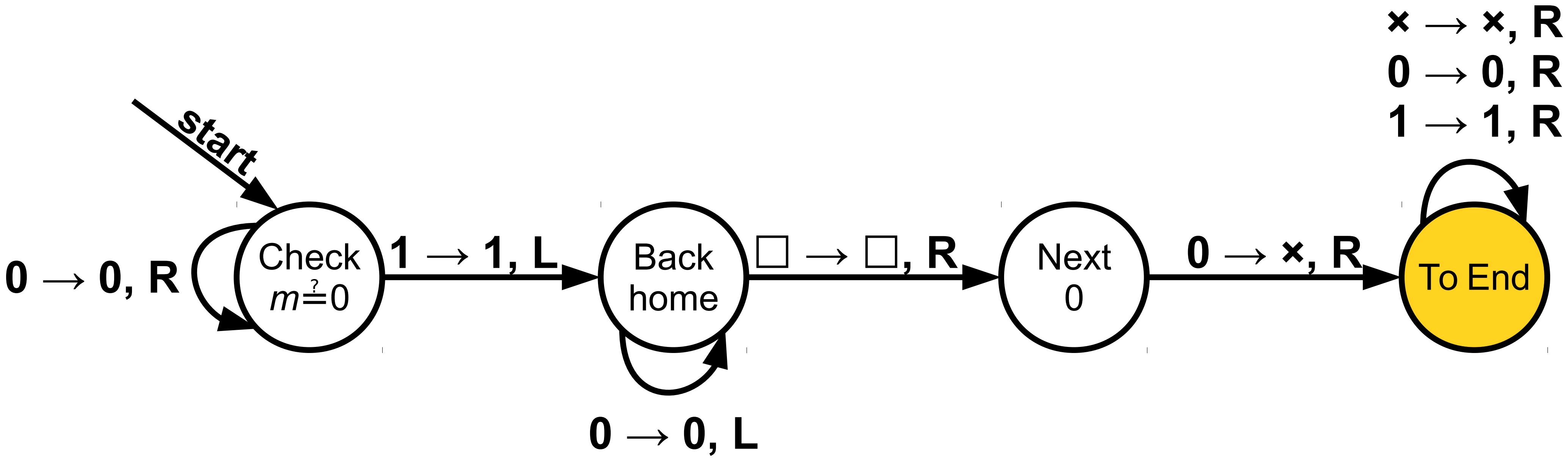
× → ×, R
0 → 0, R
1 → 1, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
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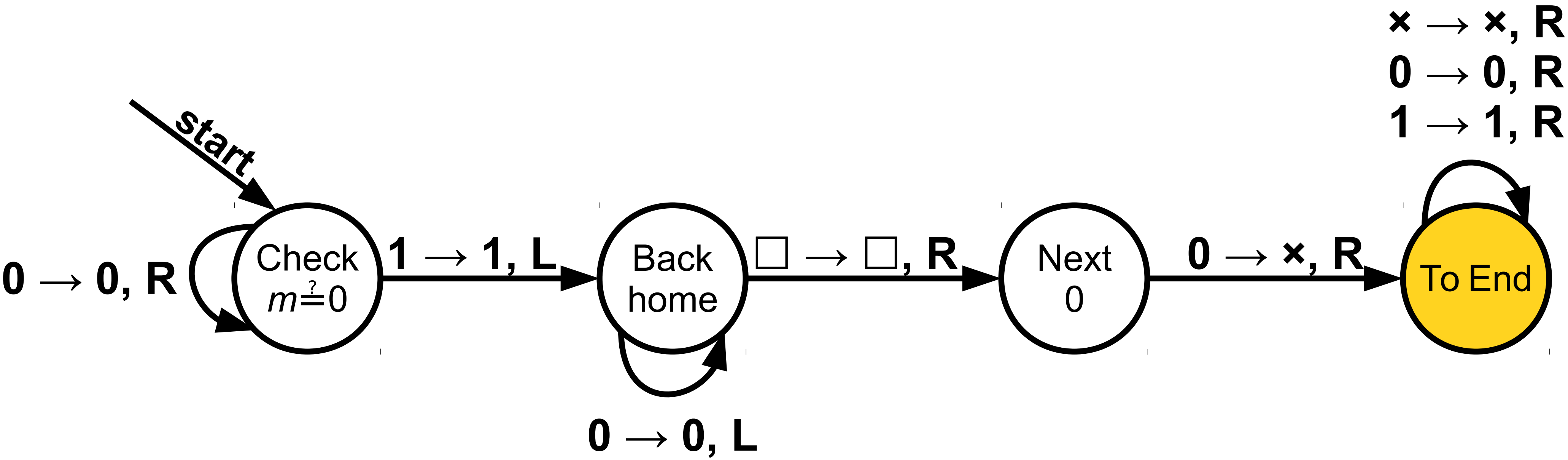
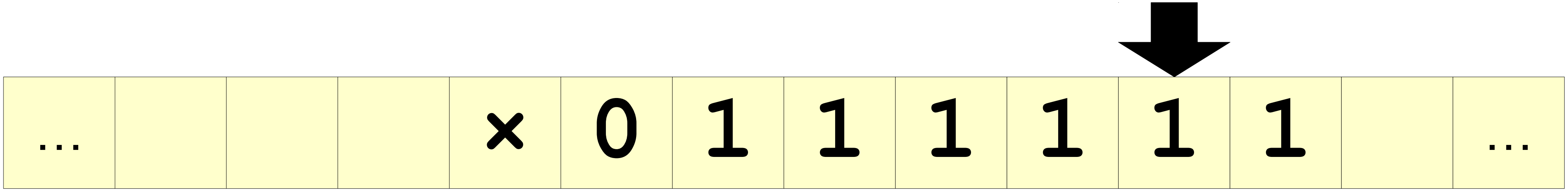
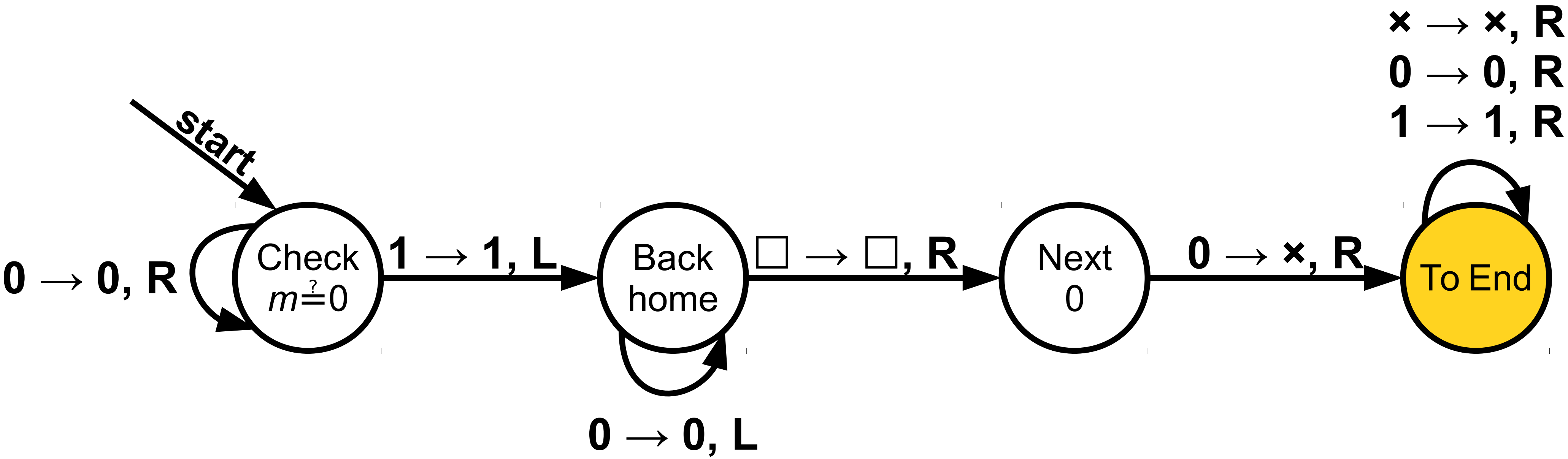
0 → ×, R
To End

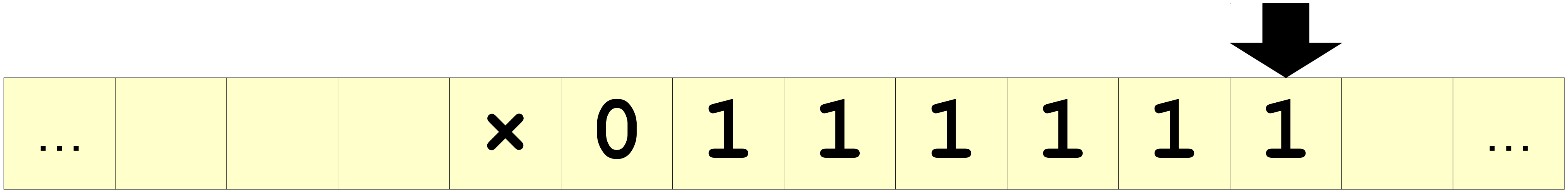
									⬇				
…				×	0	1	1	1	1	1	1		…


× → ×, R
0 → 0, R
1 → 1, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
0 → ×, R
To End

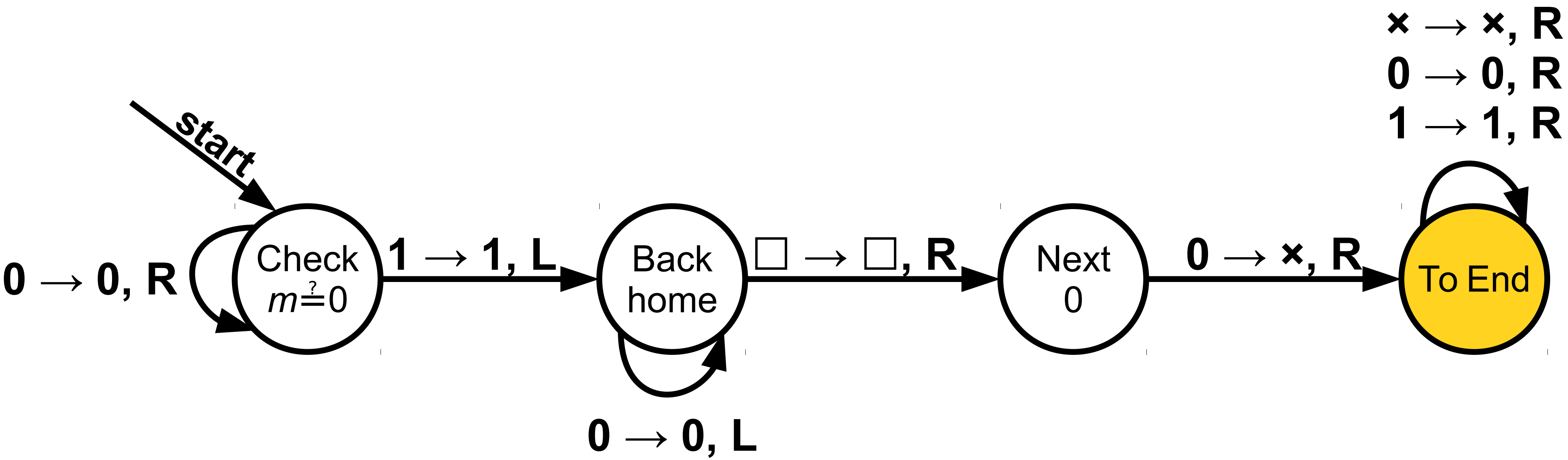


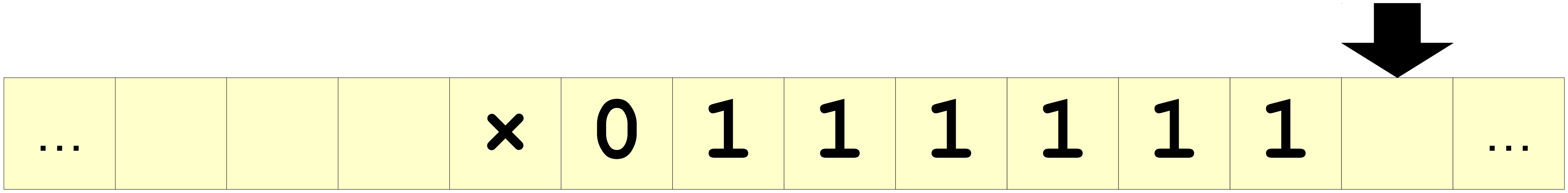
…				×	0	1	1	1	1	1	1		…



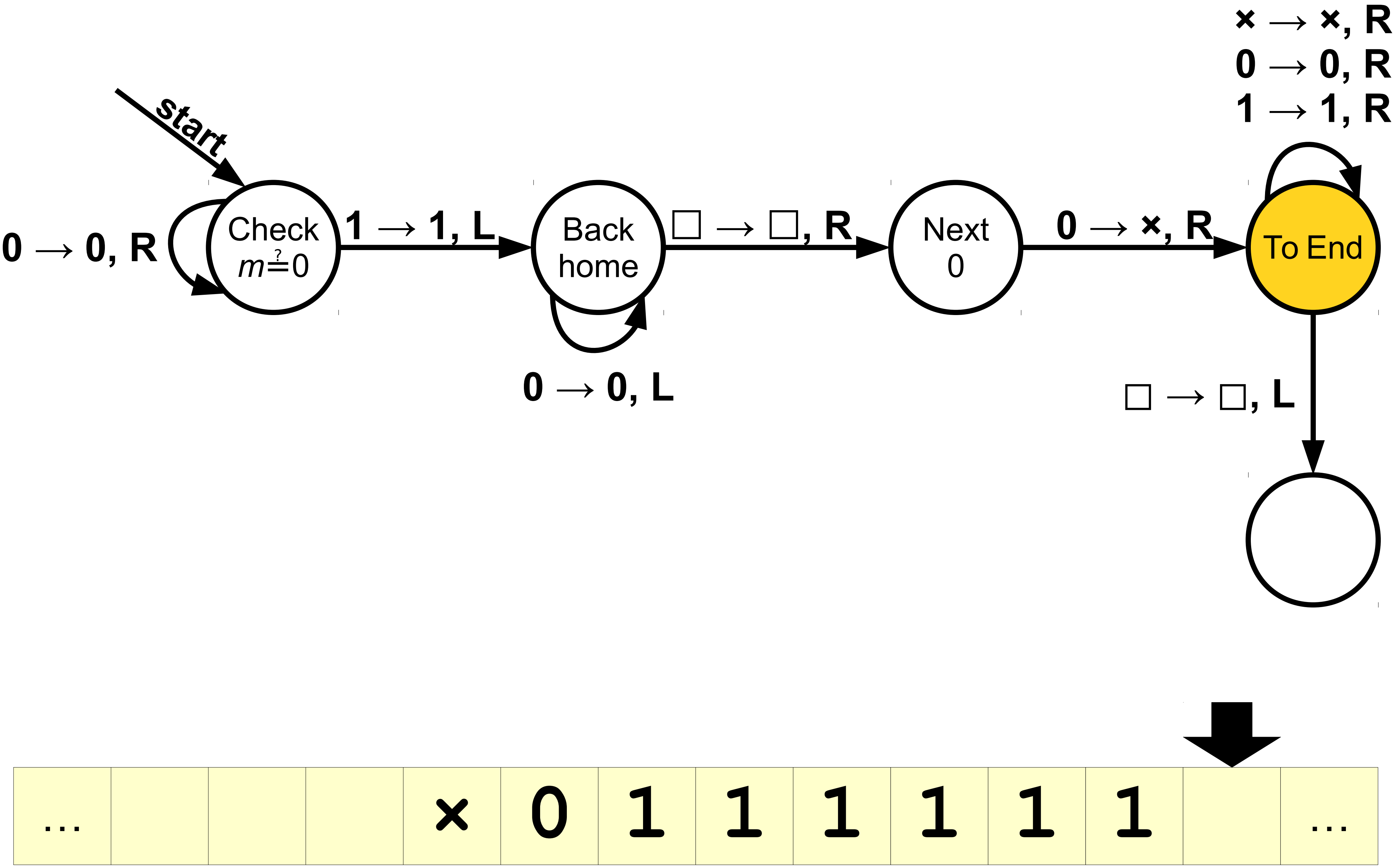


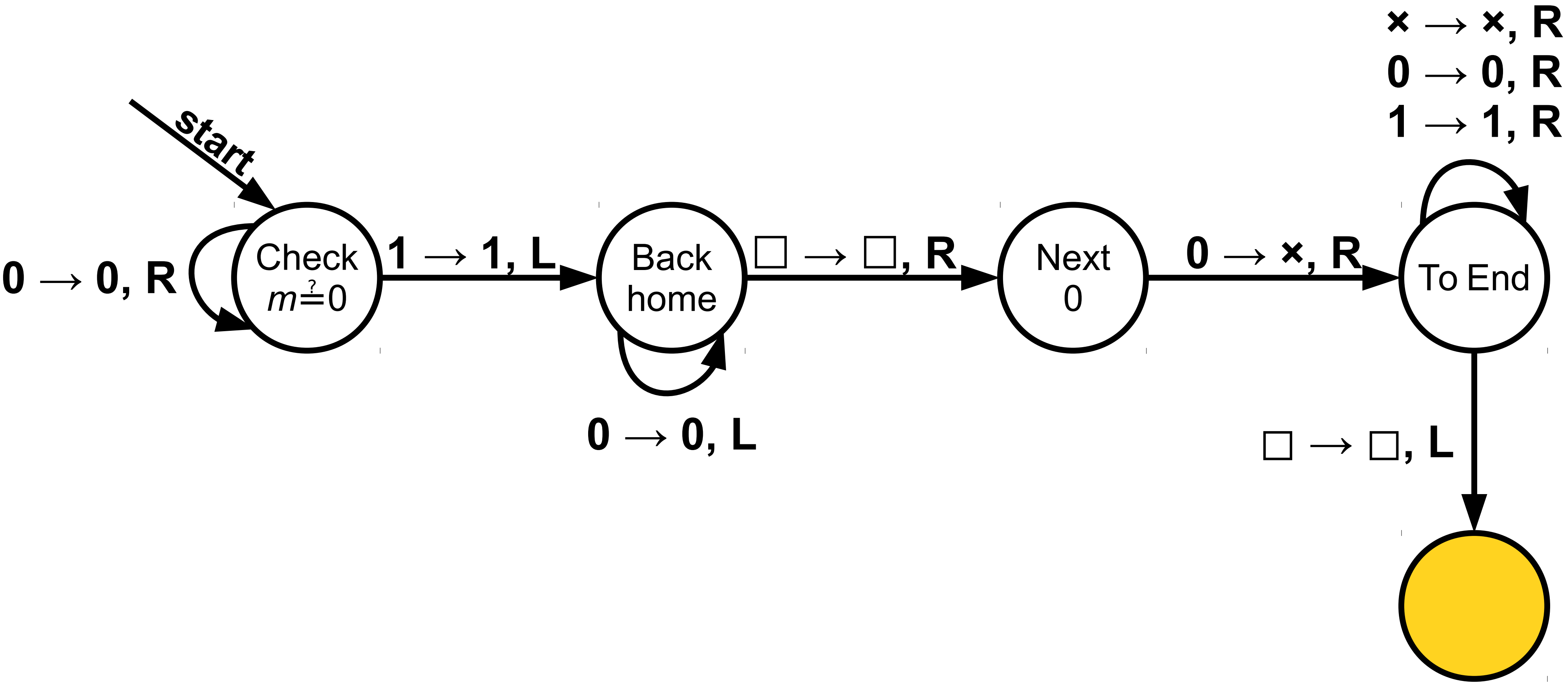
…				×	0	1	1	1	1	1	1		…


start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R

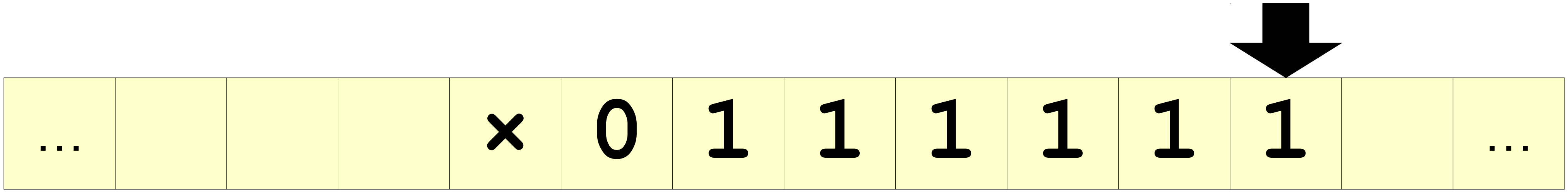


…				×	0	1	1	1	1	1	1		…

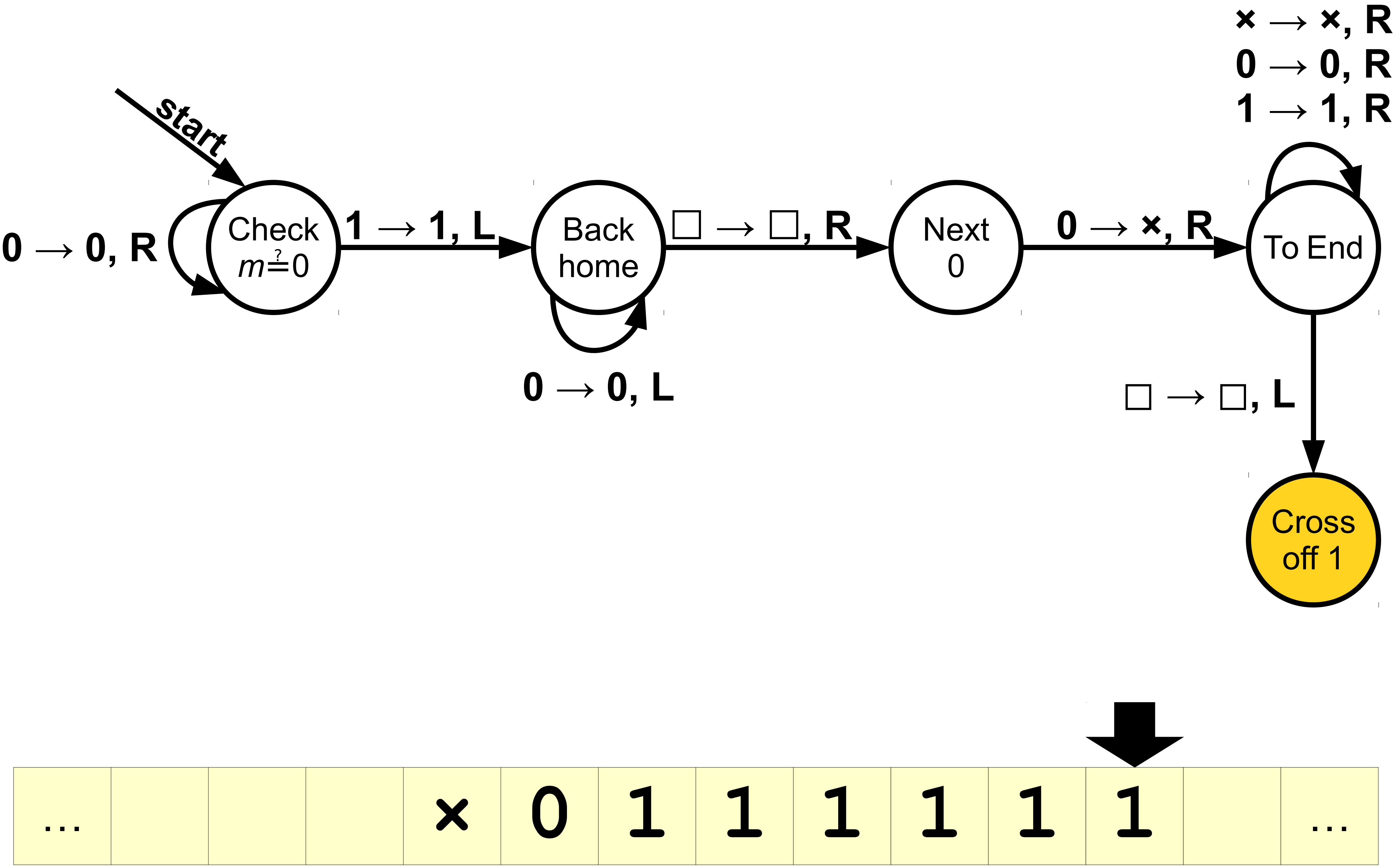

start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, L
…
×
0
1
1
1
1
1
1
…



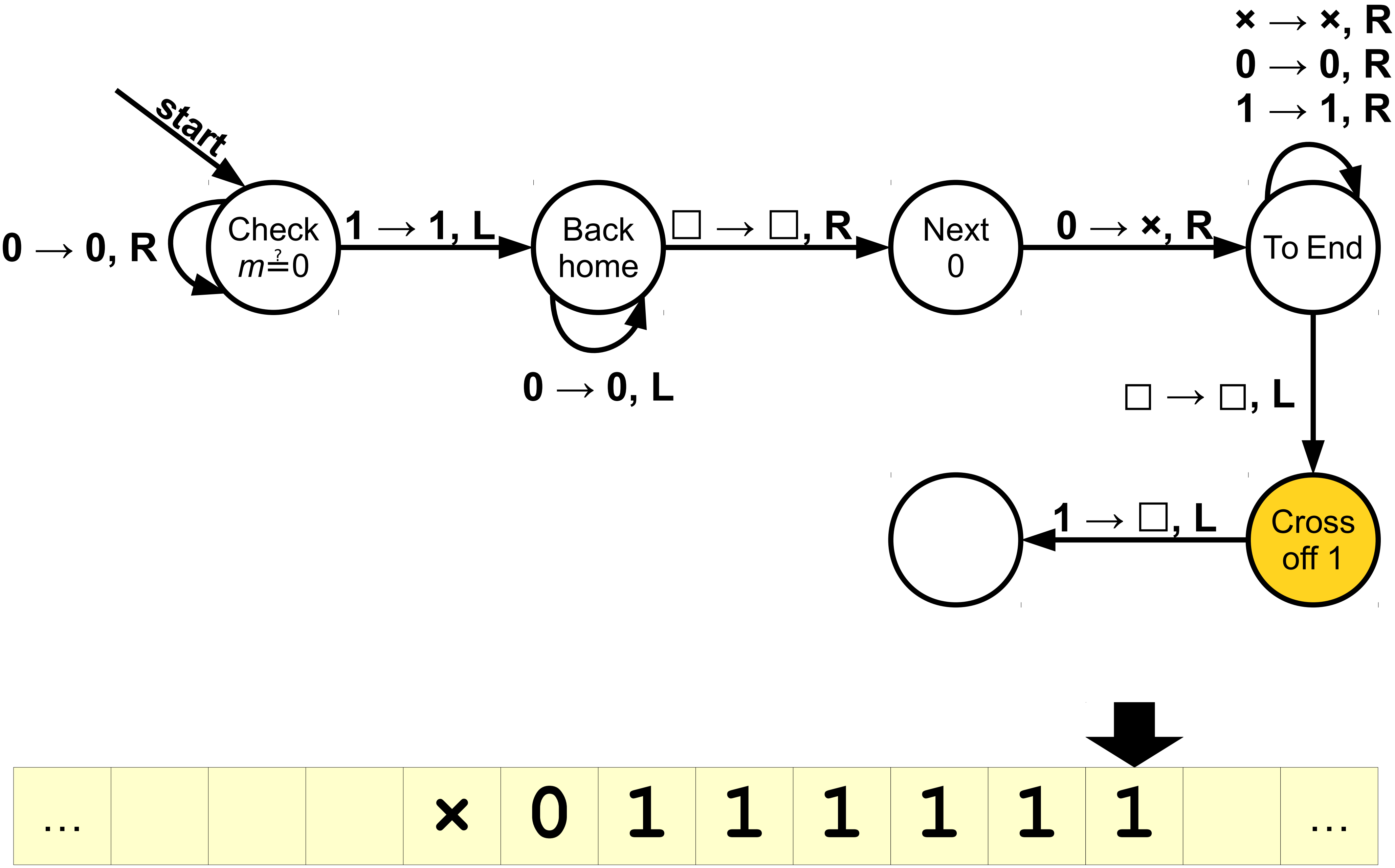
start
Check
$m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L



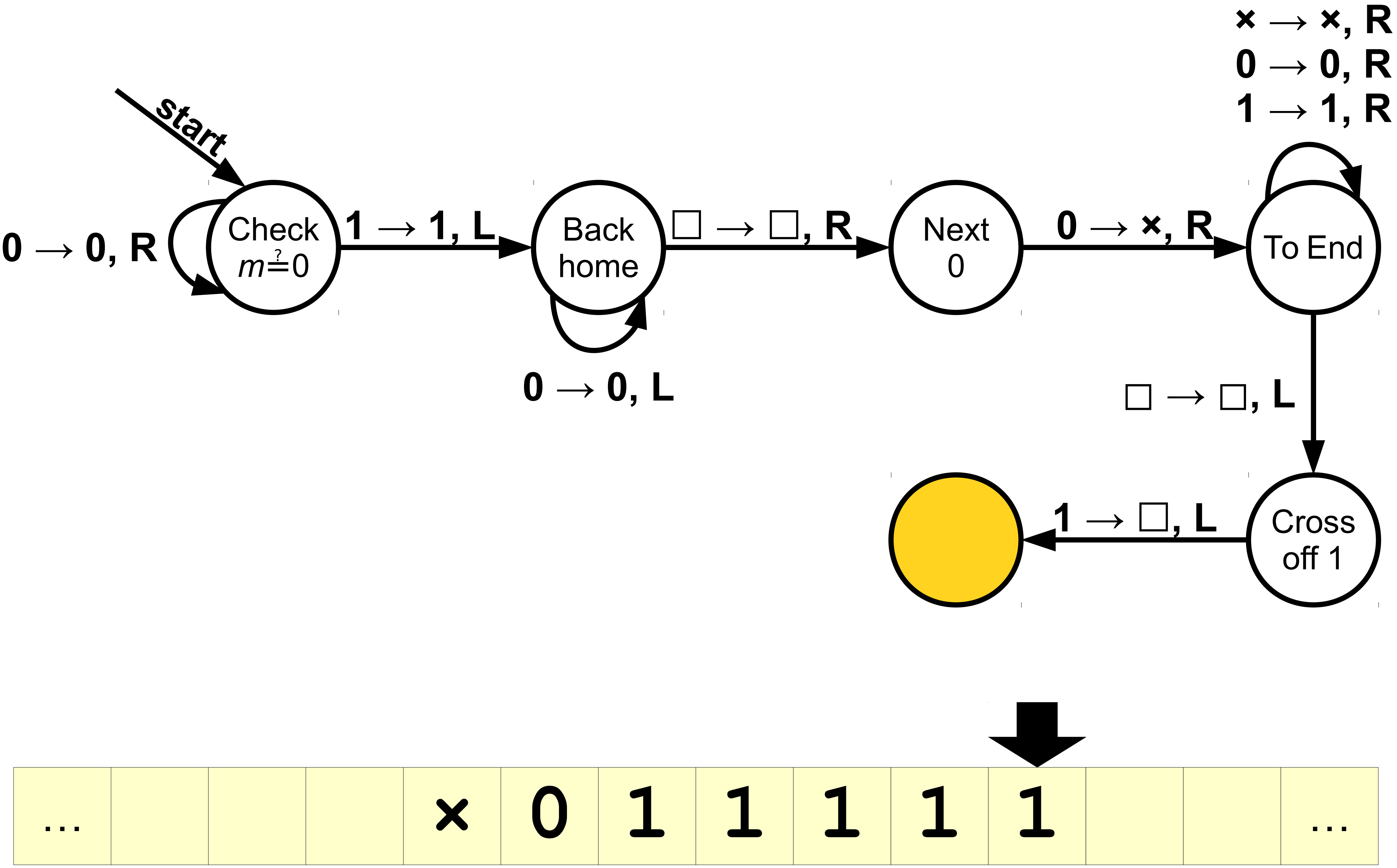
…				×	0	1	1	1	1	1	1		…

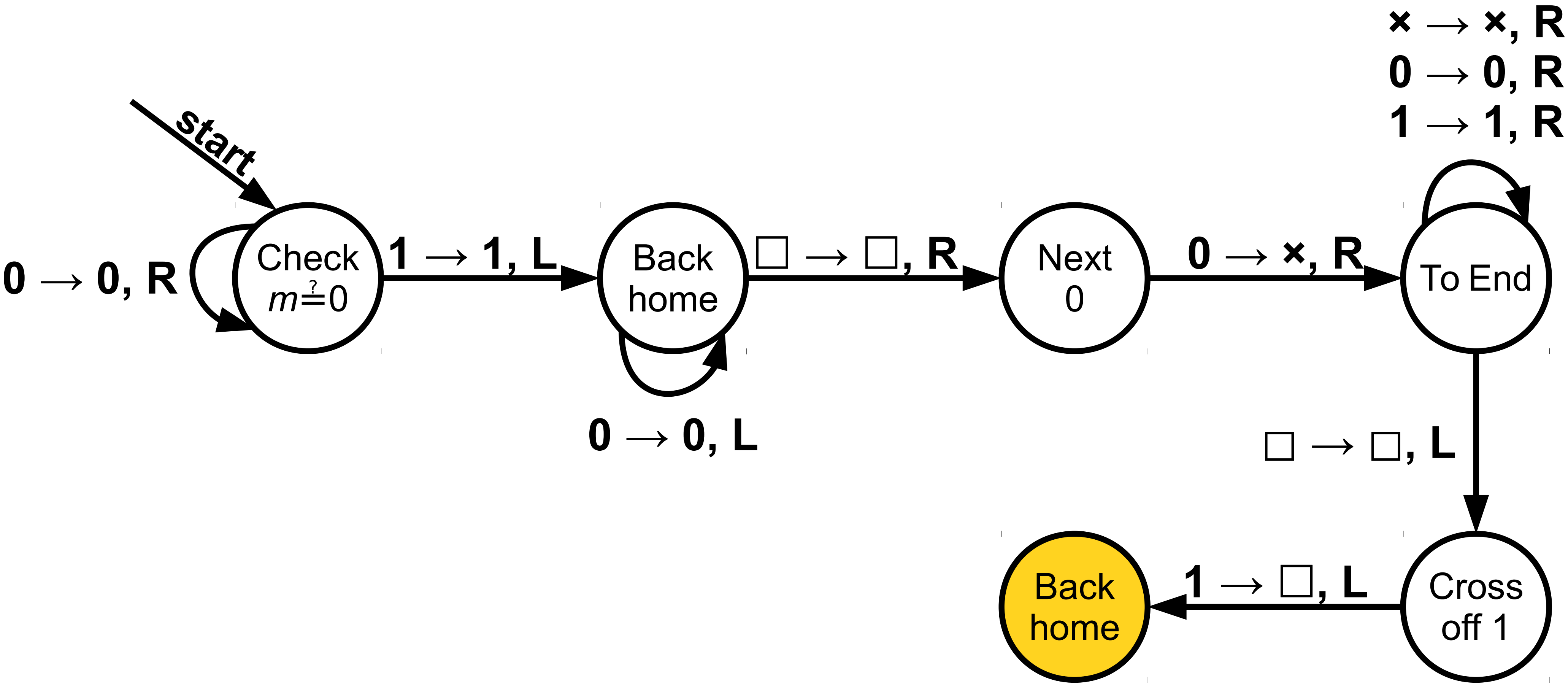

start
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, L
Cross
off 1

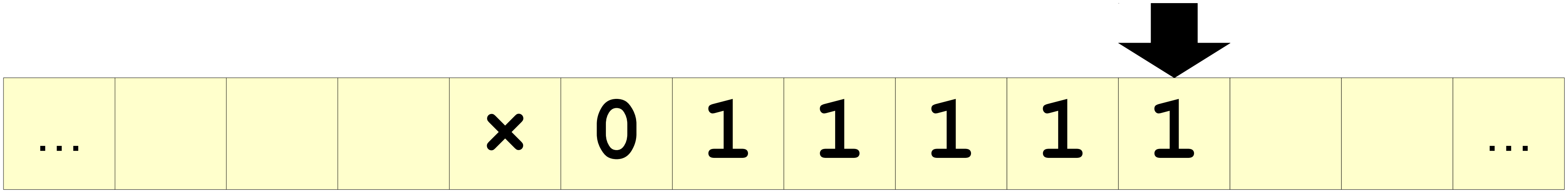
…				×	0	1	1	1	1	1	1		…


start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L

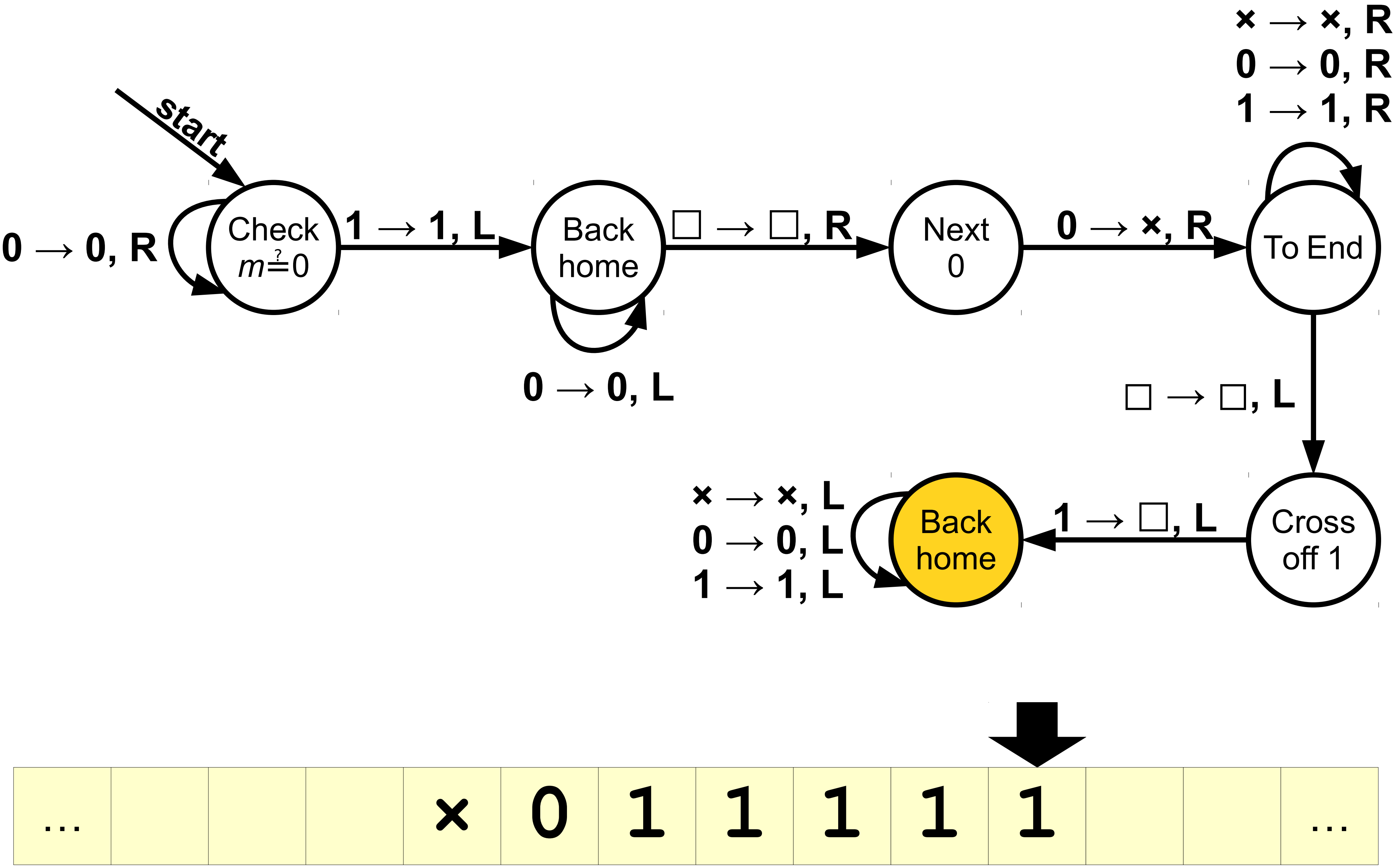
…				×	0	1	1	1	1	1	1		…


start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, L
Cross
off 1
1 → □, L
…
×
0
1
1
1
1
1
…

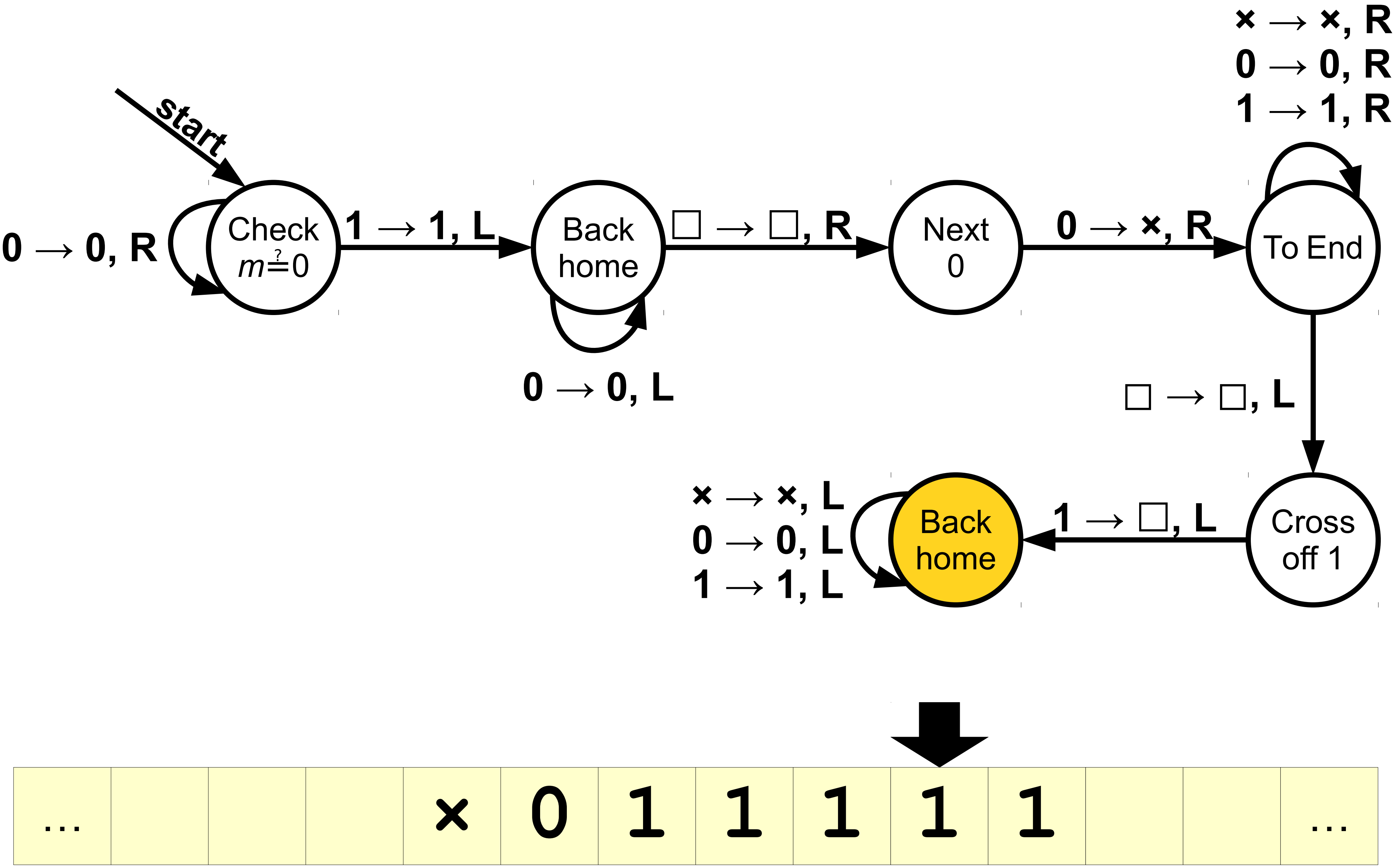

start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, L
Cross
off 1
1 → □, L
Back
home

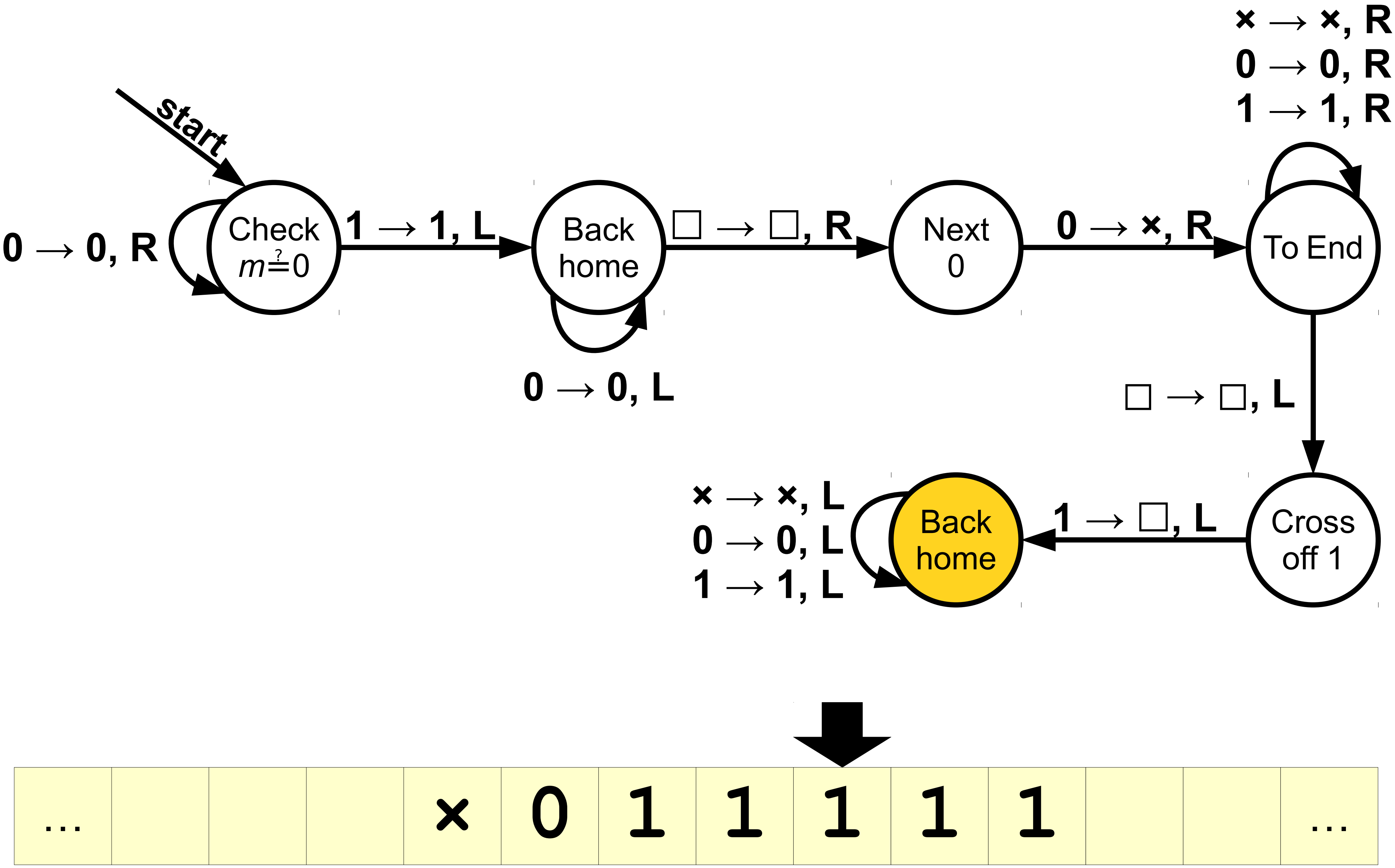


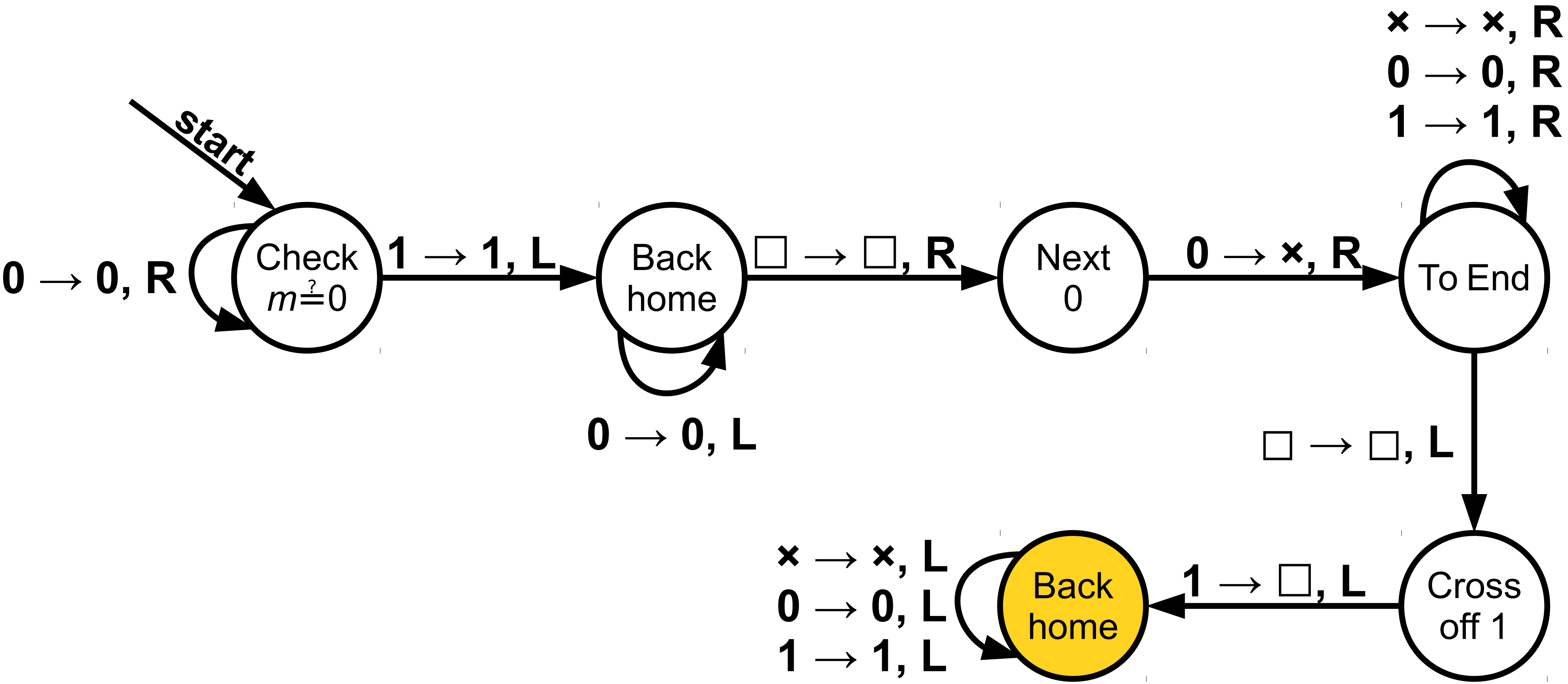
…				×	0	1	1	1	1	1			…

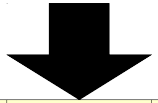

start
Check
$m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L

…				×	0	1	1	1	1	1			…

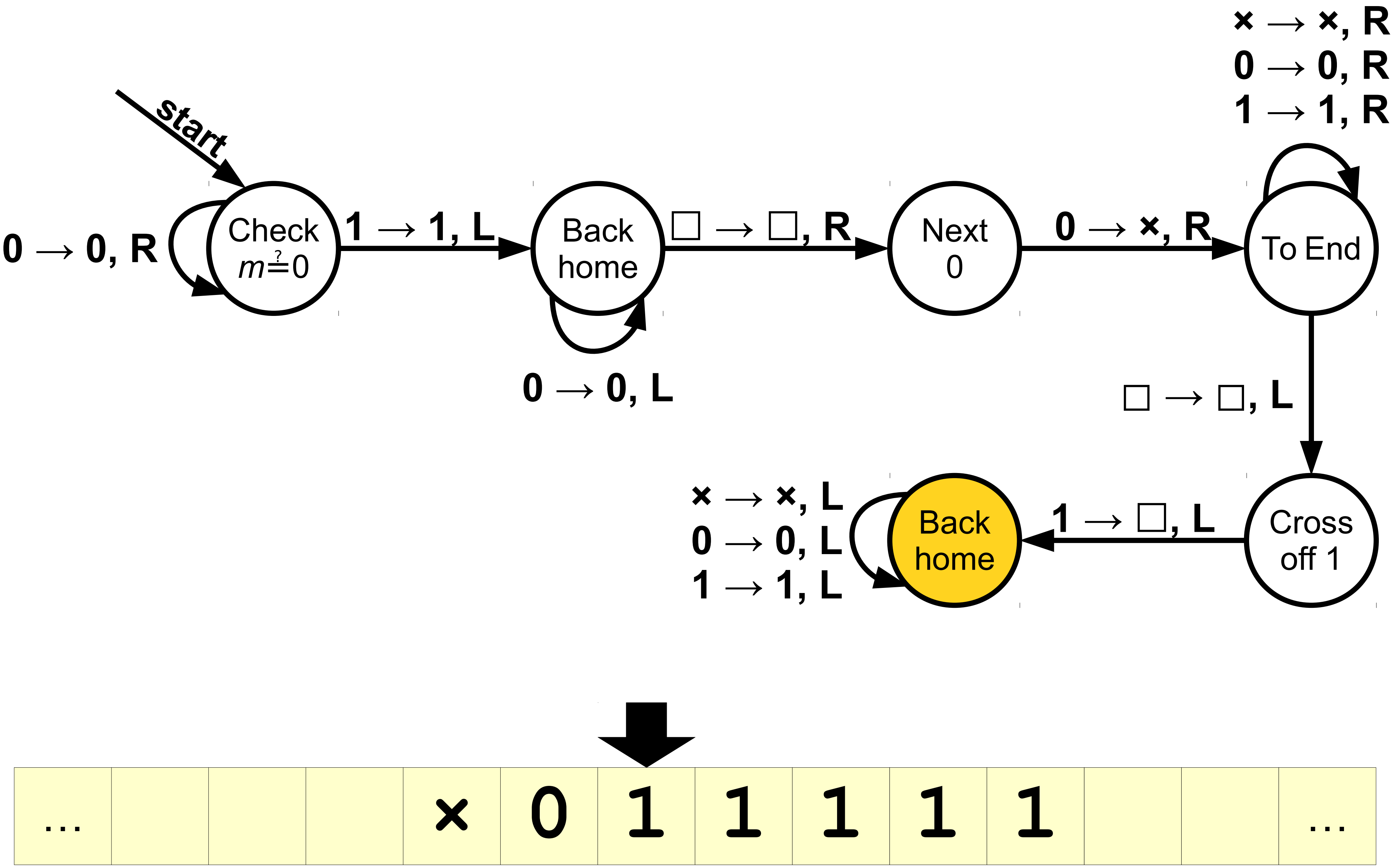

start
0 → 0, R
Check $m \stackrel{?}{=} 0$
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
…
×
0
1
1
1
1
1
…

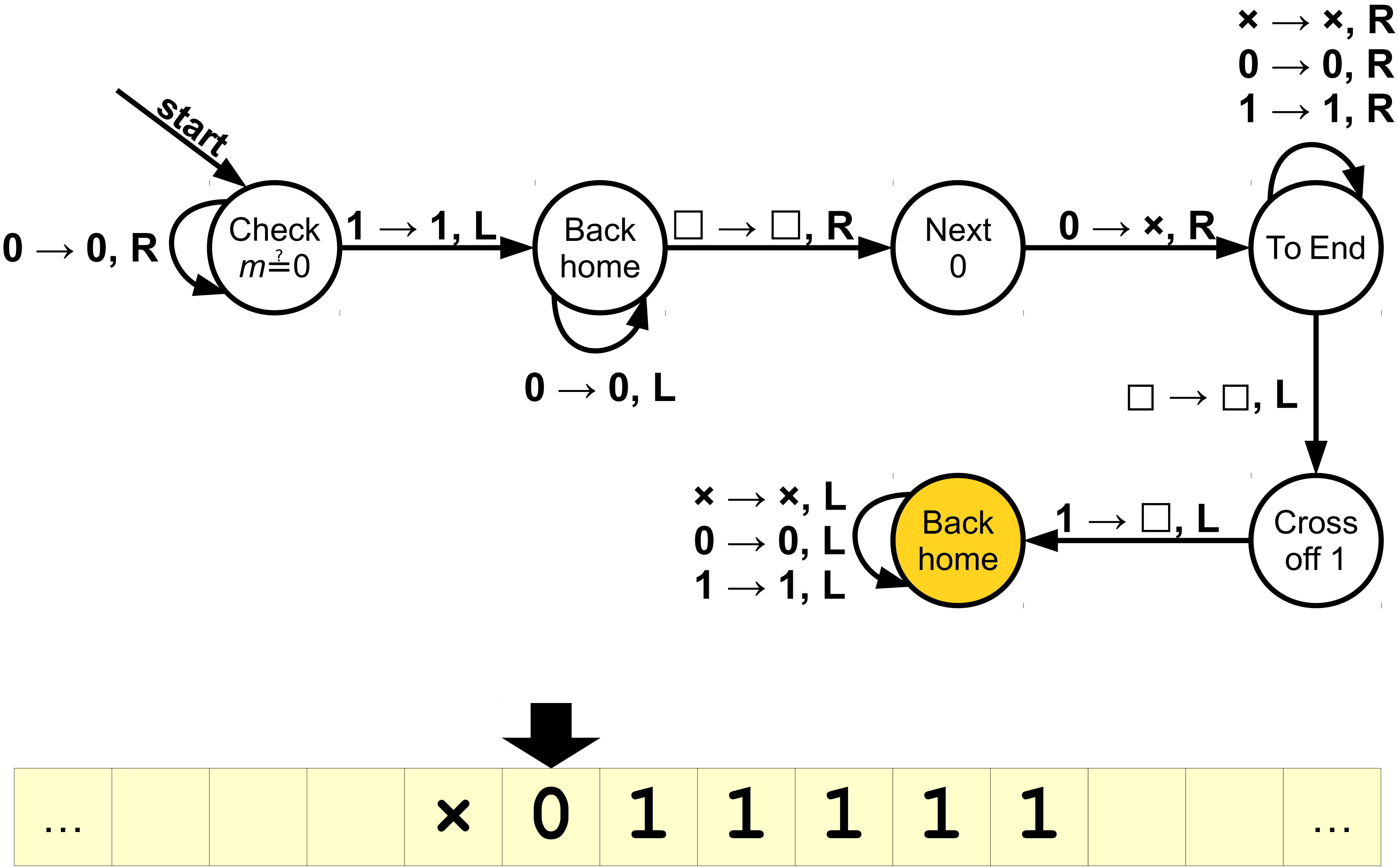

start
Check $m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
…
×
0
1
1
1
1
1
…

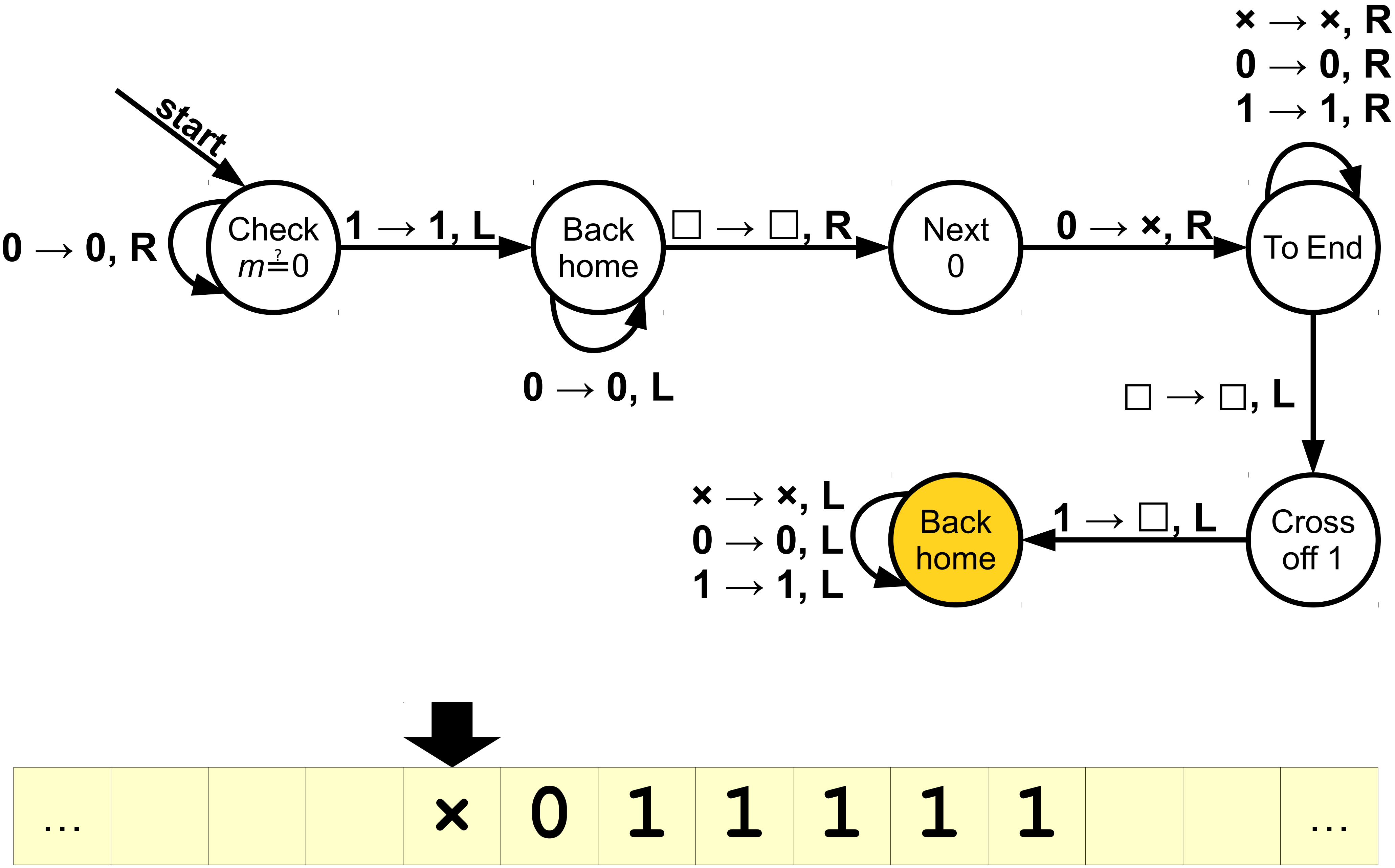

start
Check
$m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L



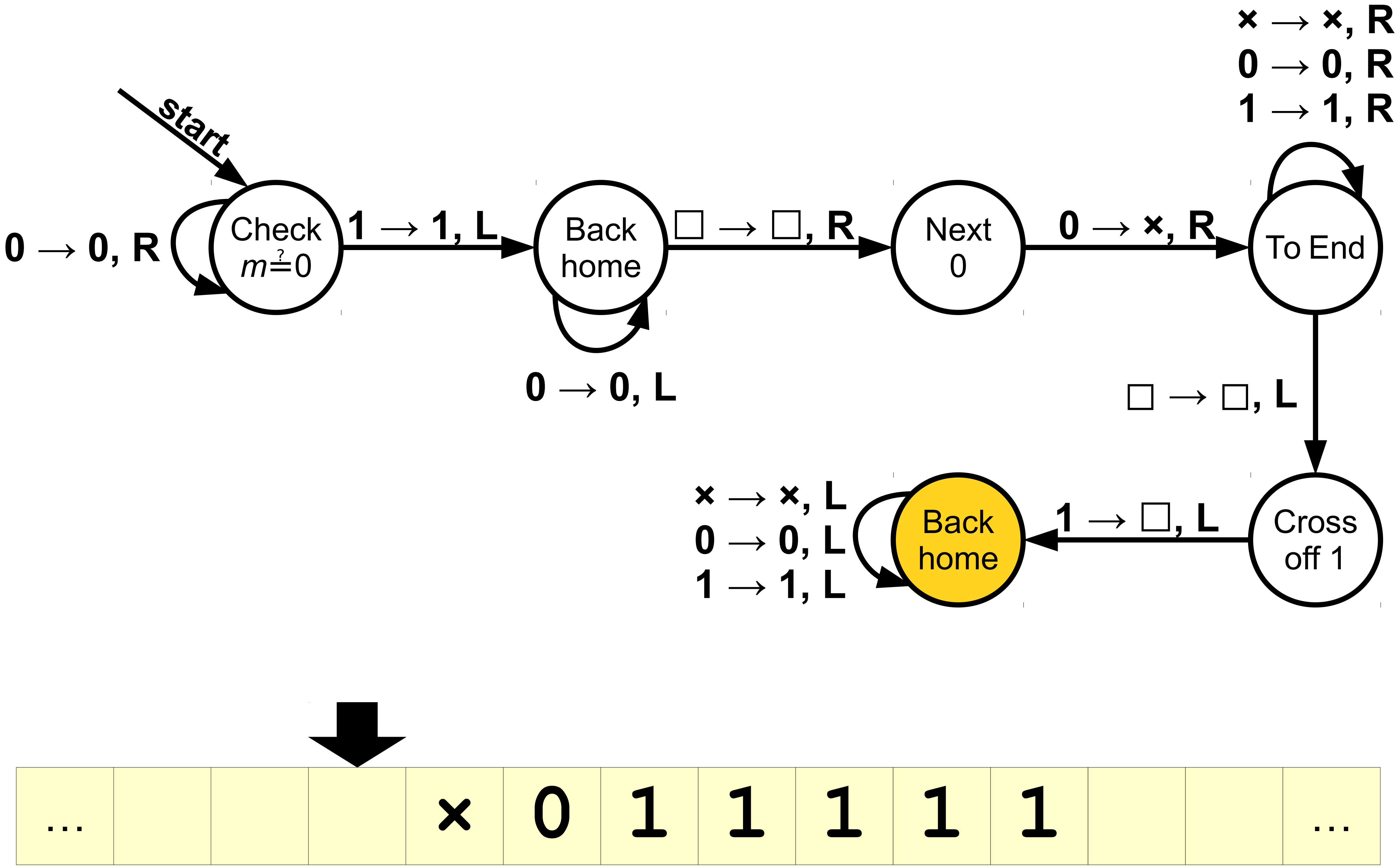
…				×	0	1	1	1	1	1			…

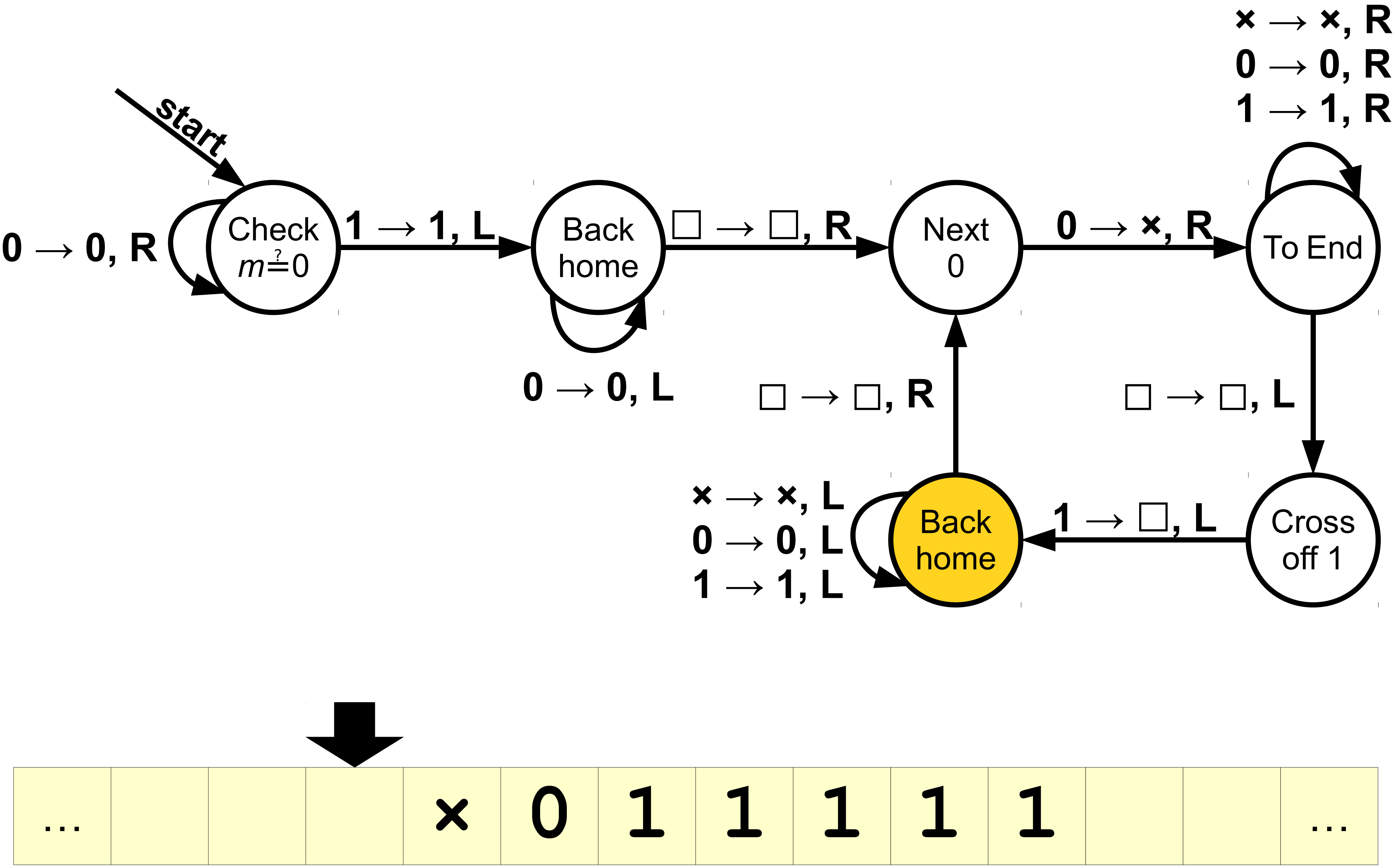

start
Check
m ≟ 0
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
…
×
0
1
1
1
1
1
…

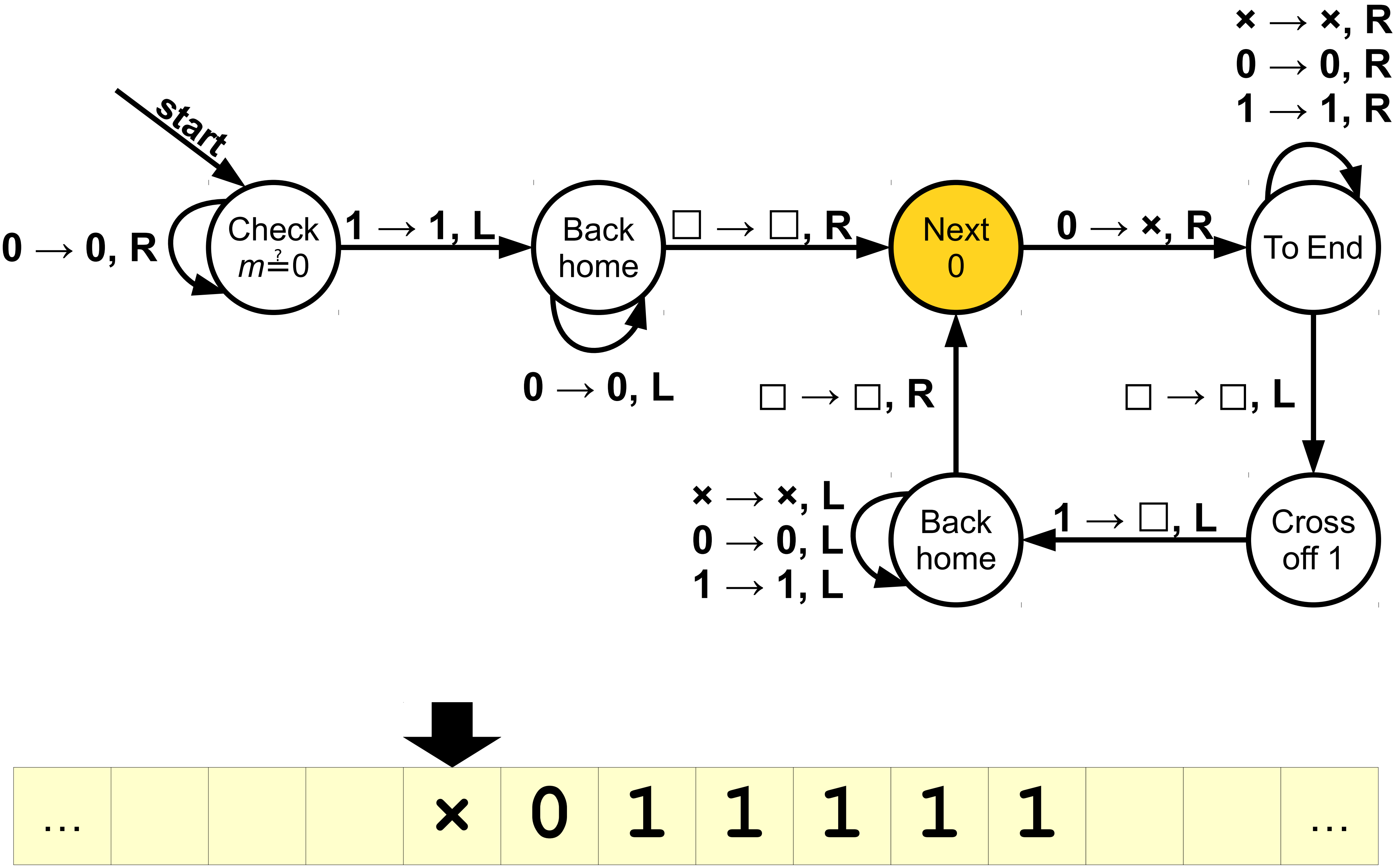

start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
…
×
0
1
1
1
1
1
…

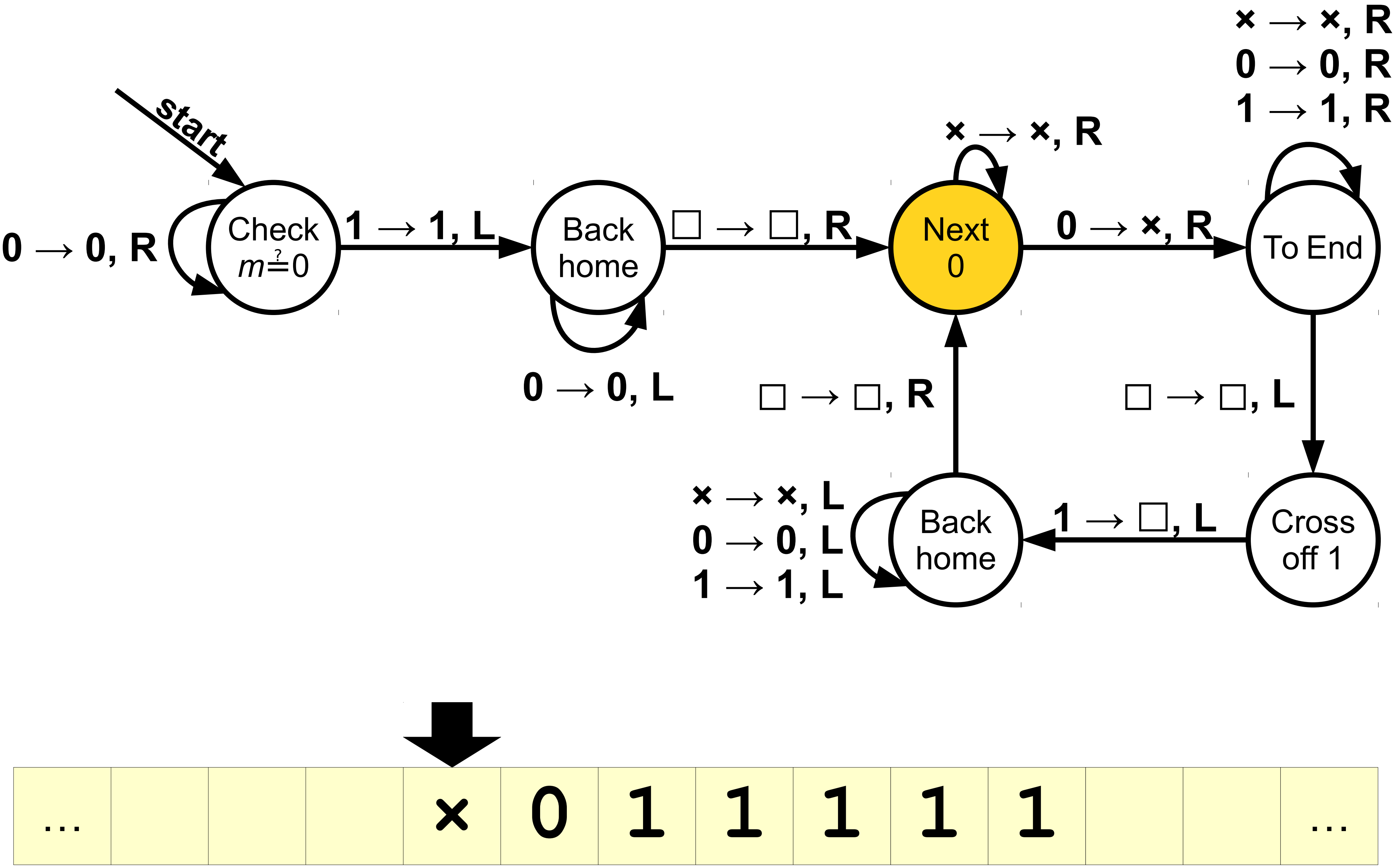

start
Check
$m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L

…				×	0	1	1	1	1	1			…

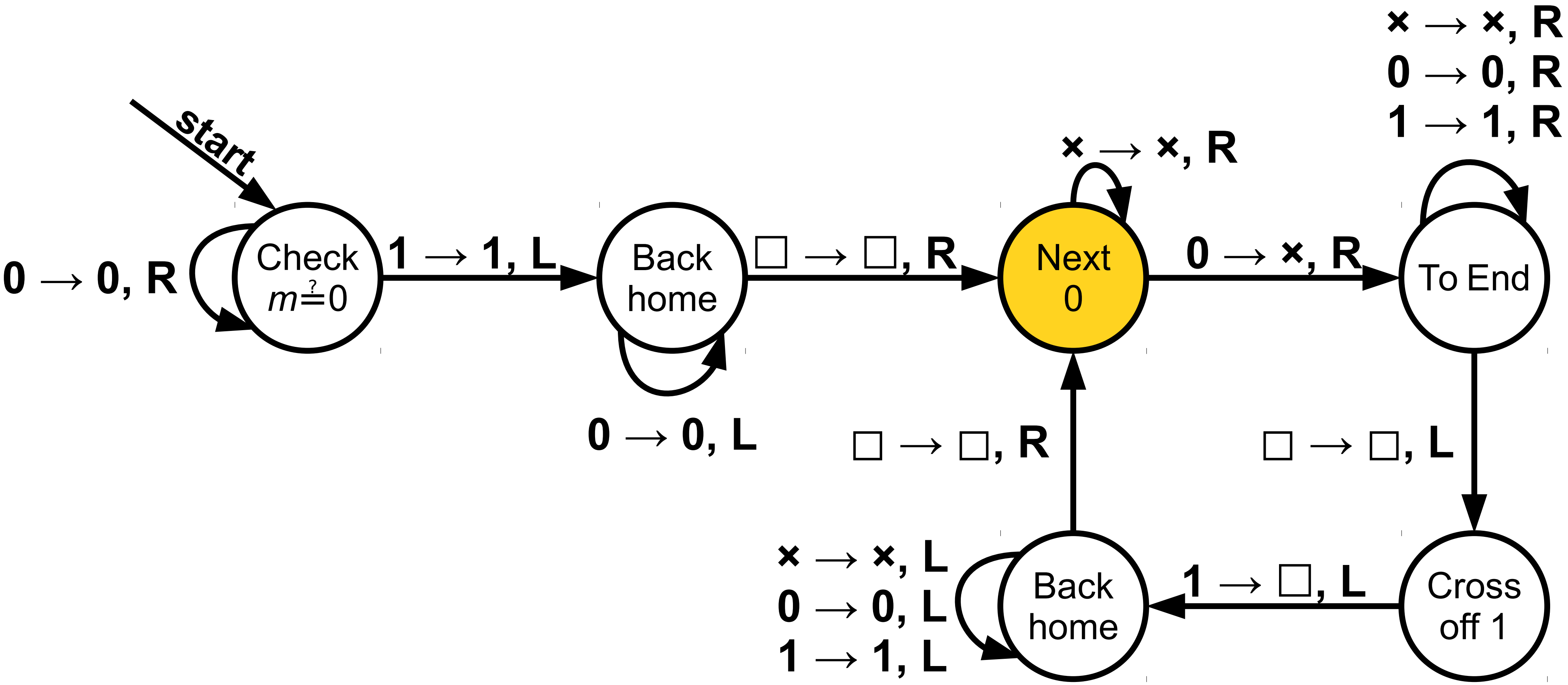

start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
…
×
0
1
1
1
1
1
…


start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
0
1
1
1
1
1
…

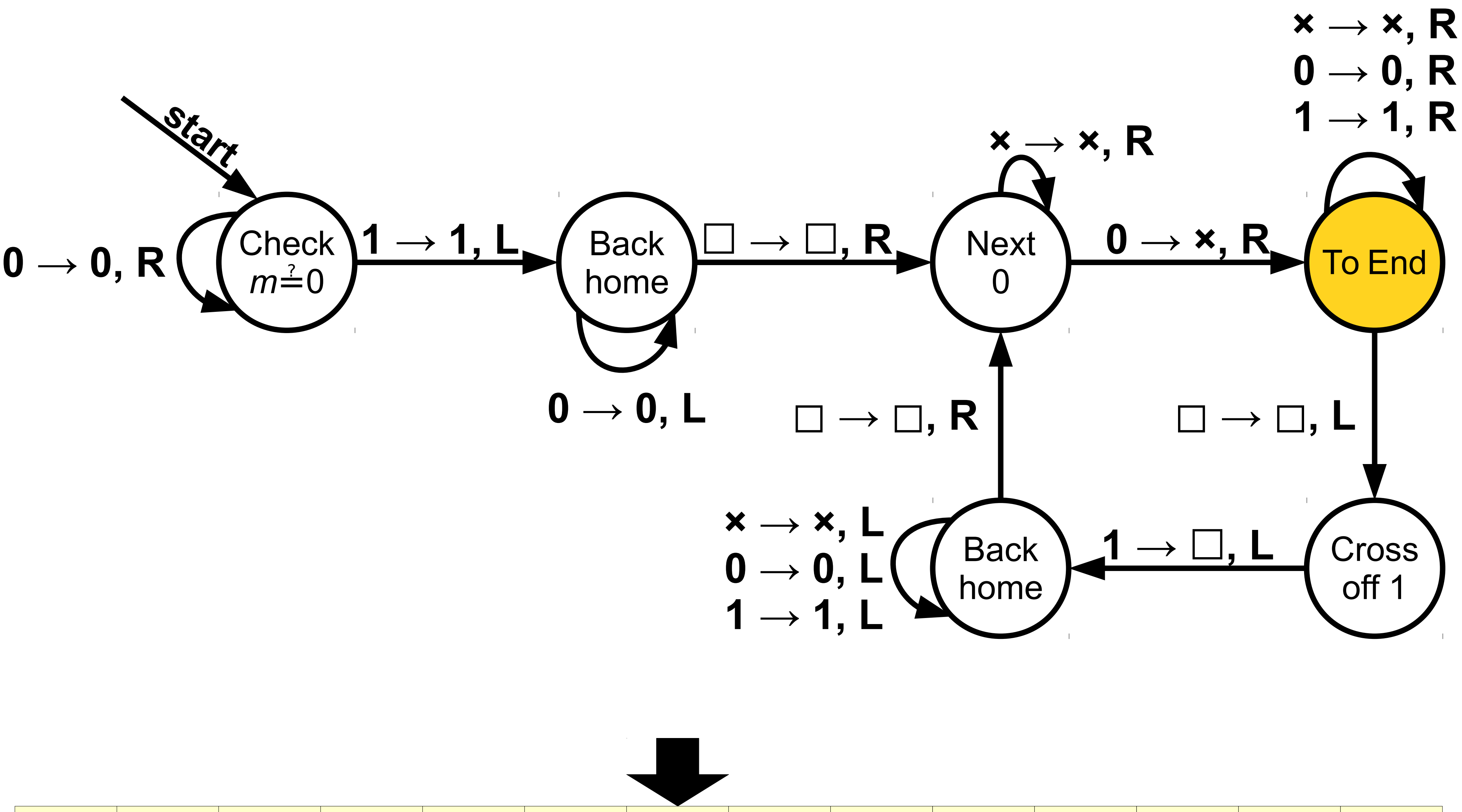

start
Check
$m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
0
1
1
1
1
1
…


start
Check
$m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
× → ×, R
Next
0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

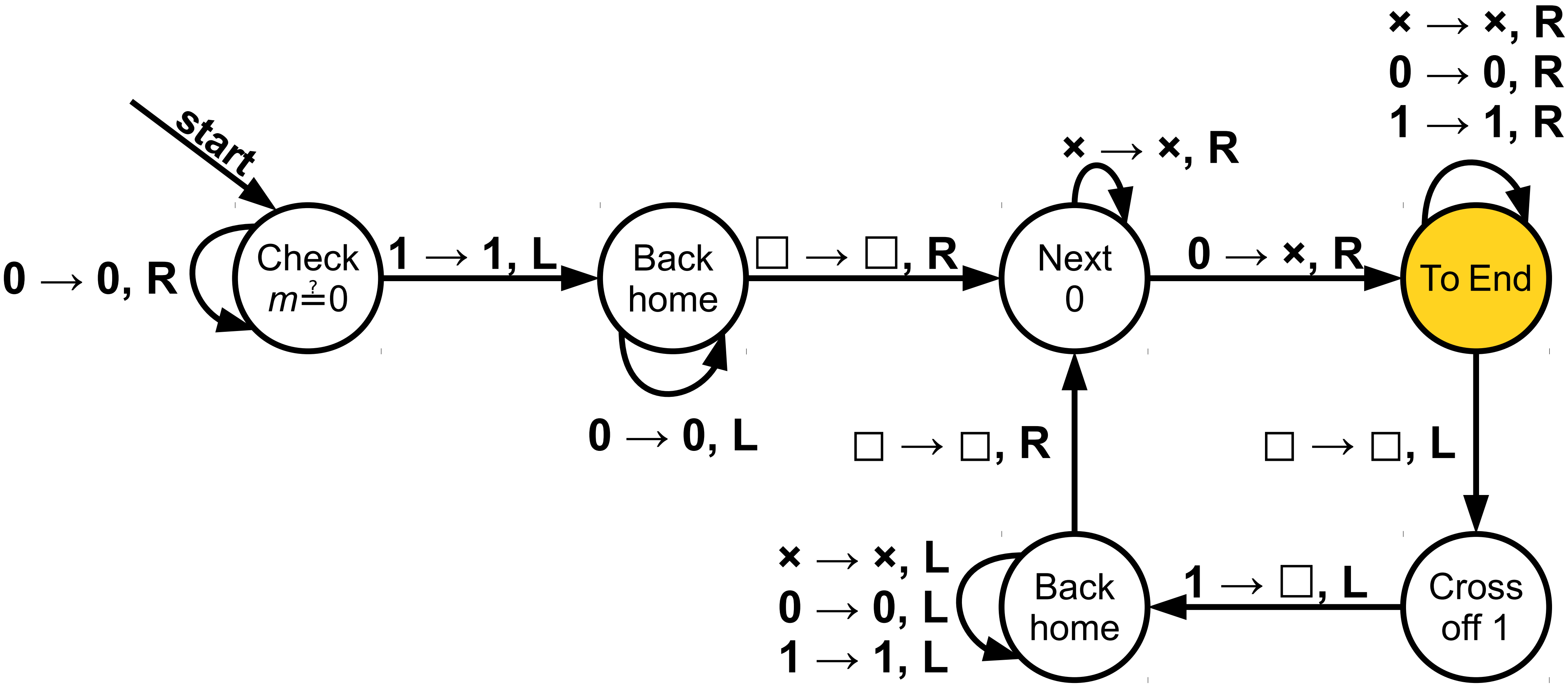
…				×	0	1	1	1	1	1			…

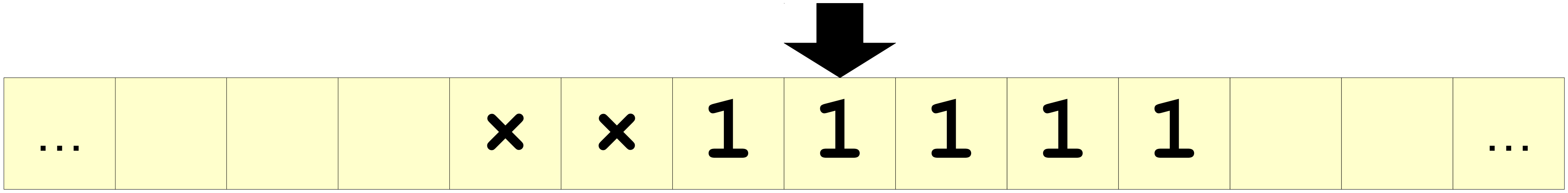

start
Check
m ≟ 0
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

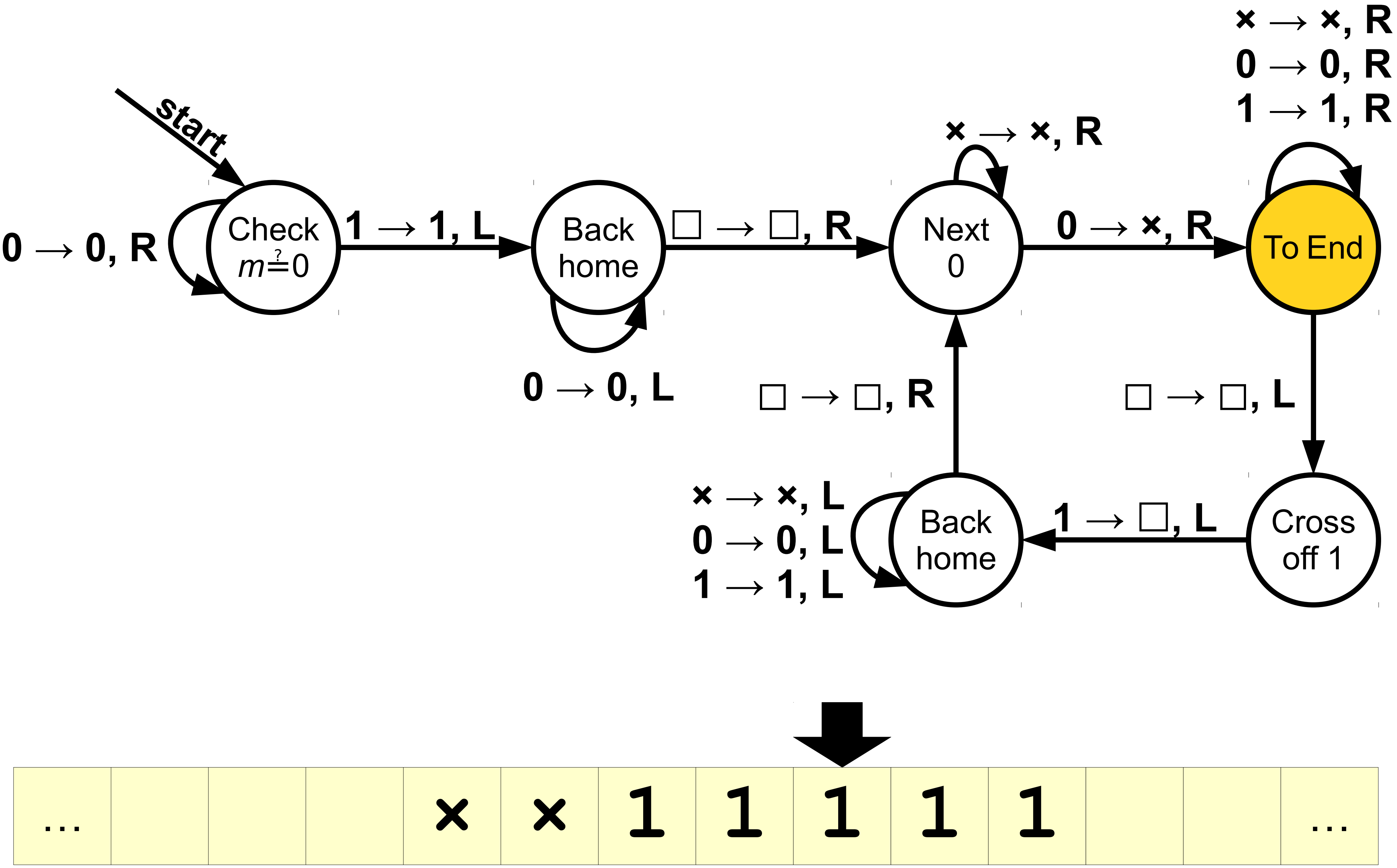
…				×	0	1	1	1	1	1			…


start
Check $m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

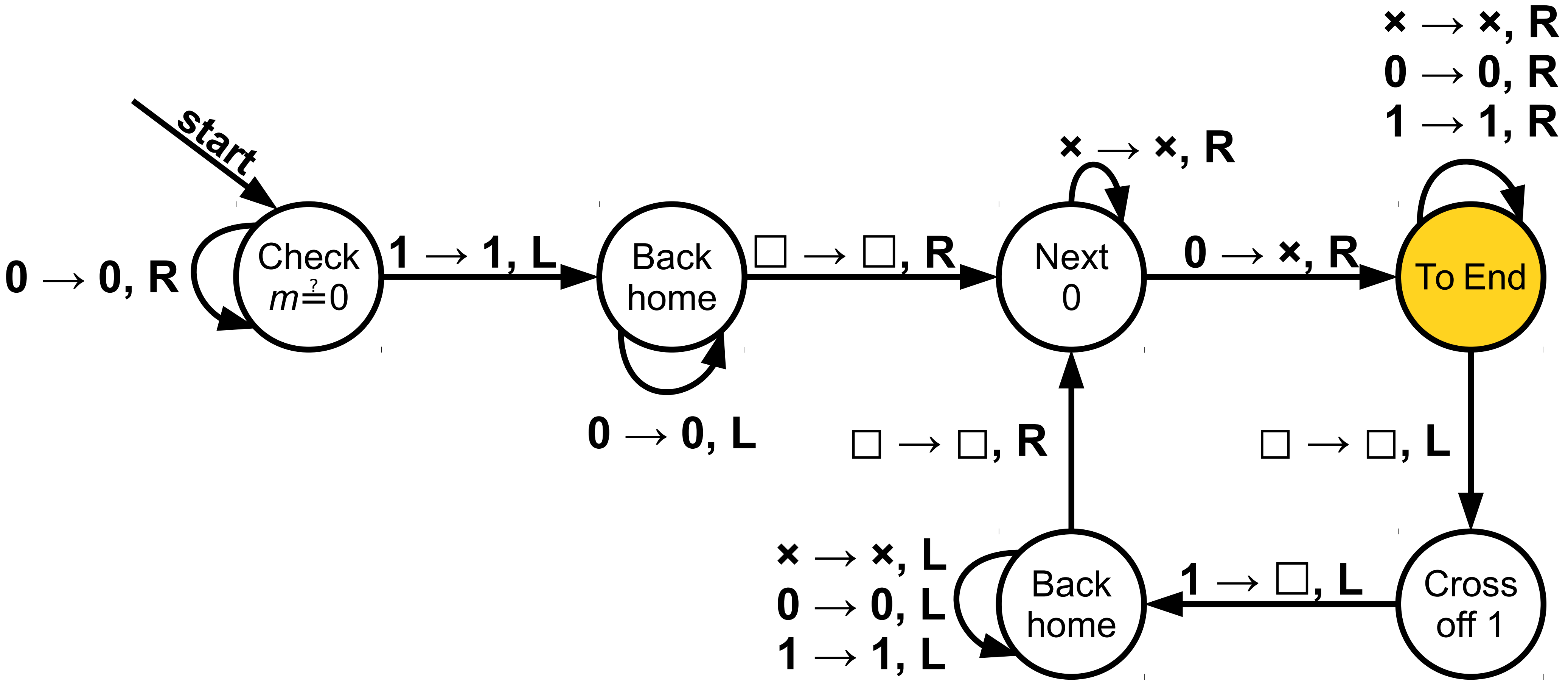
…				×	×	1	1	1	1	1			…

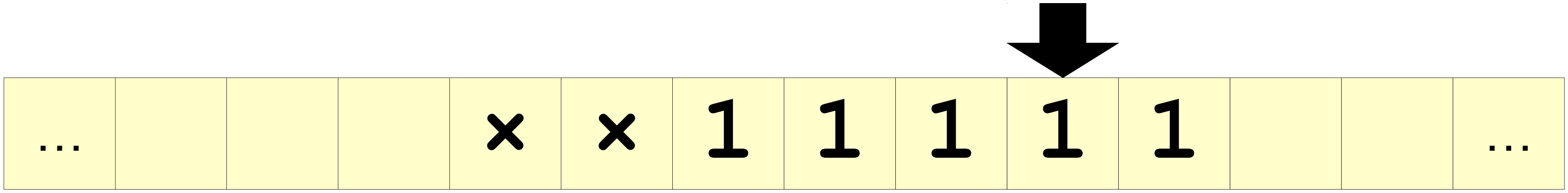

start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R


…
×
×
1
1
1
1
1
…

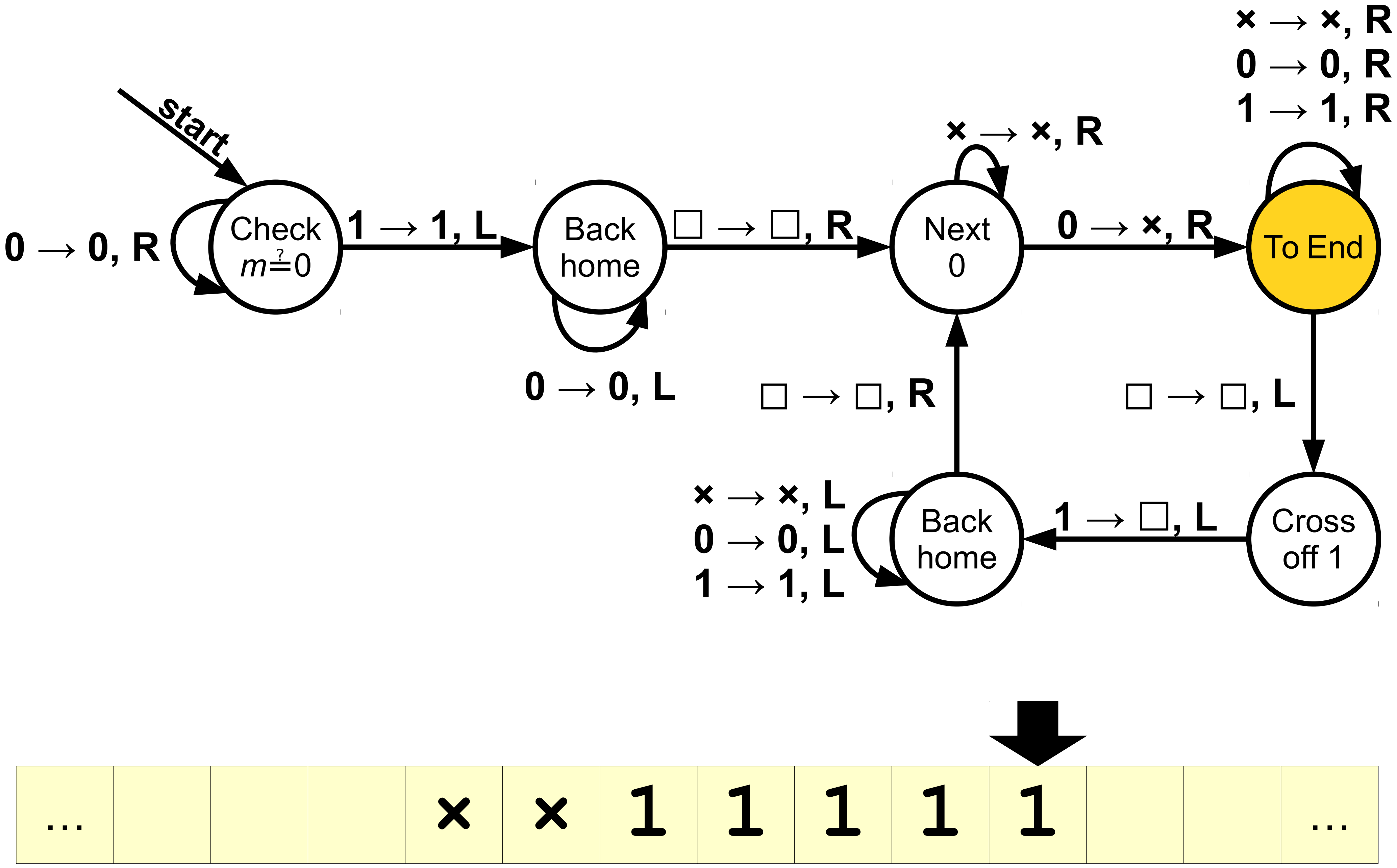

start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
× → ×, R
Next
0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1

…				×	×	1	1	1	1	1			…

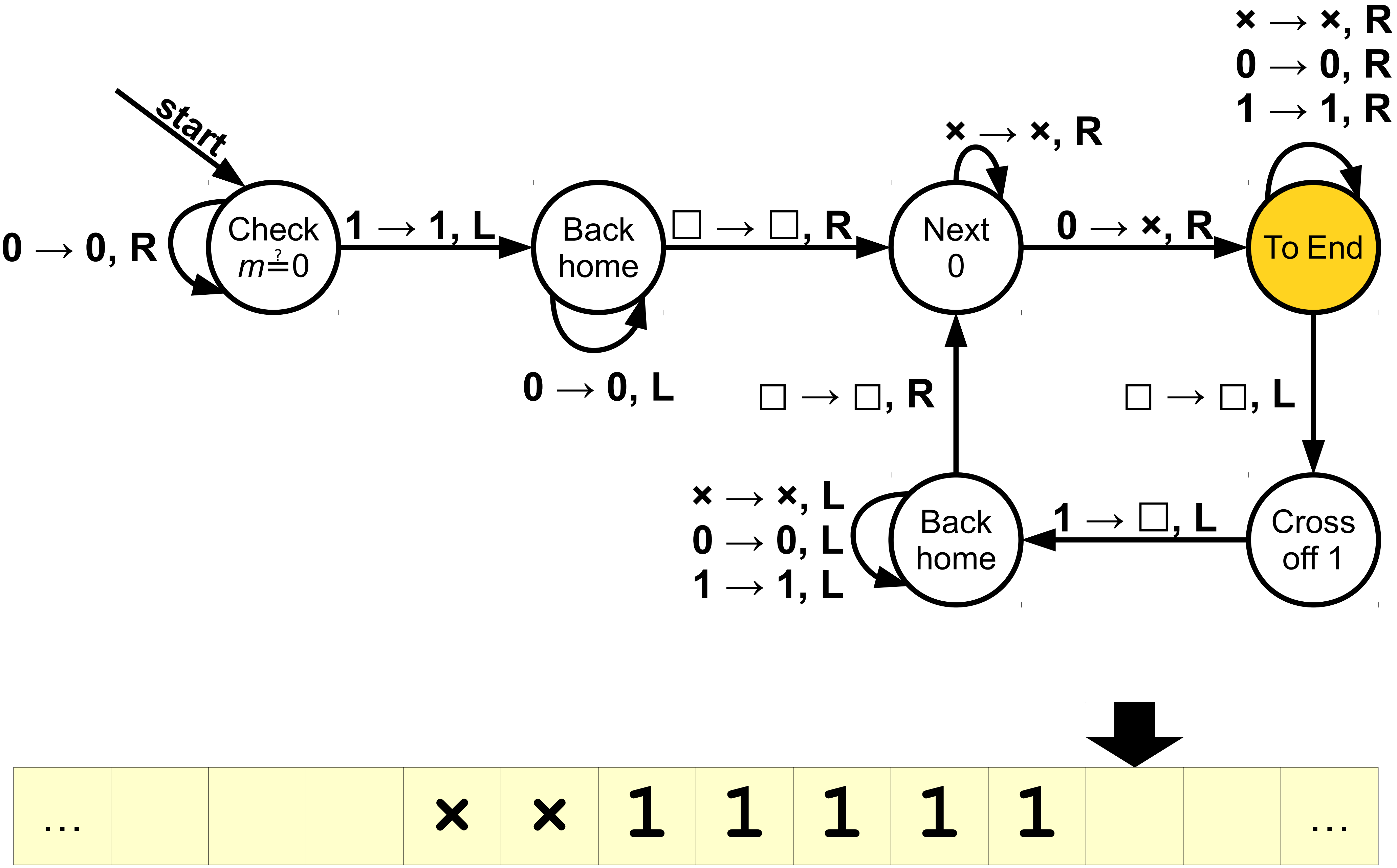

start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

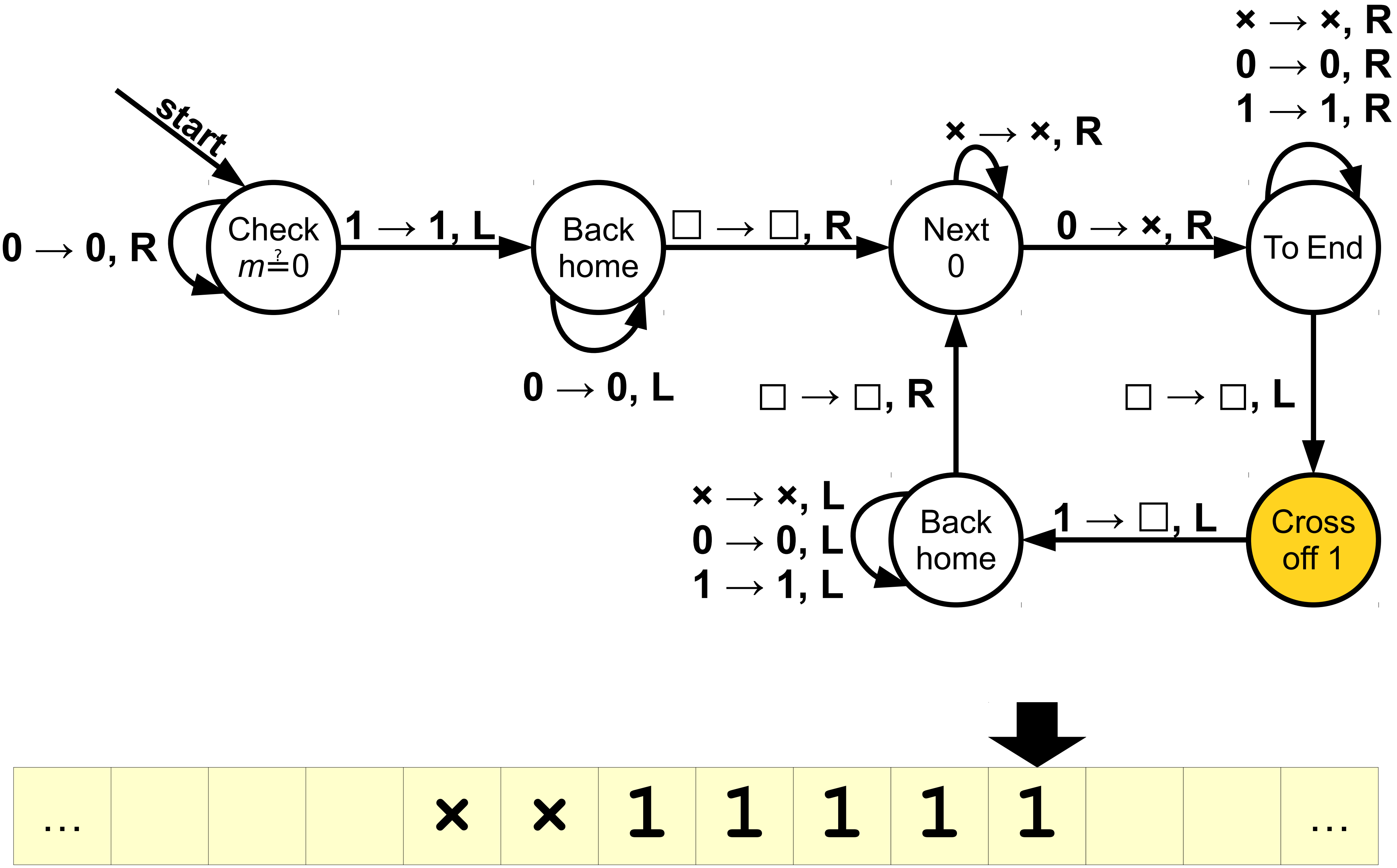


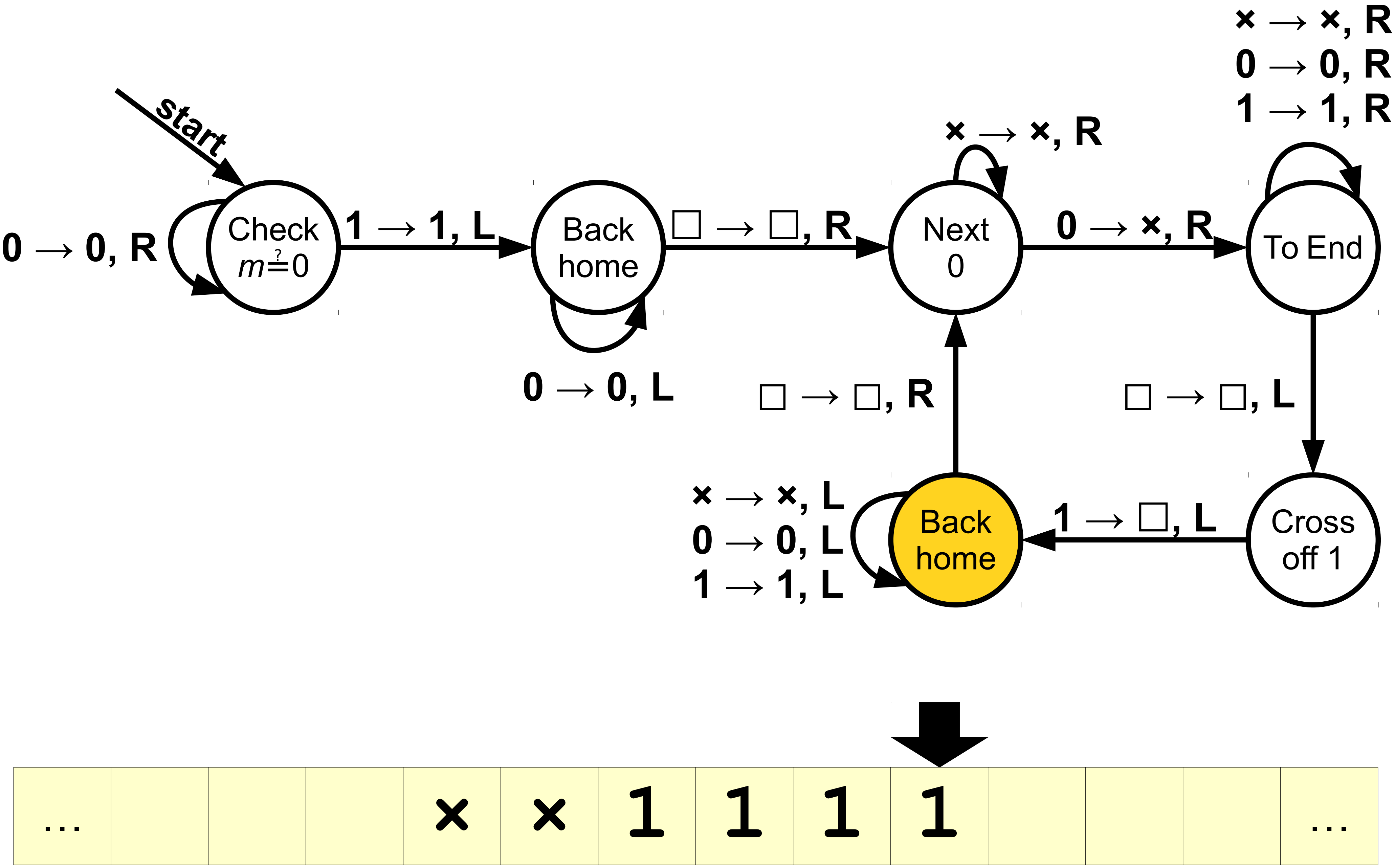
…				×	×	1	1	1	1	1			…

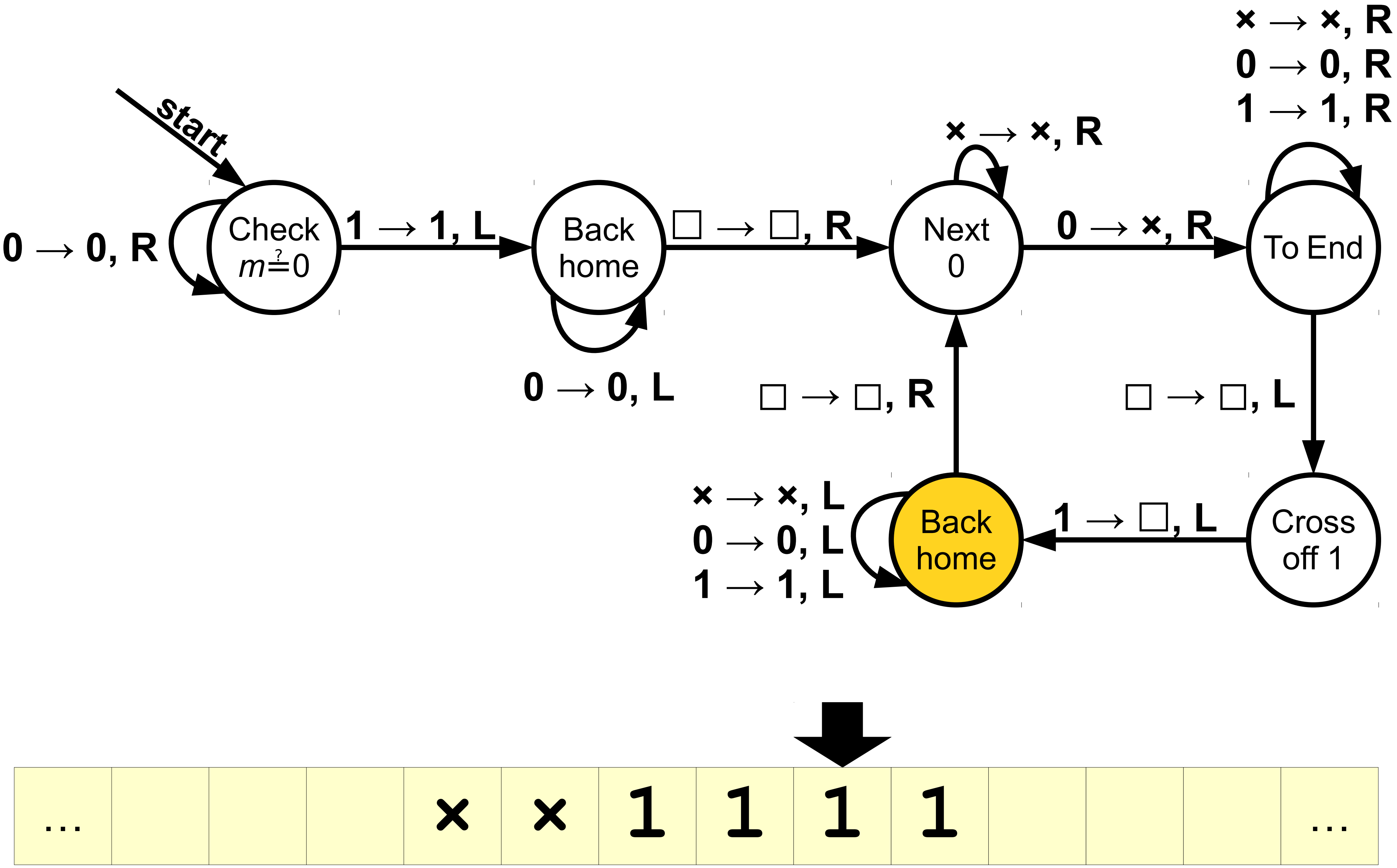

start
Check
m≟0
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

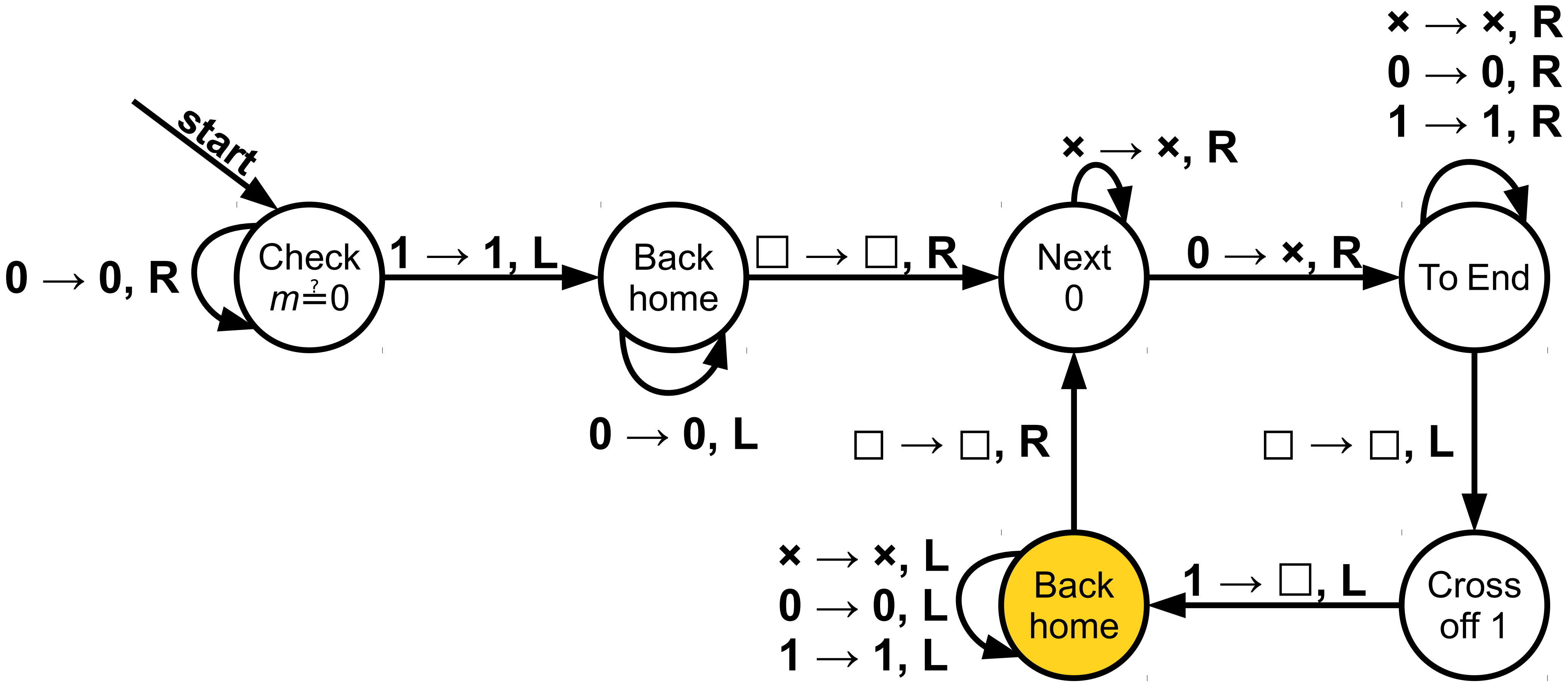
…				×	×	1	1	1	1	1			…

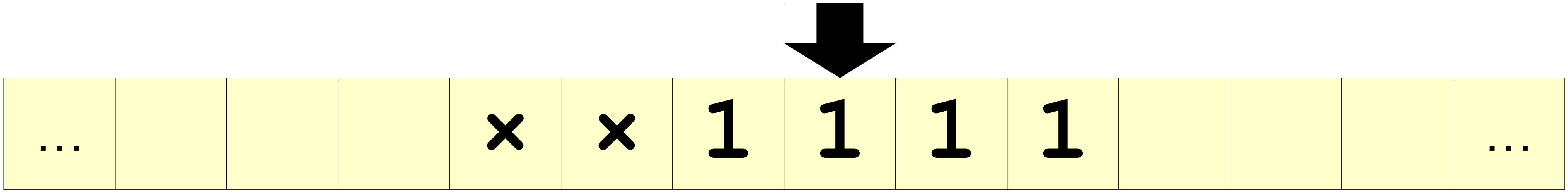

start
Check $m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
1
1
1
1
1
…

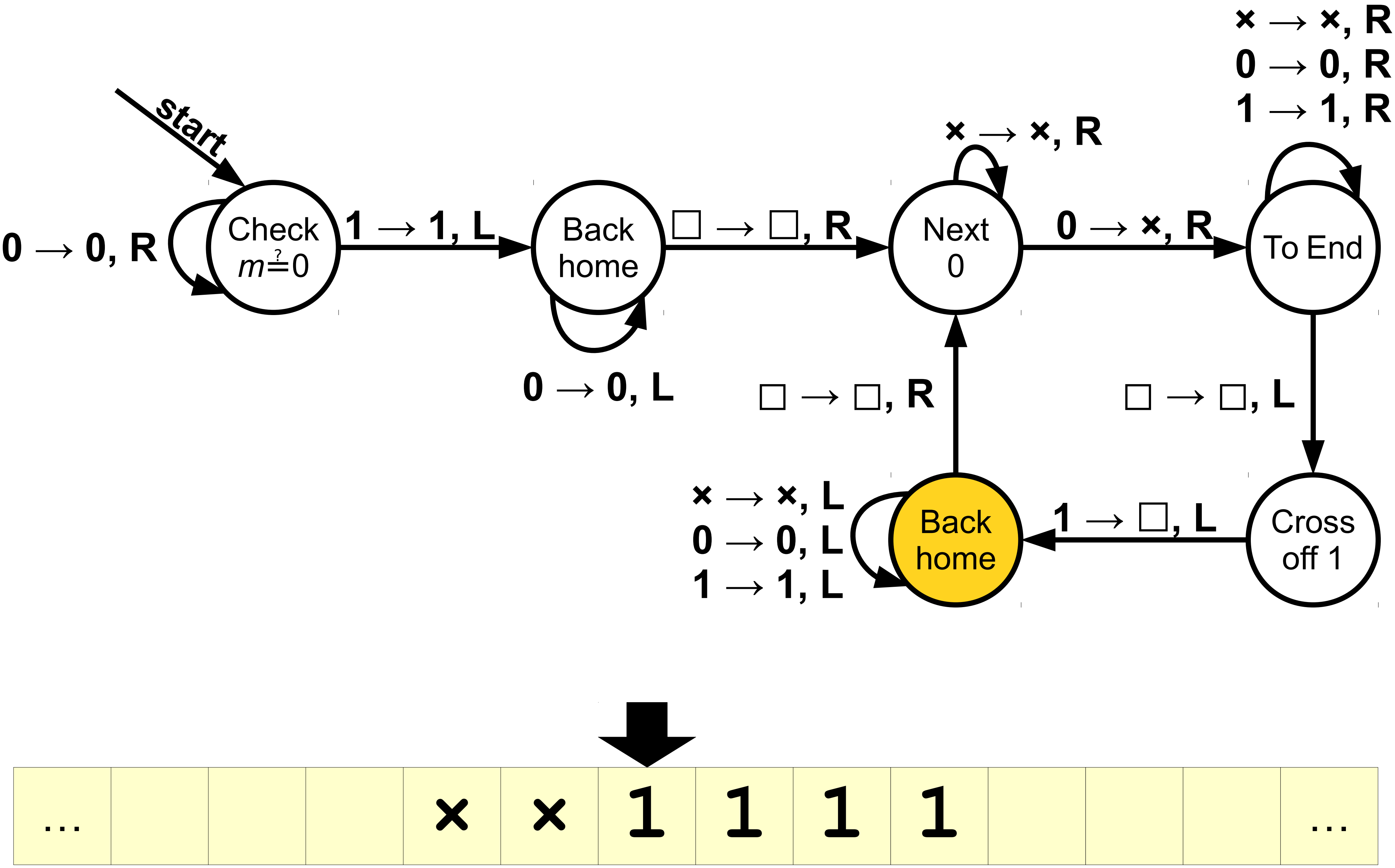

start
Check $m\overset{?}{=}0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
1
1
1
1
1
…


start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
… × × 1 1 1 1 …

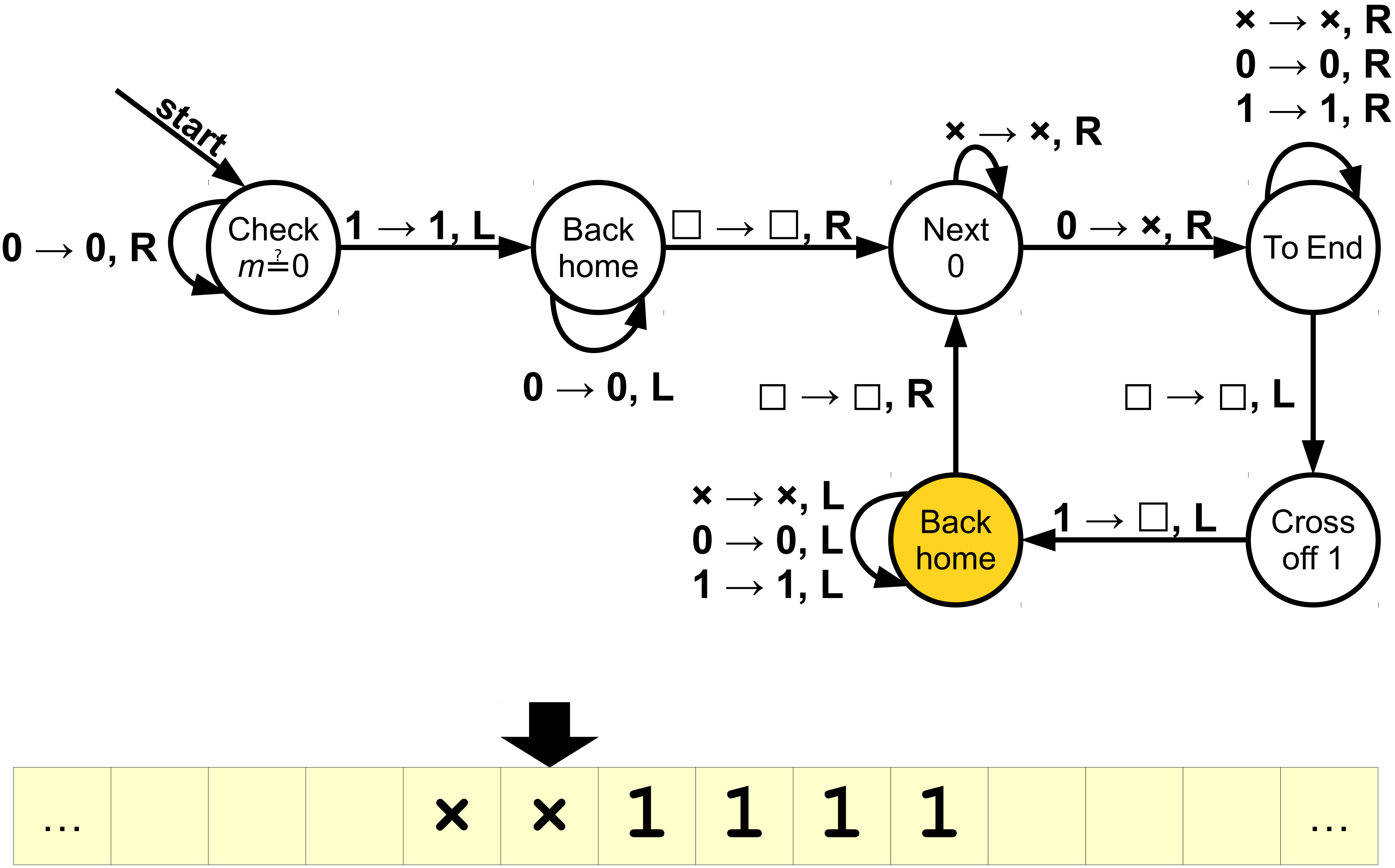

start
Check
$m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
1
1
1
1
…

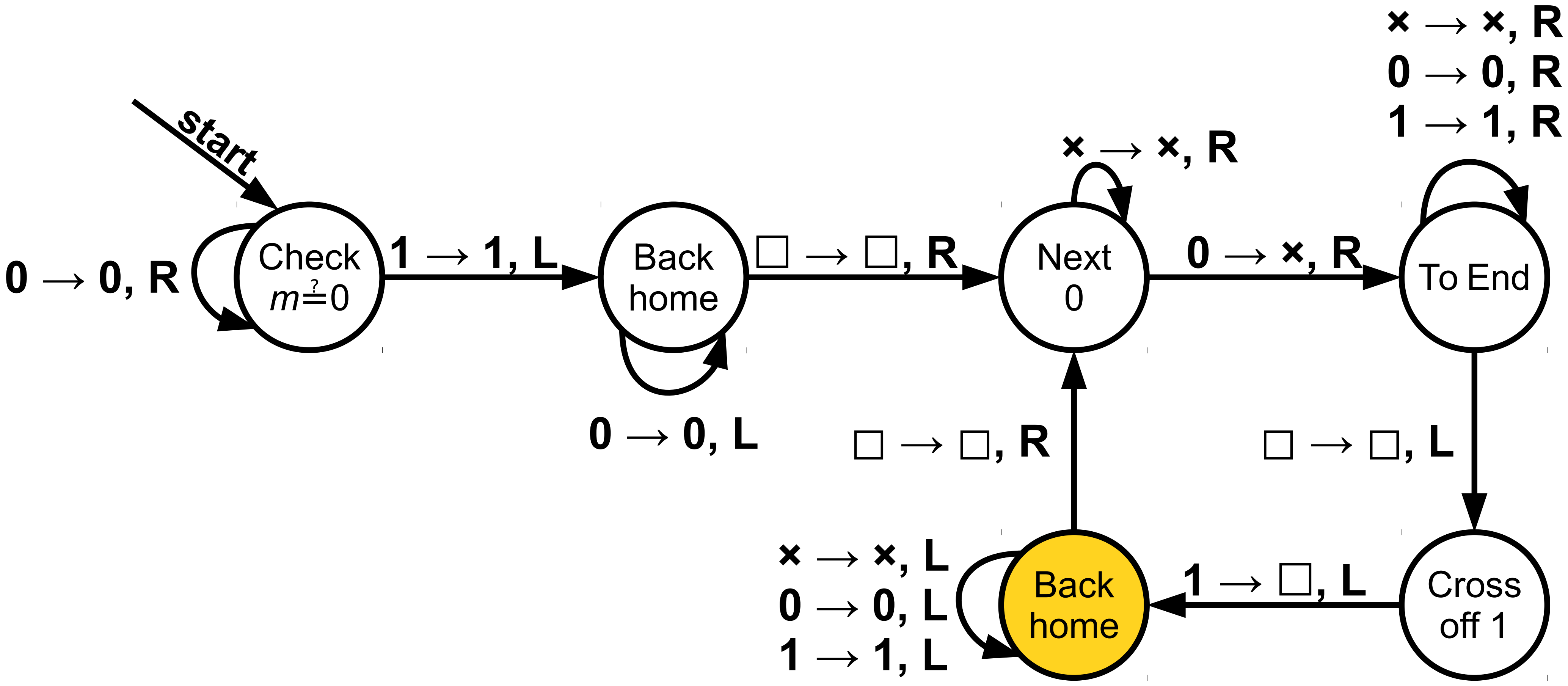

start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
× → ×, R
Next
0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, L
□ → □, R
Cross
off 1
1 → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home


…
×
×
1
1
1
1
…

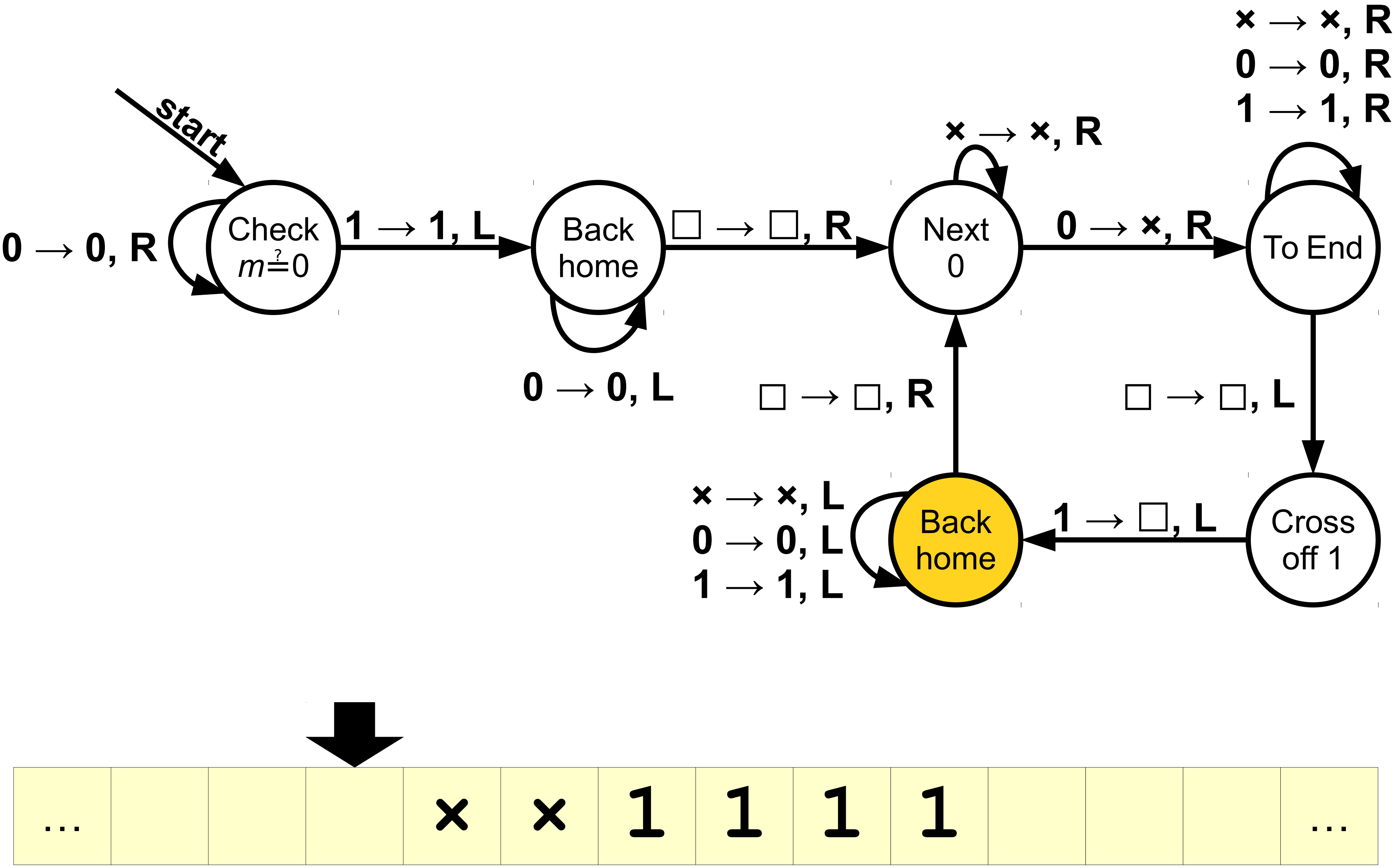

start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
0 → 0, L
□ → □, R
× → ×, R
Next
0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

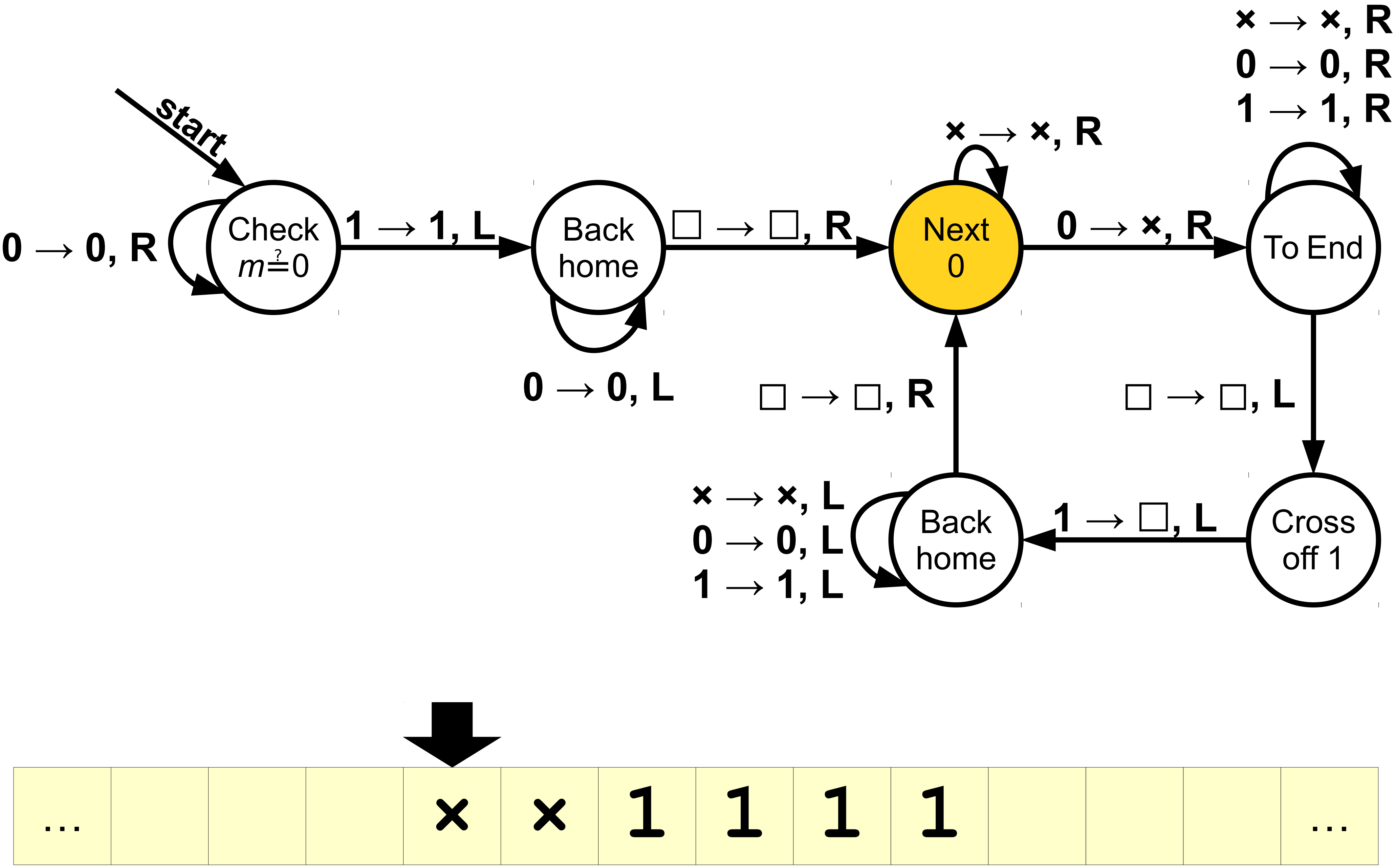
…				×	×	1	1	1	1				…

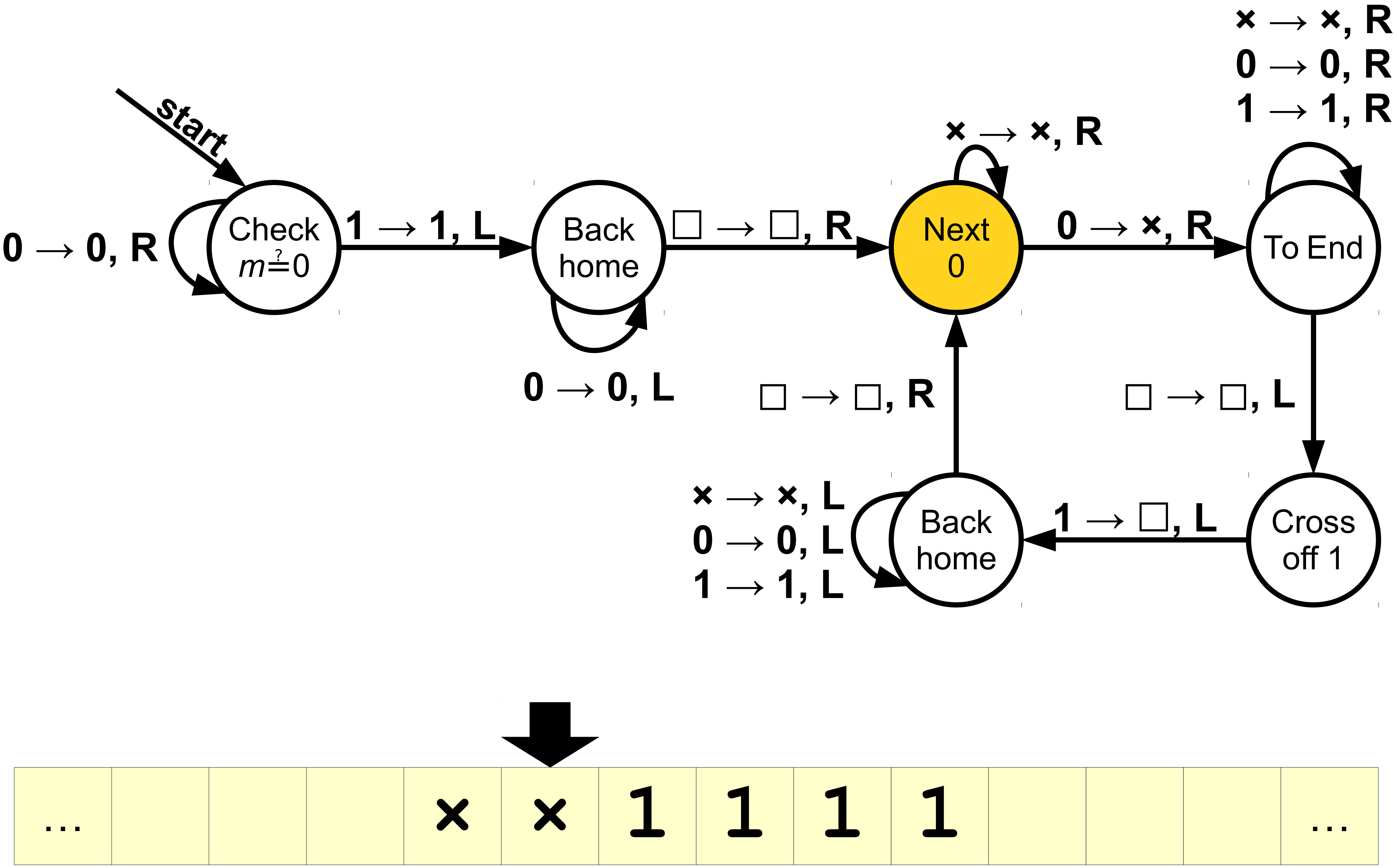

start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
1
1
1
1
…


start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
□ → □, R
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L

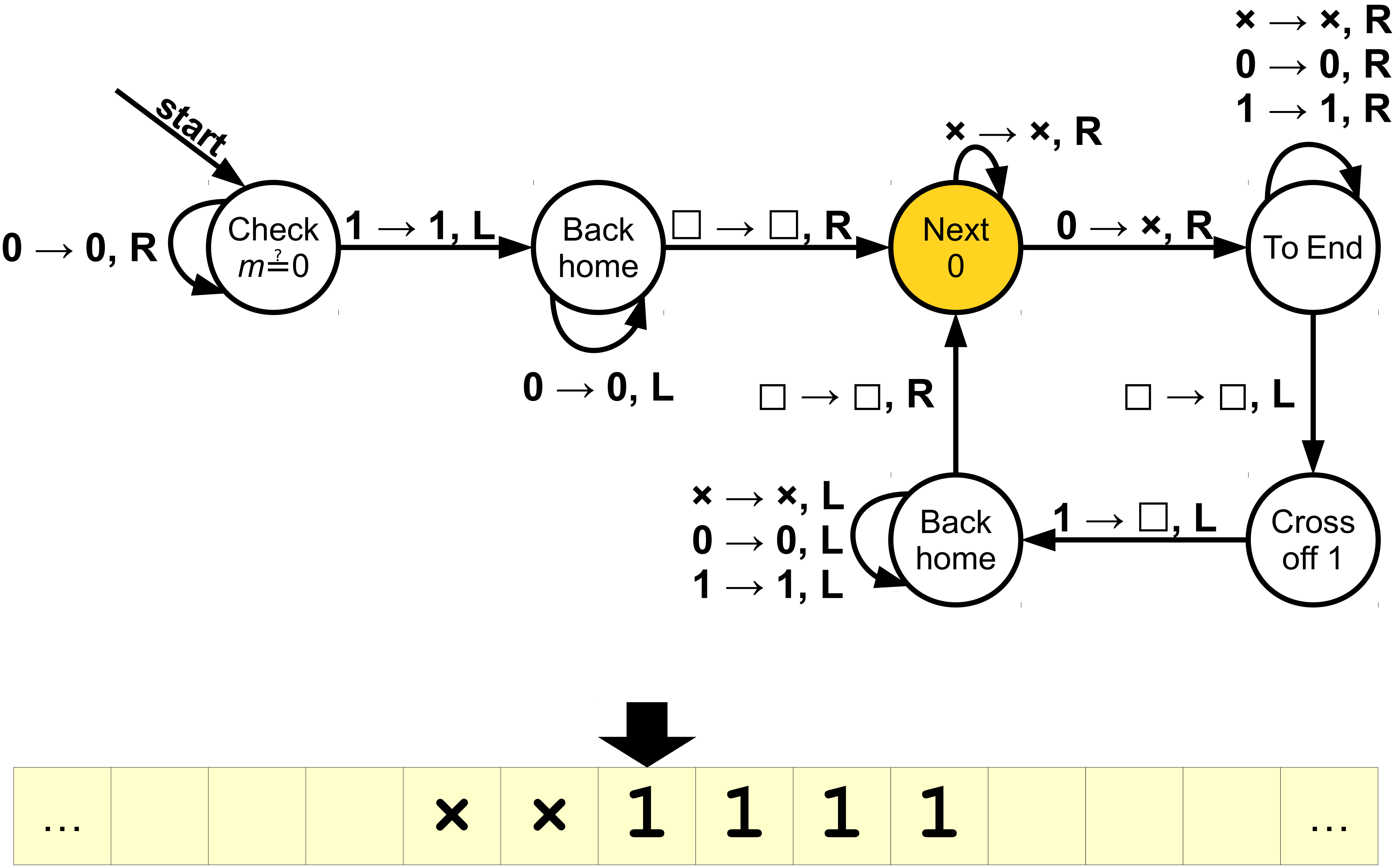
…				×	×	1	1	1	1				…


start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
1
1
1
1
…

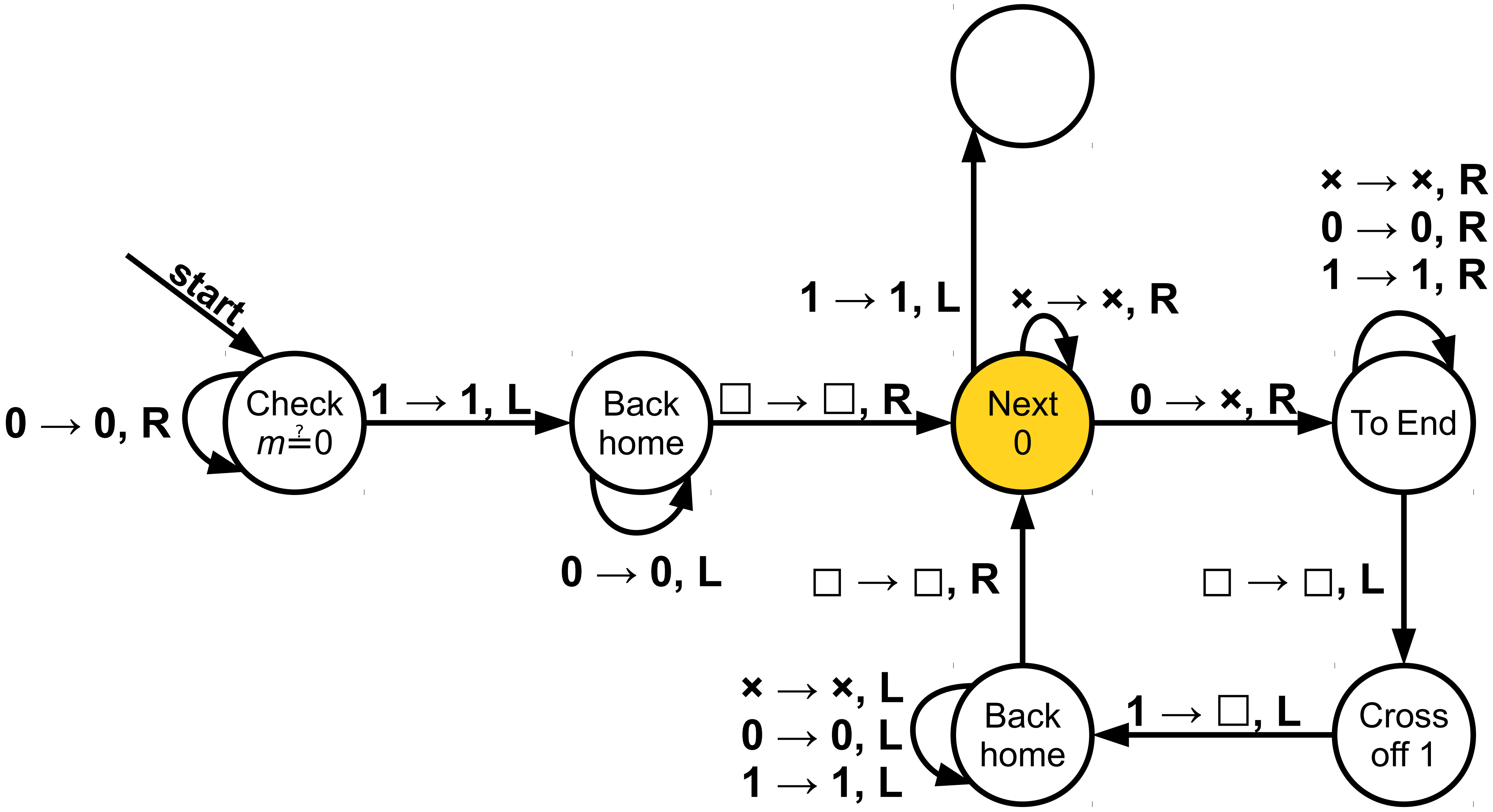

start
Check
$m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
1
1
1
1
…


start
Check
$m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

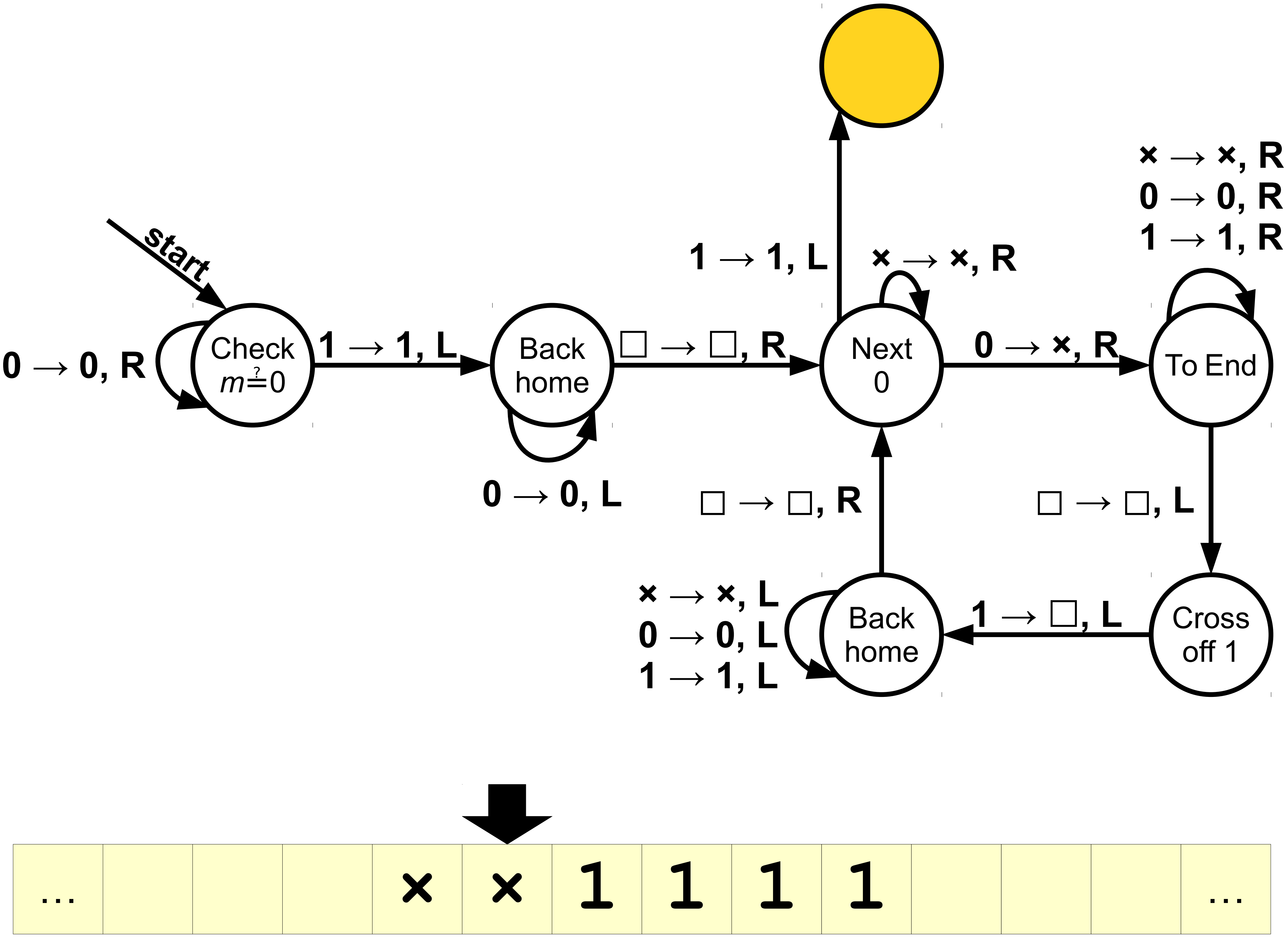
…				×	×	1	1	1	1				…

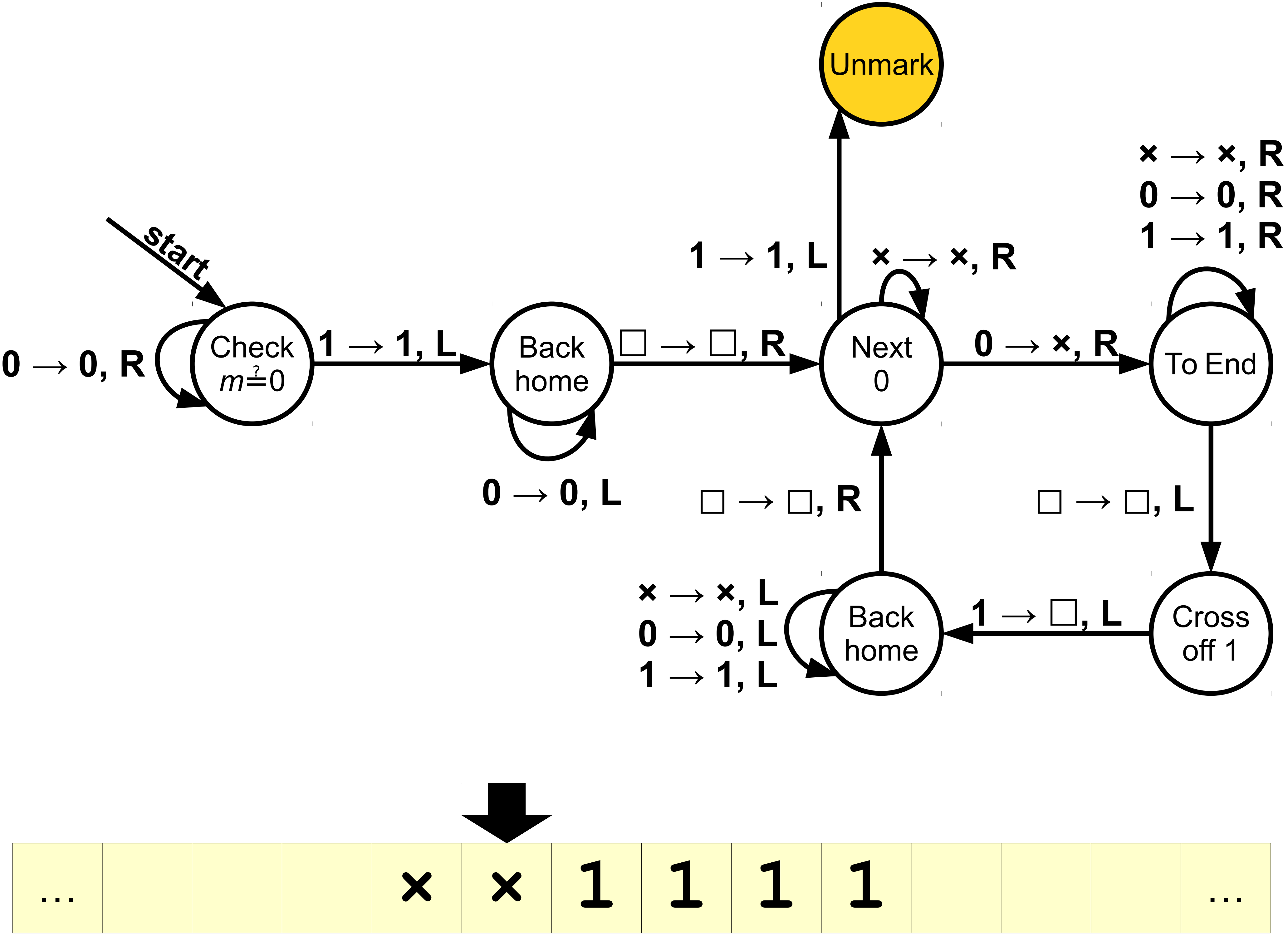

start
Check
$m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

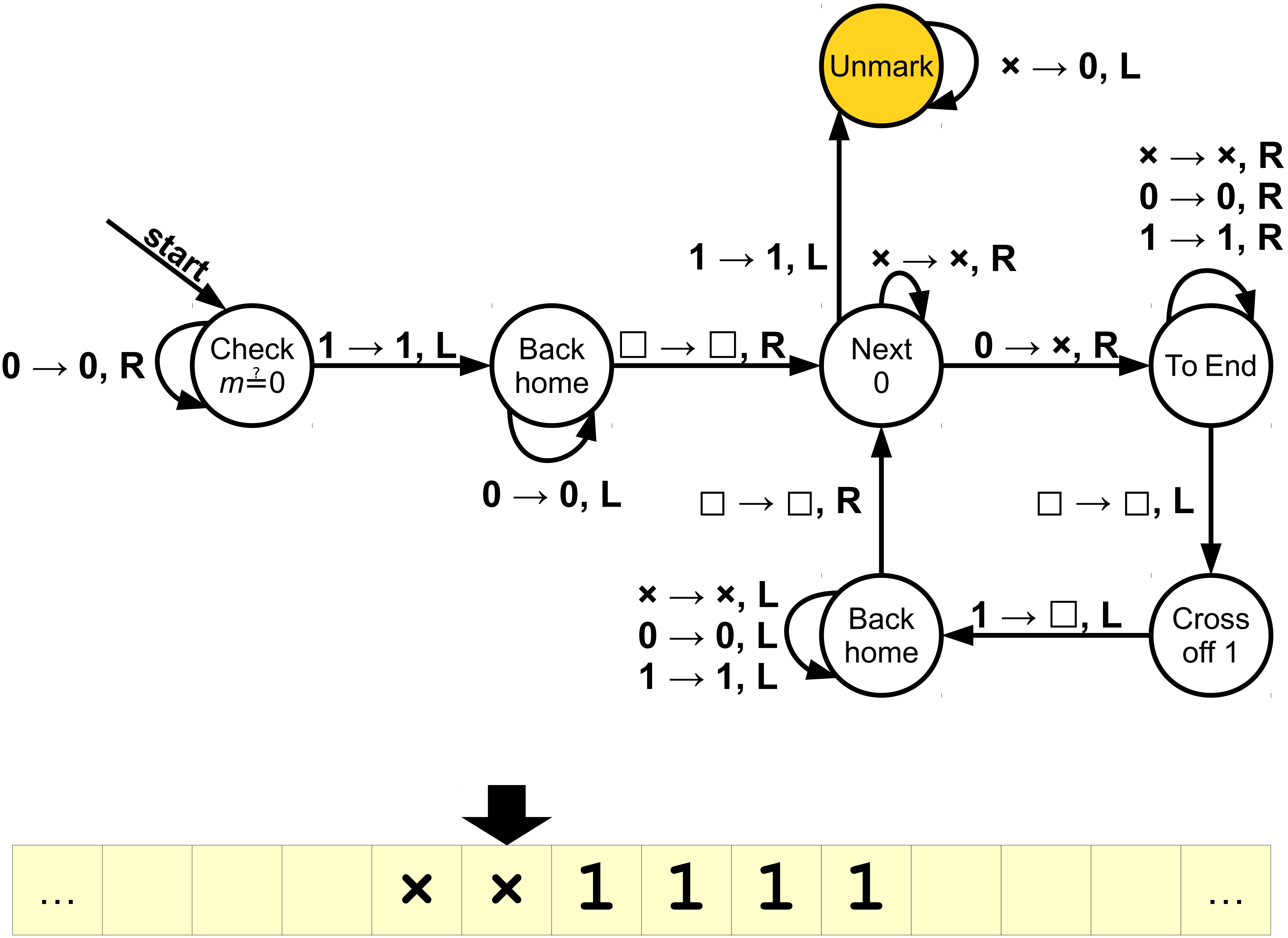
…				×	×	1	1	1	1				…

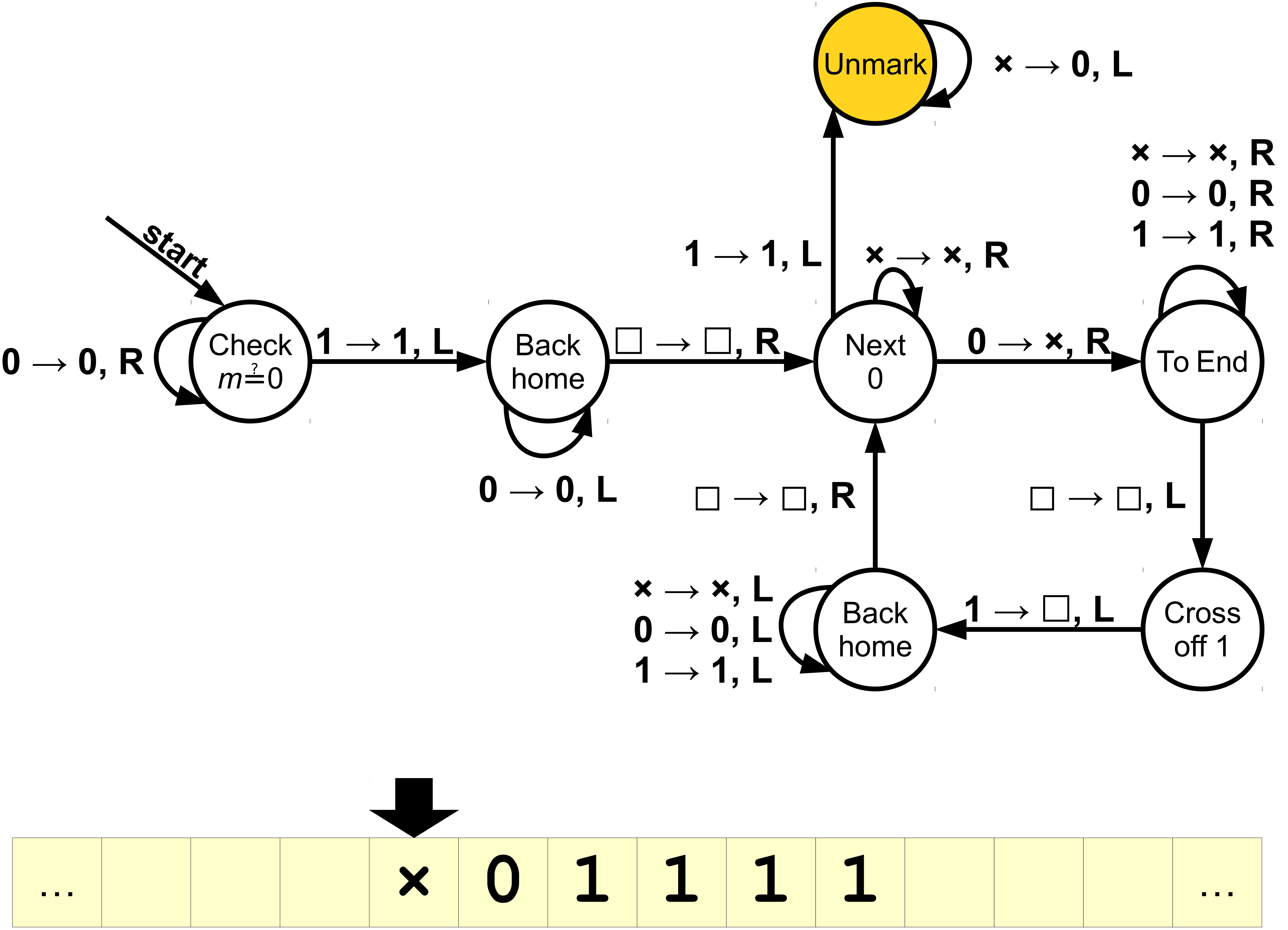

start
Check $m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
1 → 1, L
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

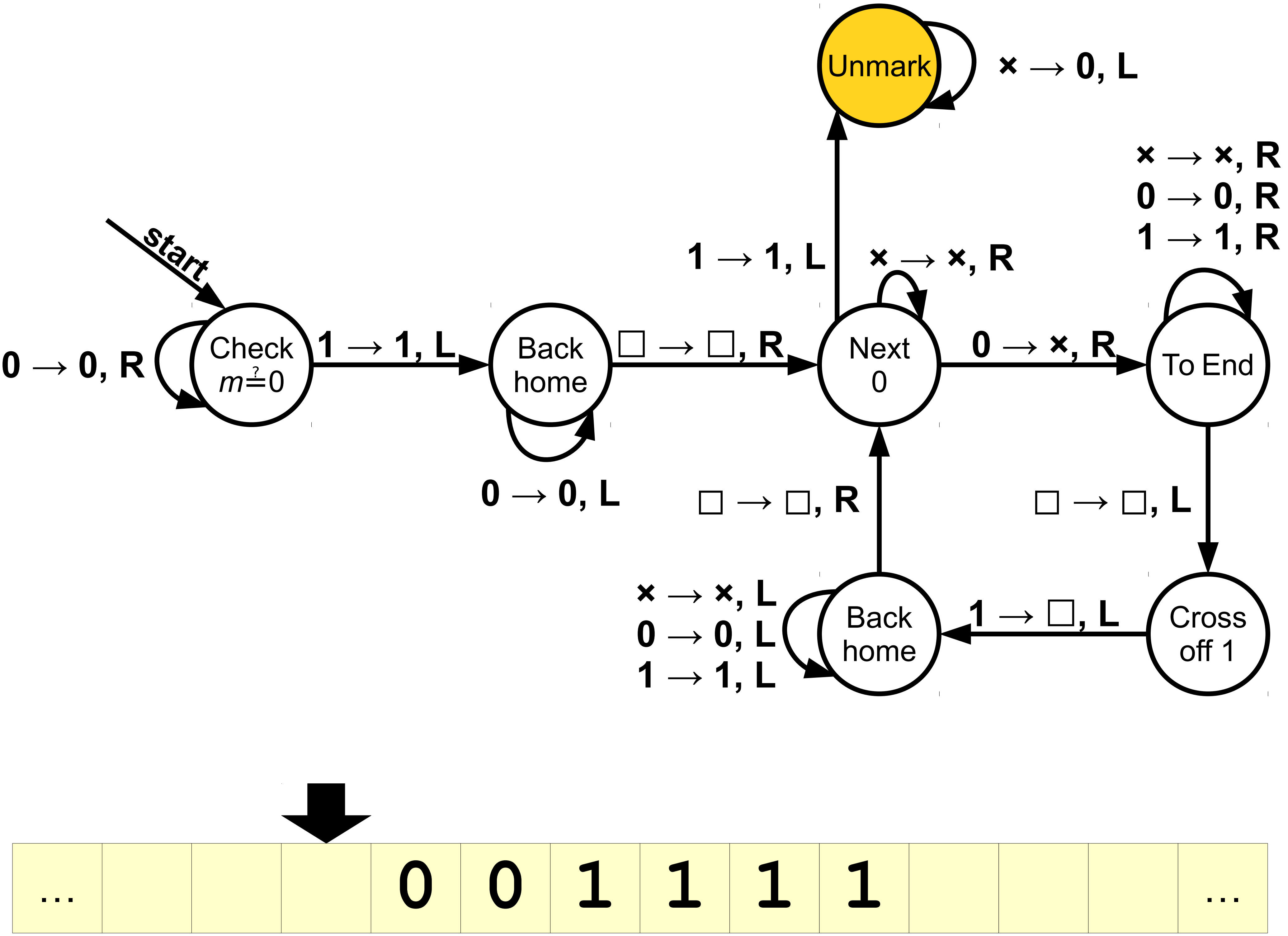
…				×	×	1	1	1	1				…


start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
0 → 0, L
□ → □, R
1 → 1, L
× → ×, R
Next
0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, L
□ → □, R
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
1
1
1
1
…


start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
1 → 1, L
Unmark
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
1
1
1
1
…


Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
×
×
1
1
1
1
…


start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
1 → 1, L
× → ×, R
Unmark
× → 0, L
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
0
1
1
1
1
…


Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
0
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1
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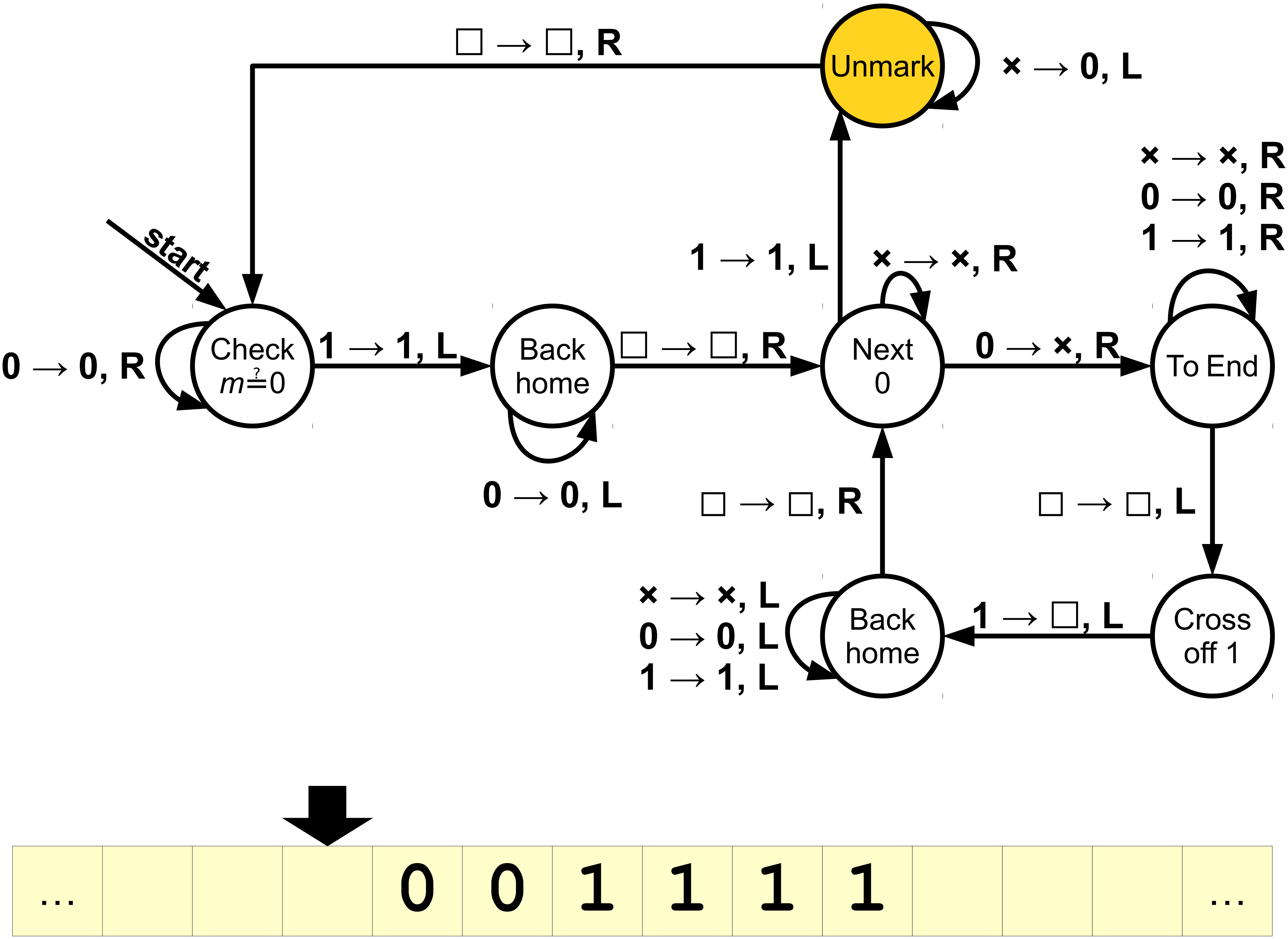
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
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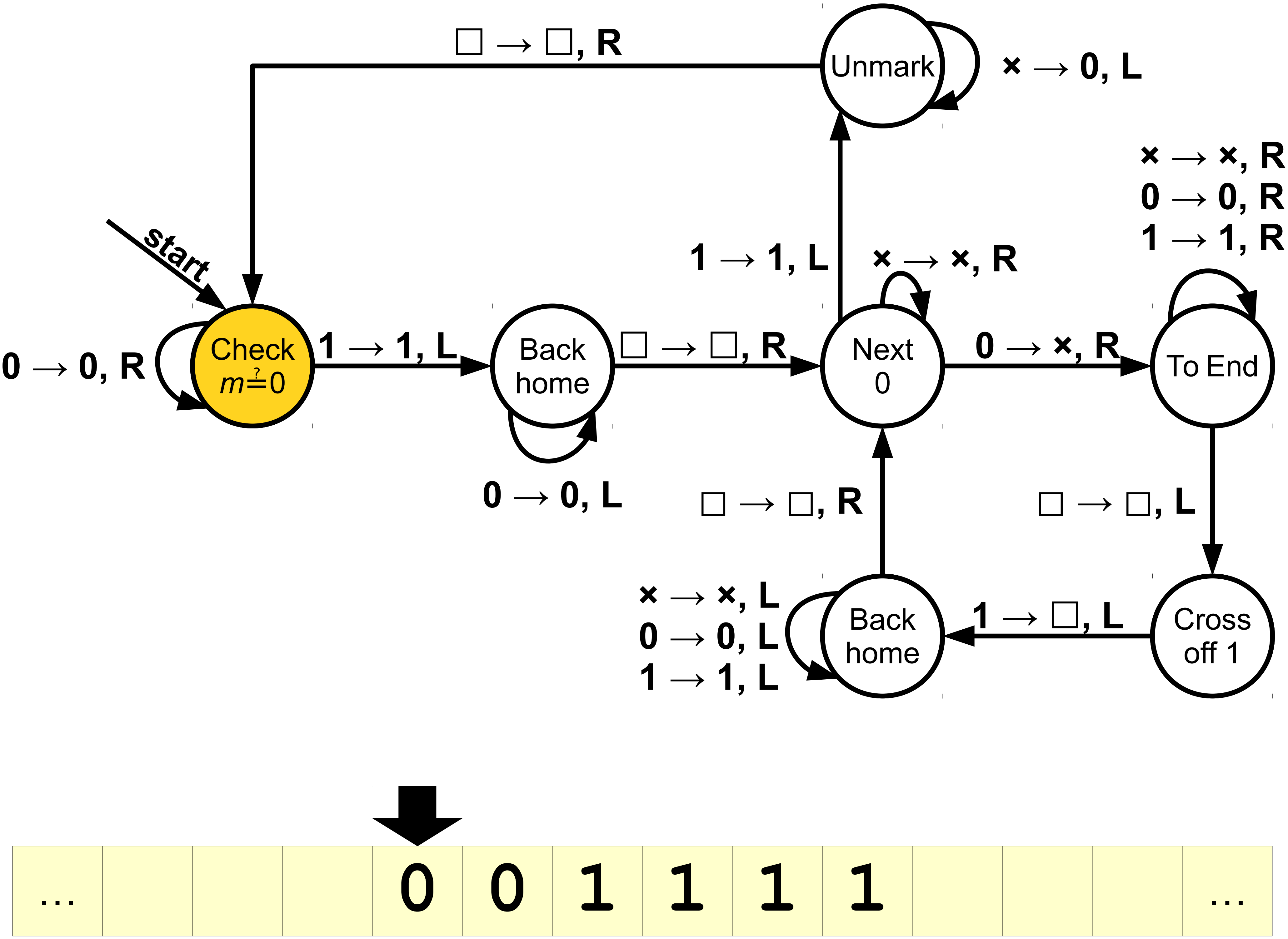
□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
□ → □, R
Next
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0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
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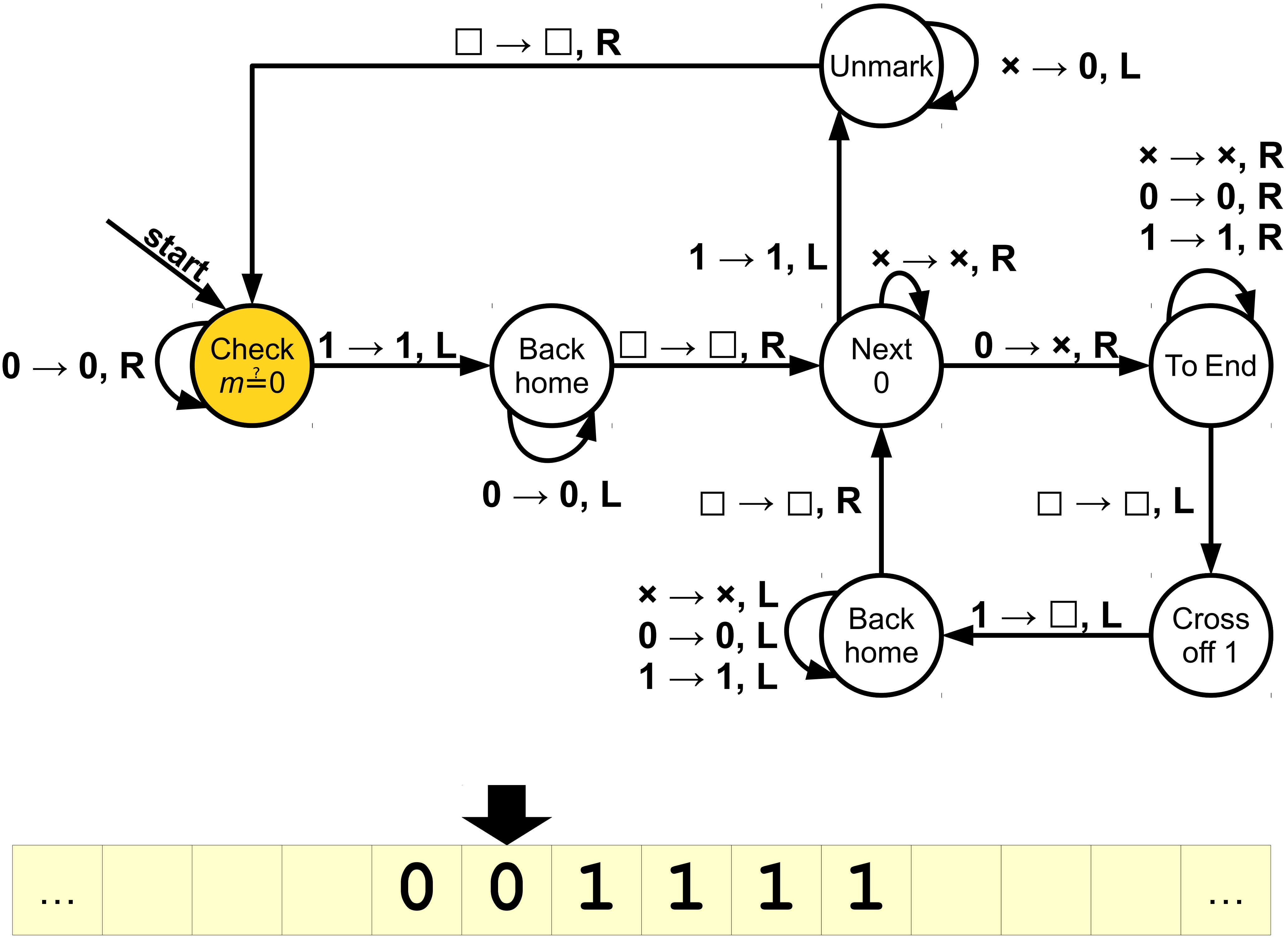
□ → □, R
Unmark
× → 0, L
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1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
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0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
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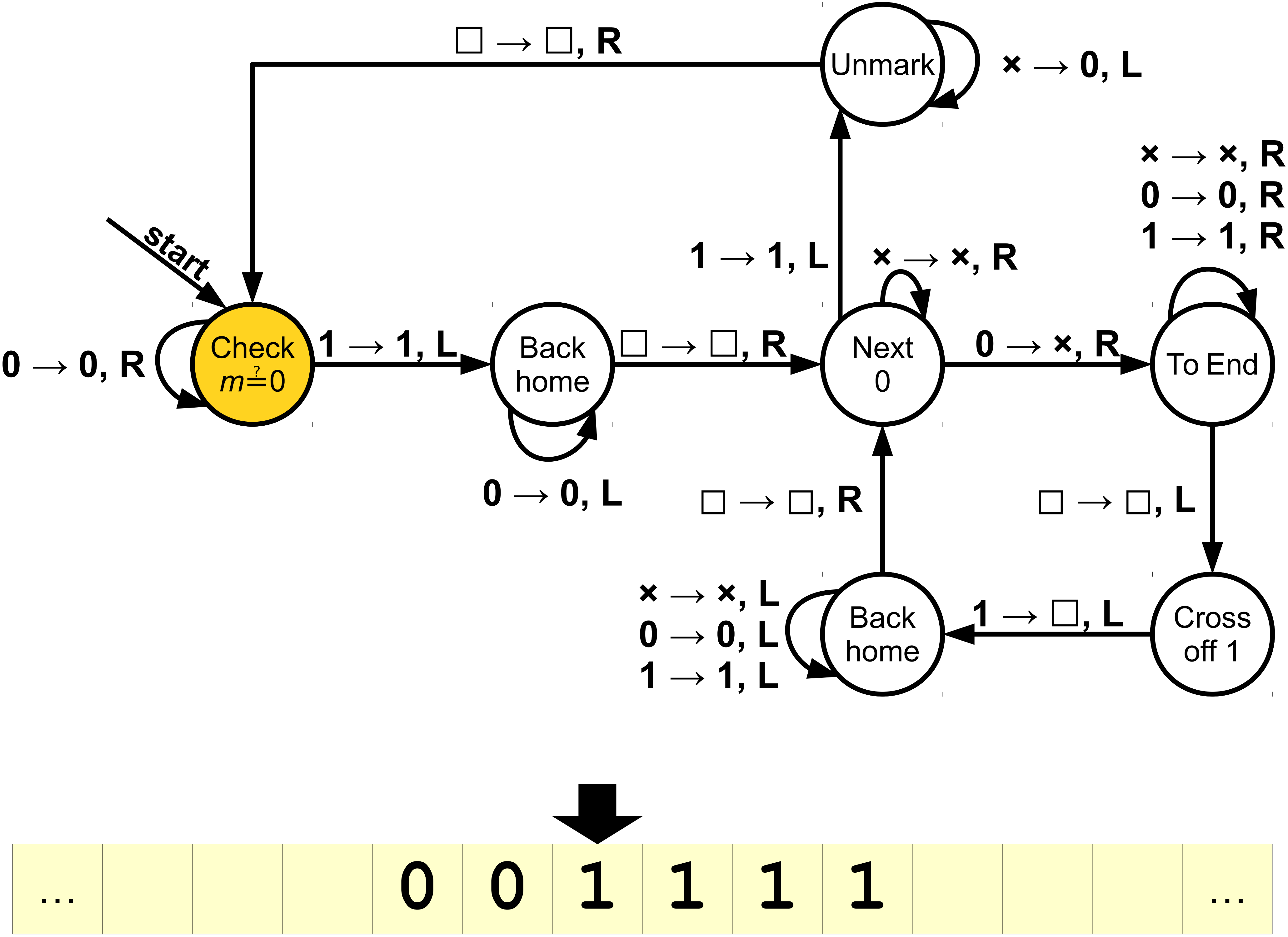
□ → □, R
Unmark
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× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
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0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
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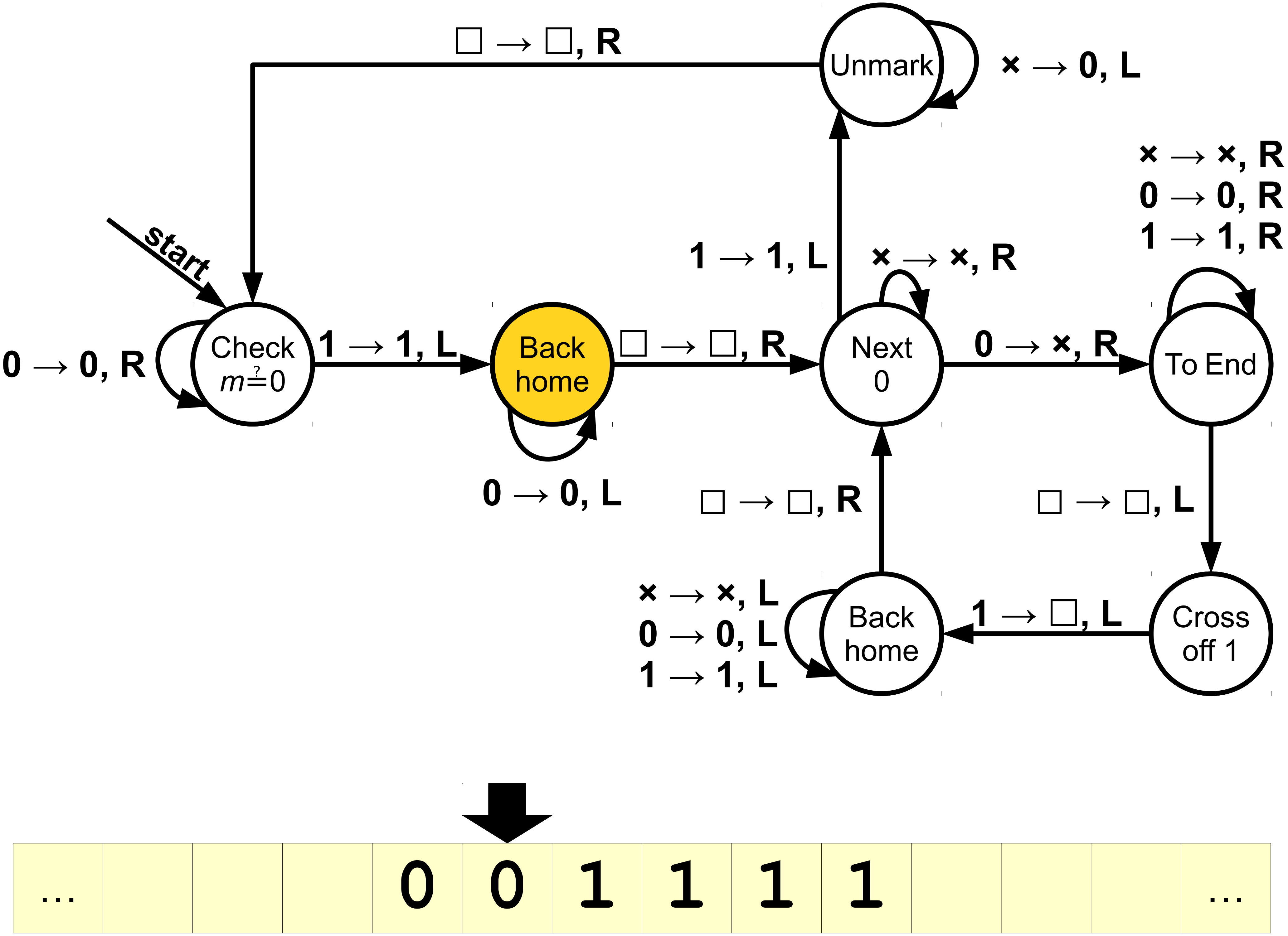
start
Check
$m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
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0
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1
1
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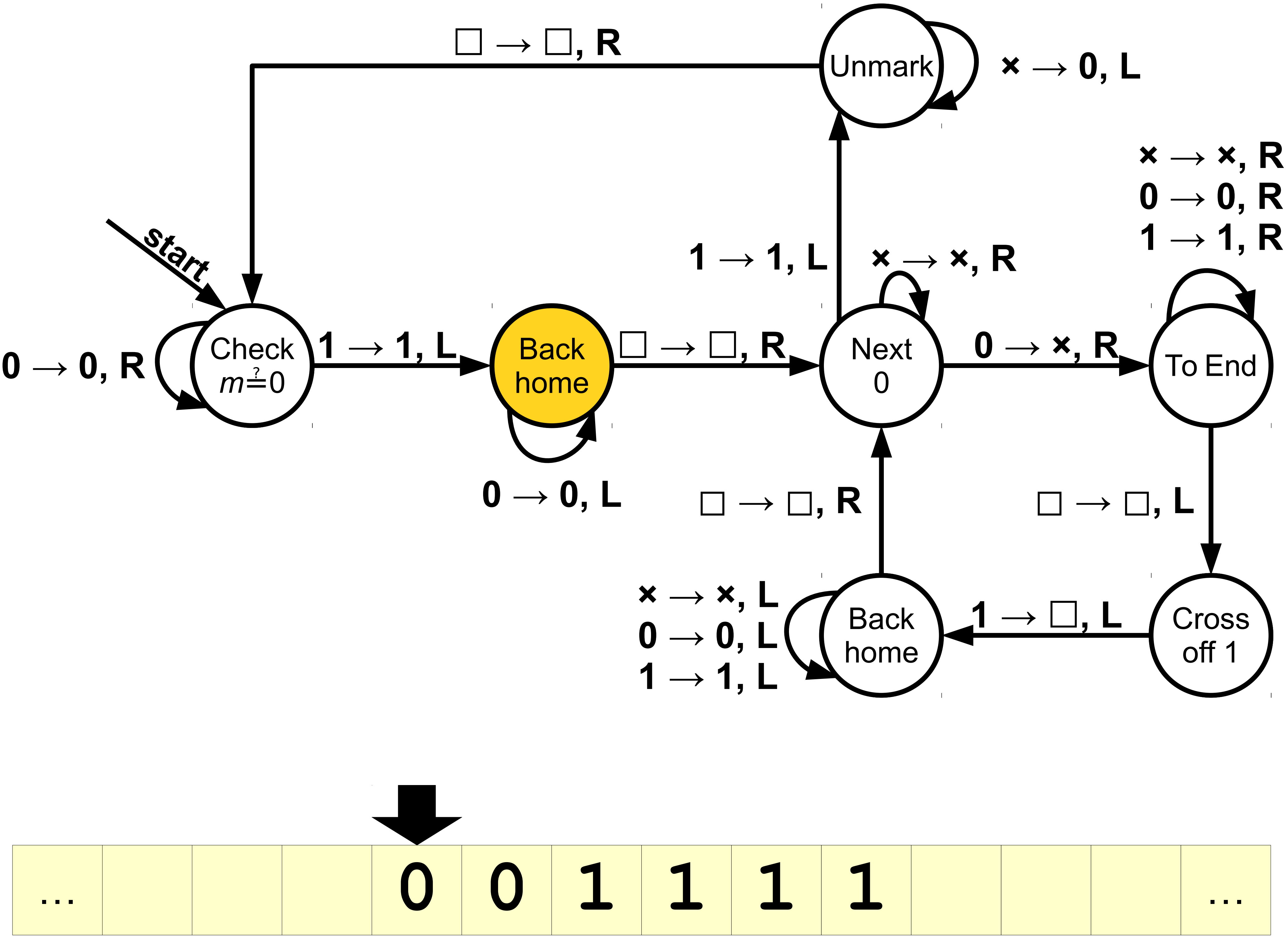
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
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1
1
1
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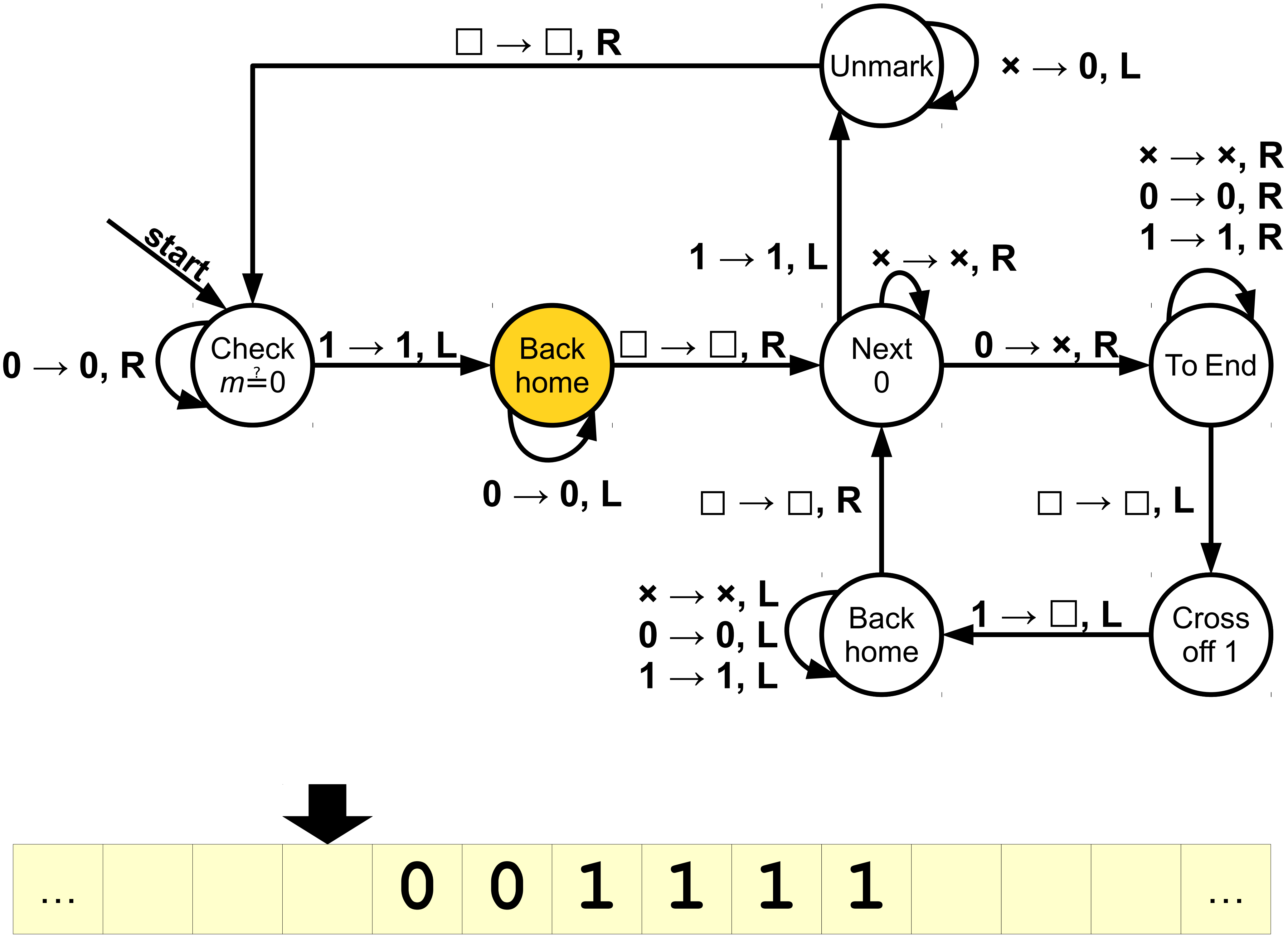
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
0
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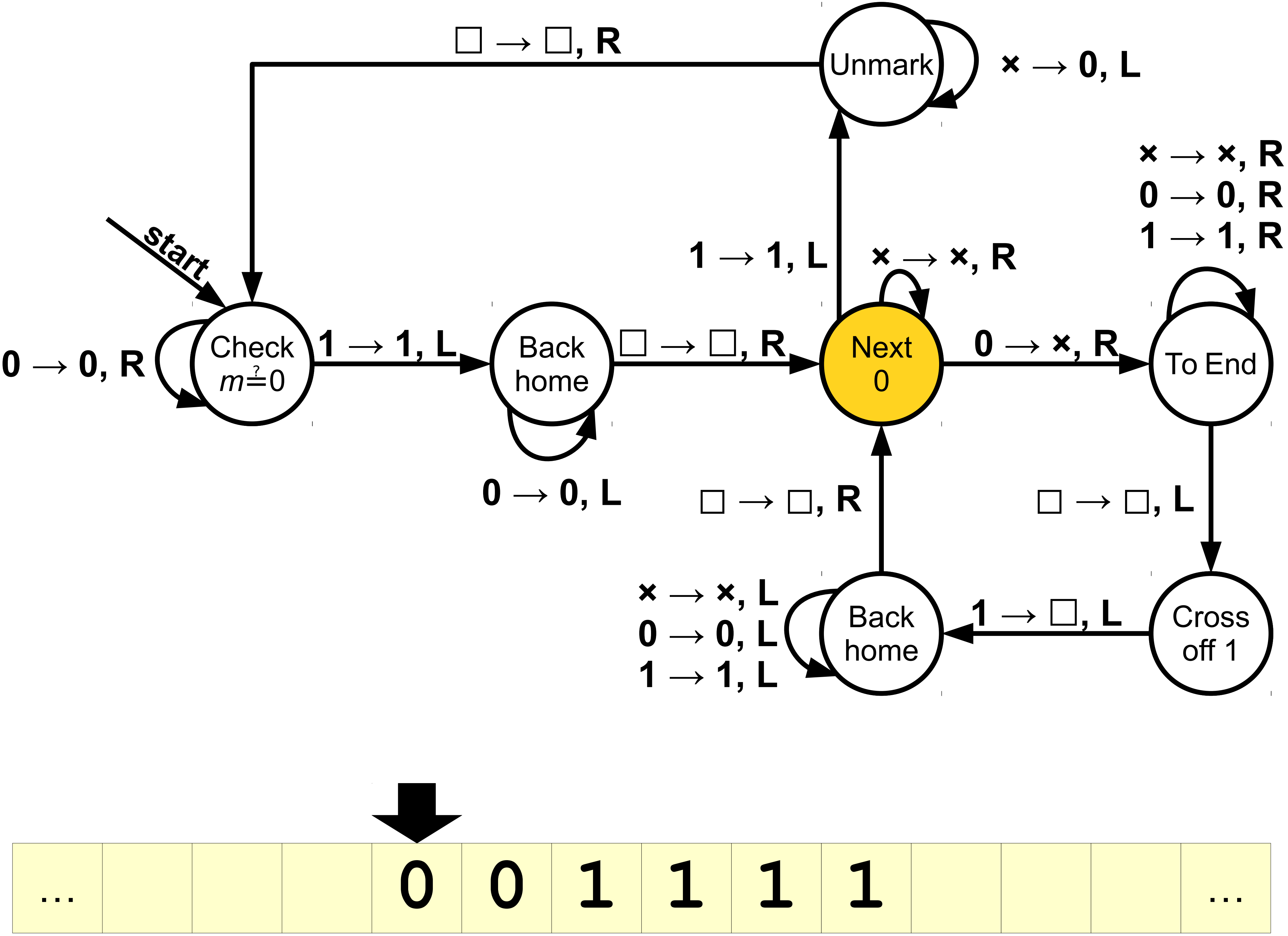
…



start
Check $m\overset{?}{=}0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
1 → 1, L
× → ×, R
0 → ×, R
Unmark
□ → □, R
× → 0, L
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
0
0
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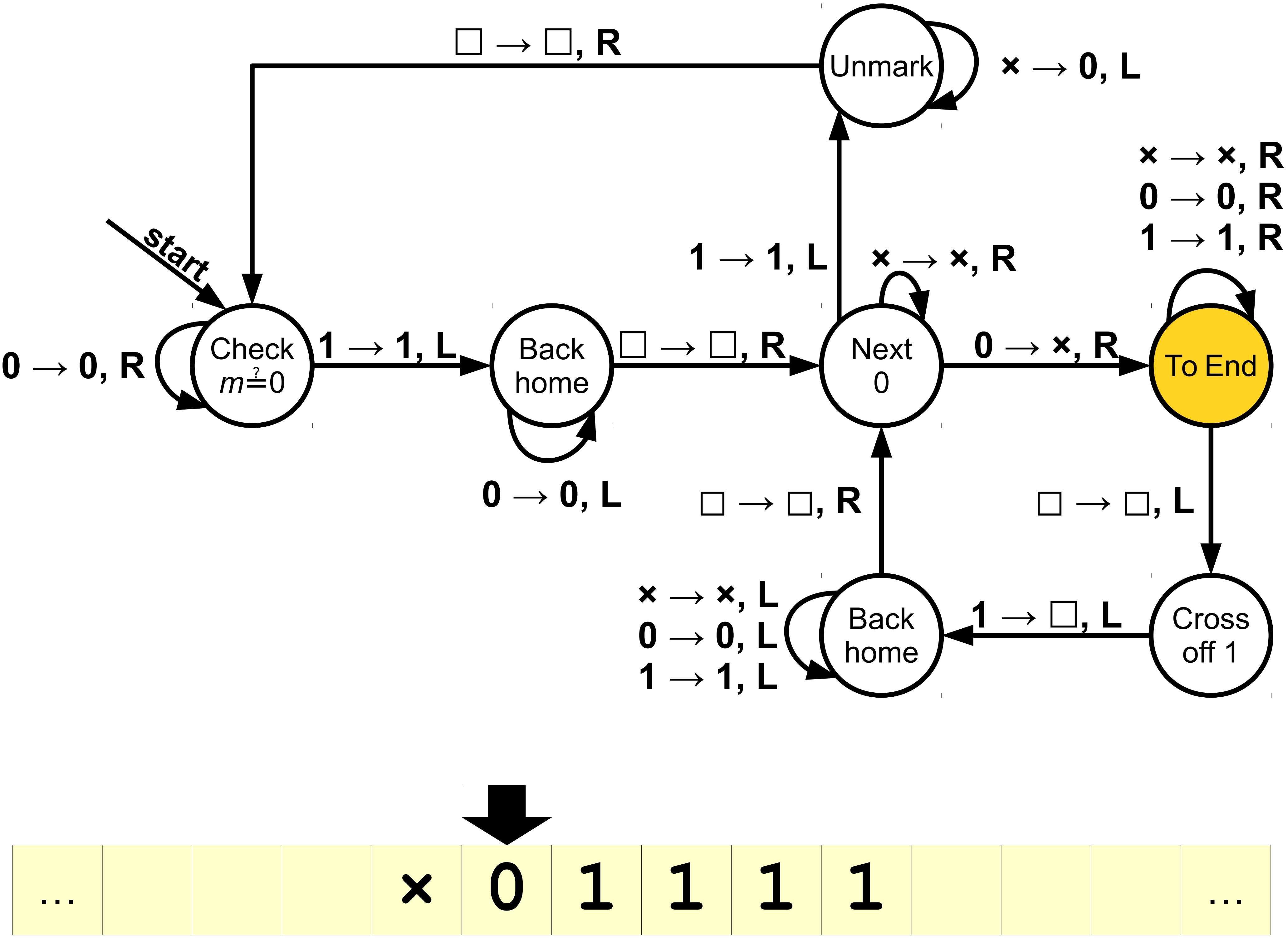
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
start
1 → 1, L
× → ×, R
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
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1
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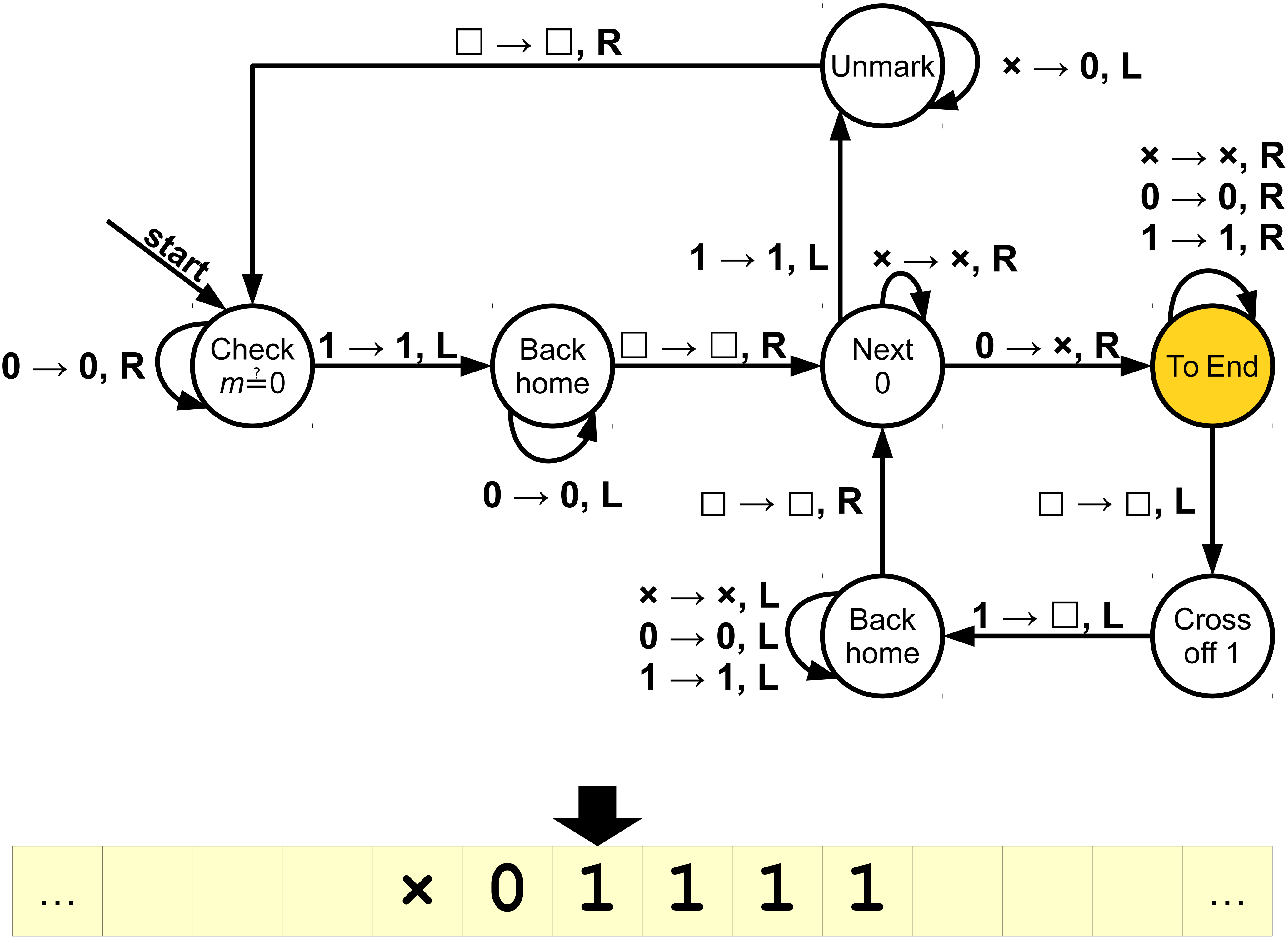
…


start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
1 → 1, L
0 → ×, R
Unmark
× → 0, L
□ → □, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
0
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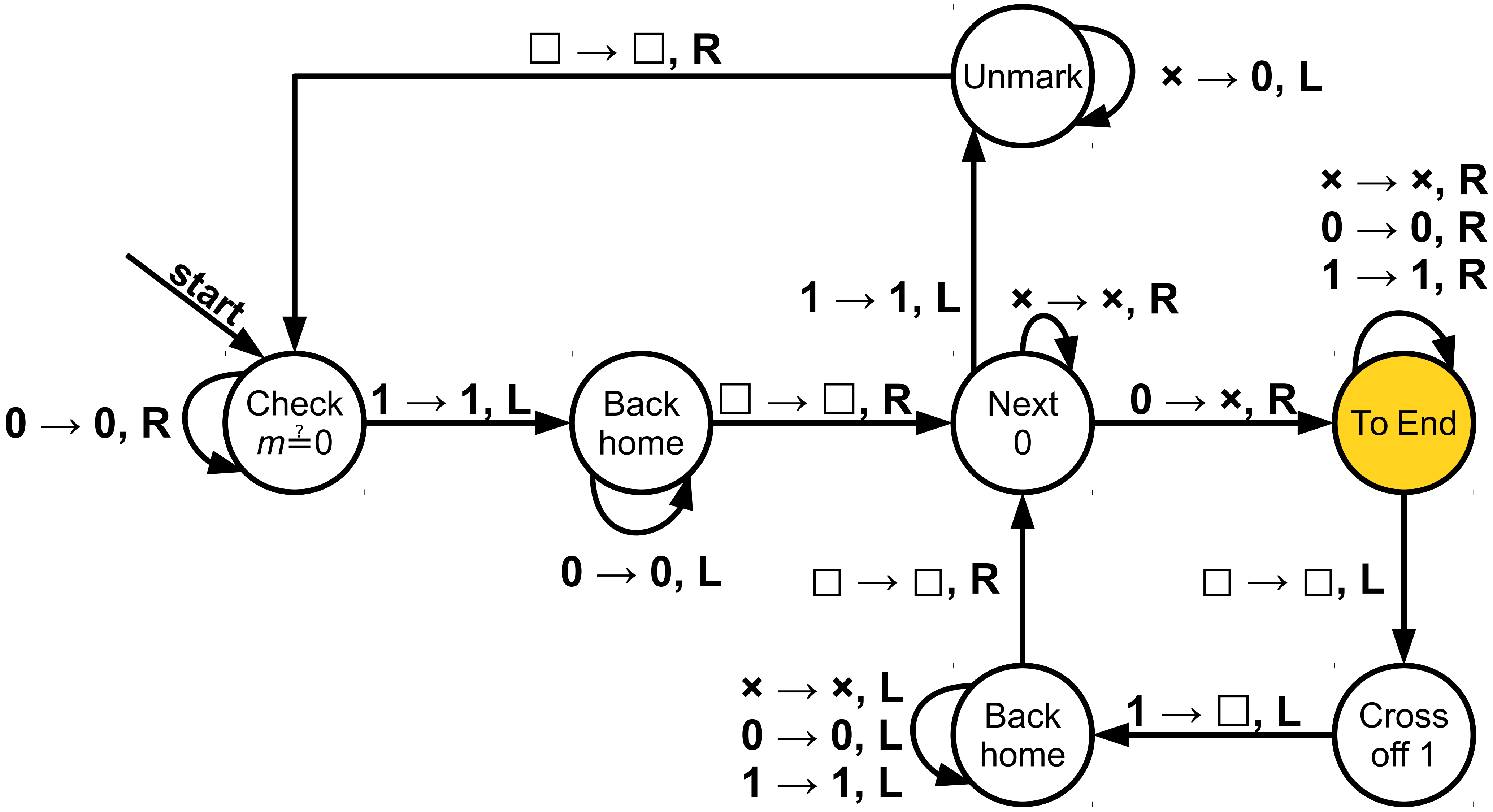
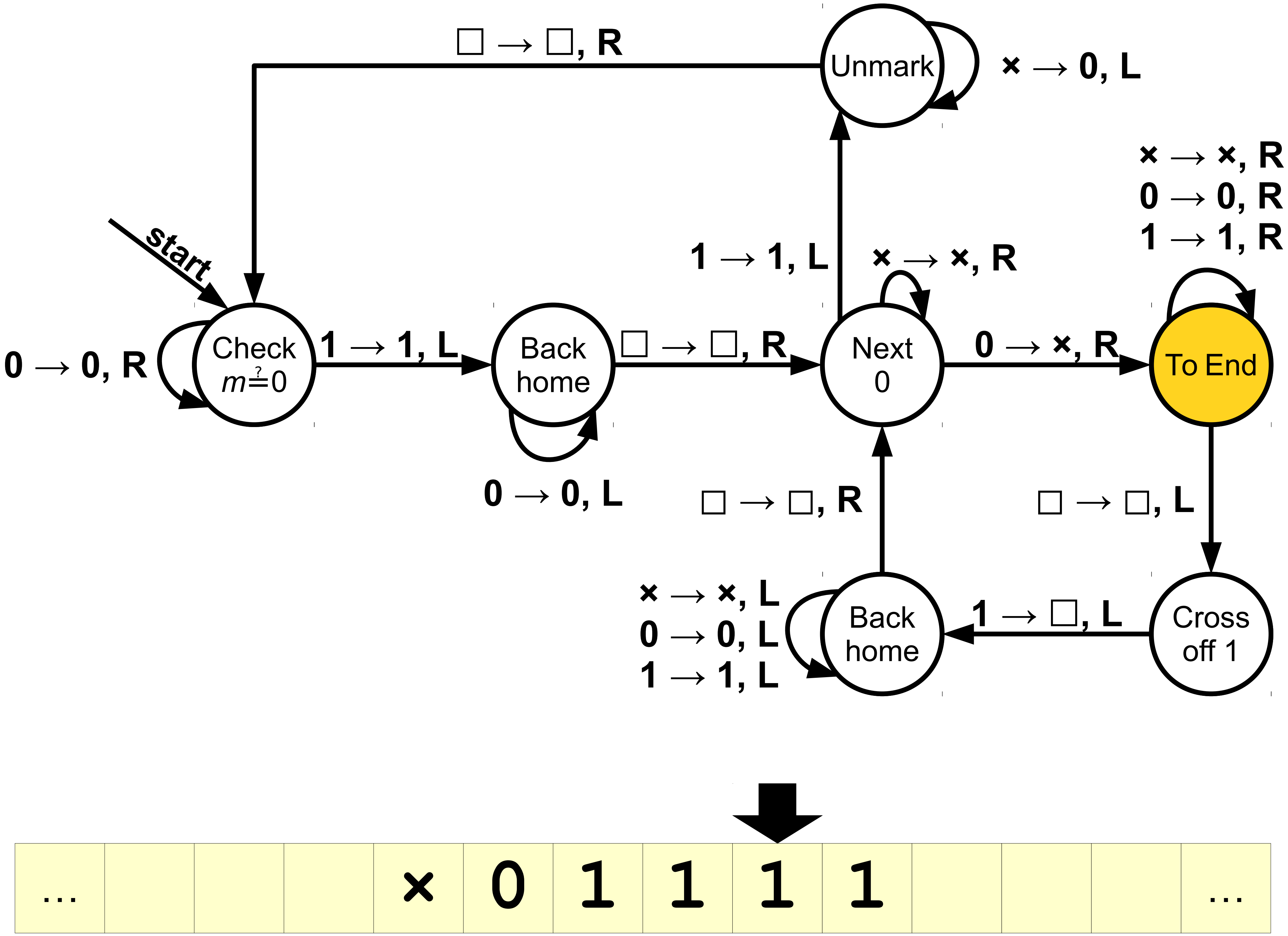
…


start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R

…				×	0	1	1	1	1				…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
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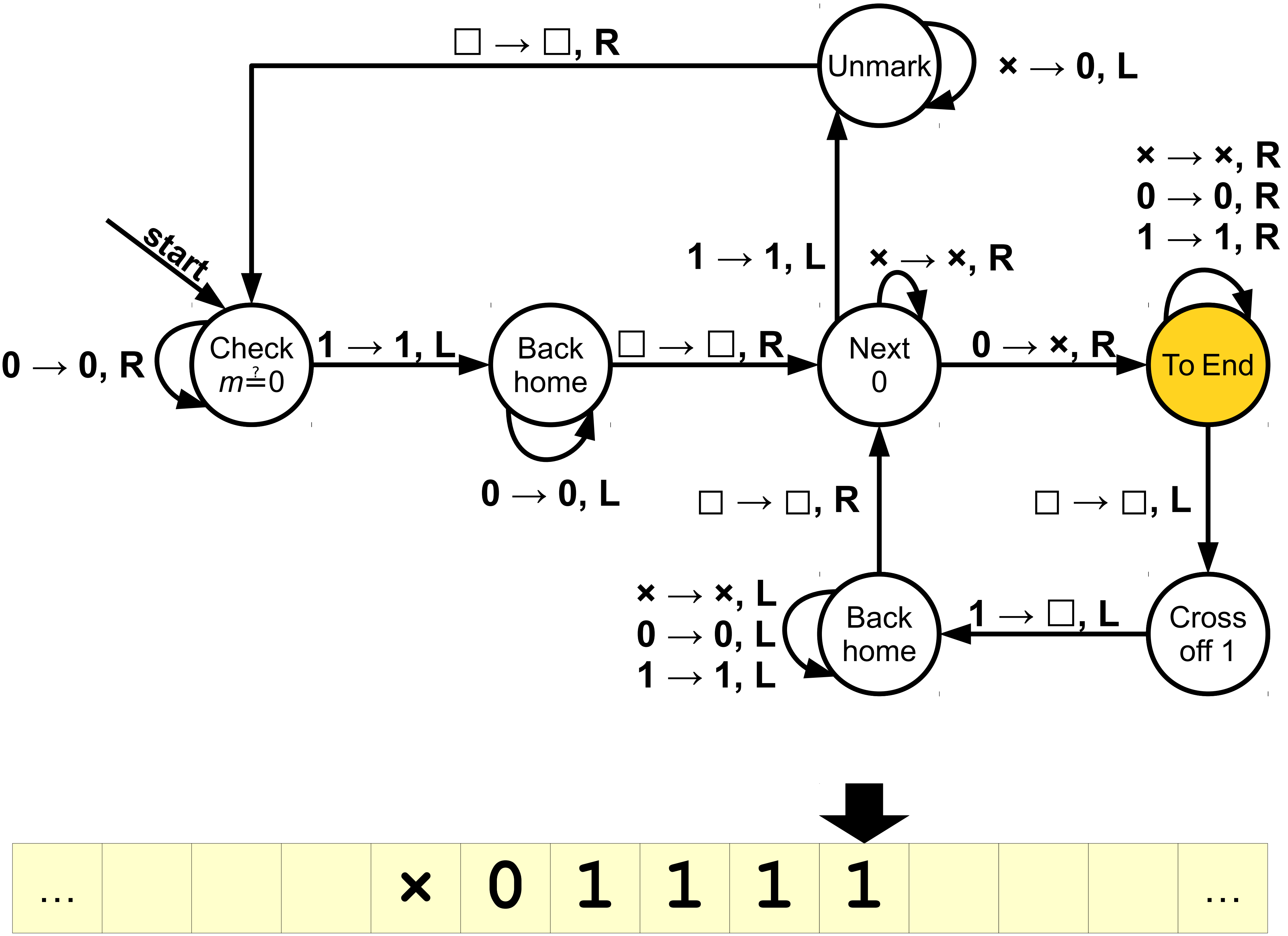
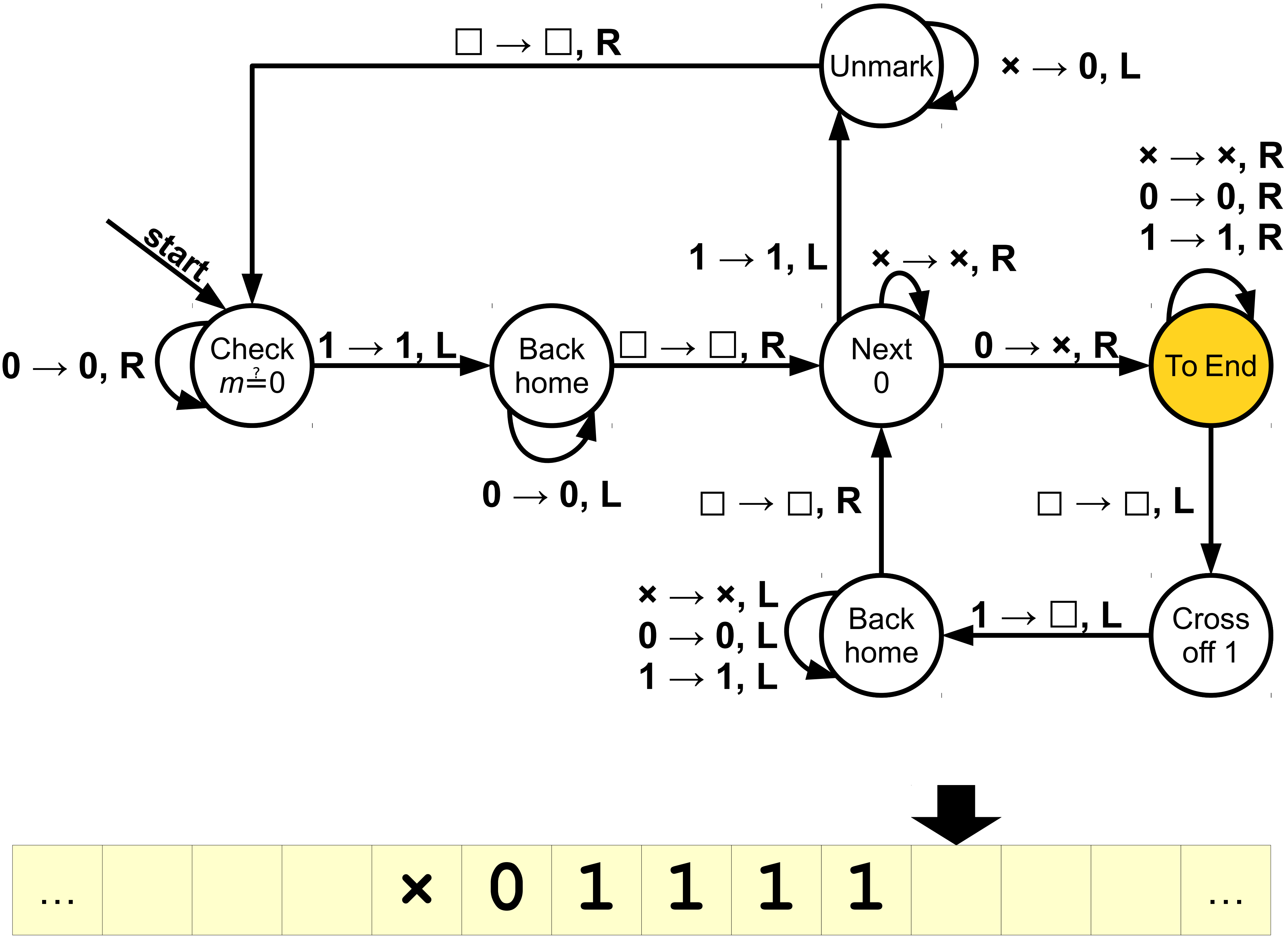
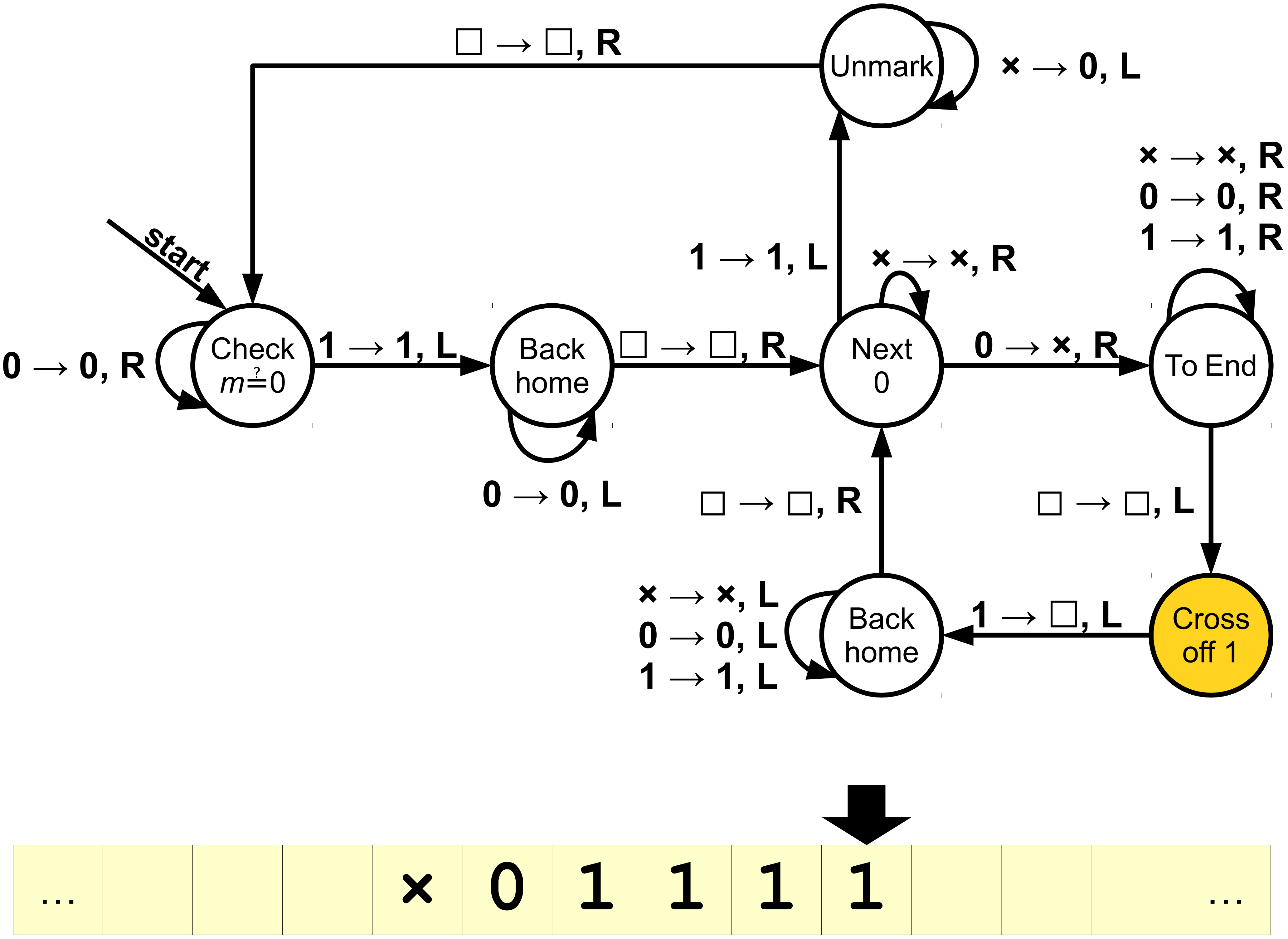
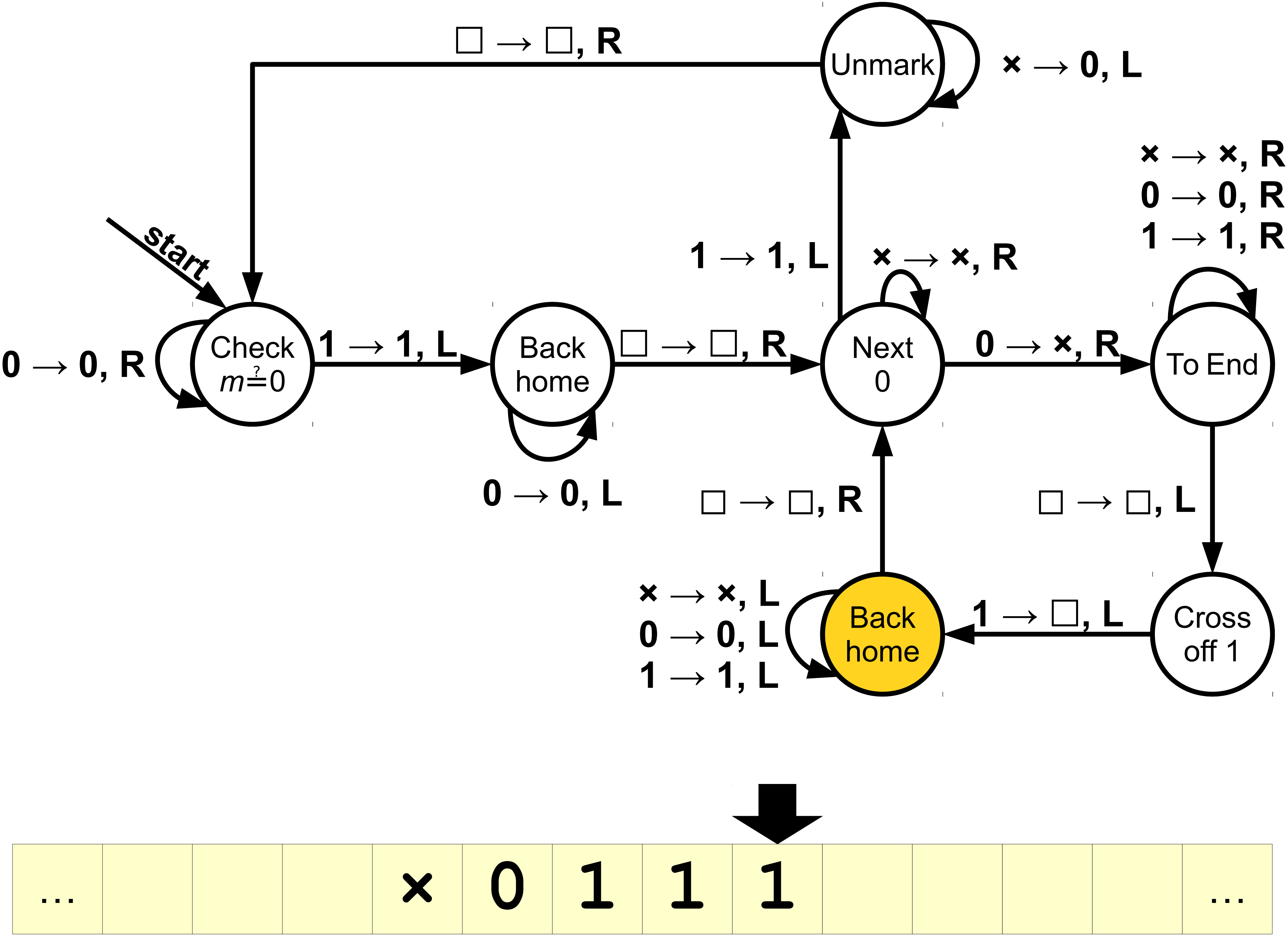
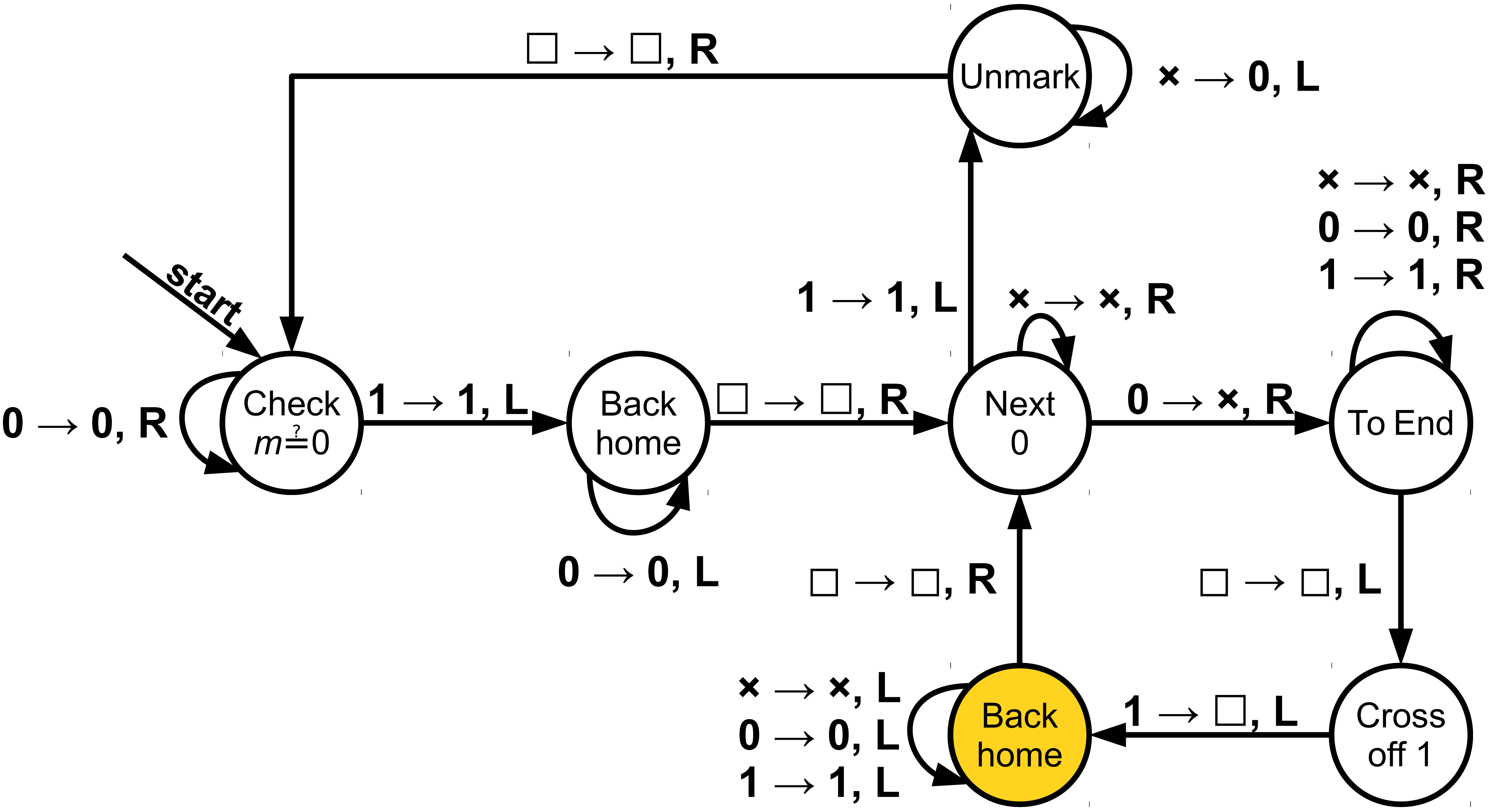
…

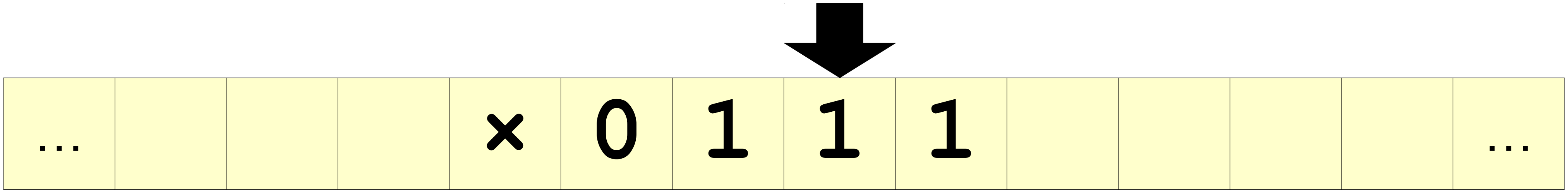

start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
1 → 1, L
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
Unmark
× → 0, L
□ → □, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
× 0 1 1 1 1
…

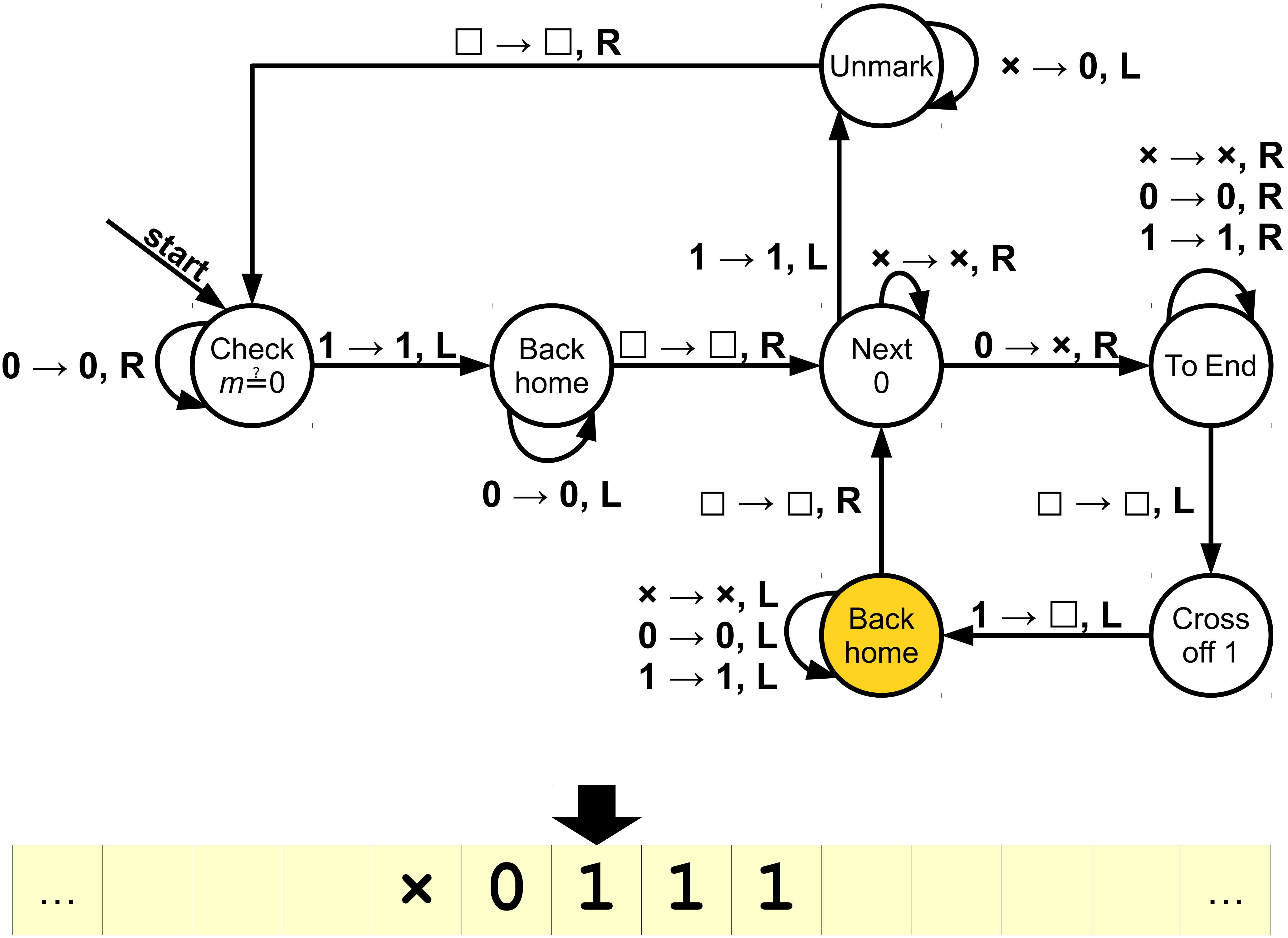

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
start
1 → 1, L
× → ×, R
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
1
1
1
…

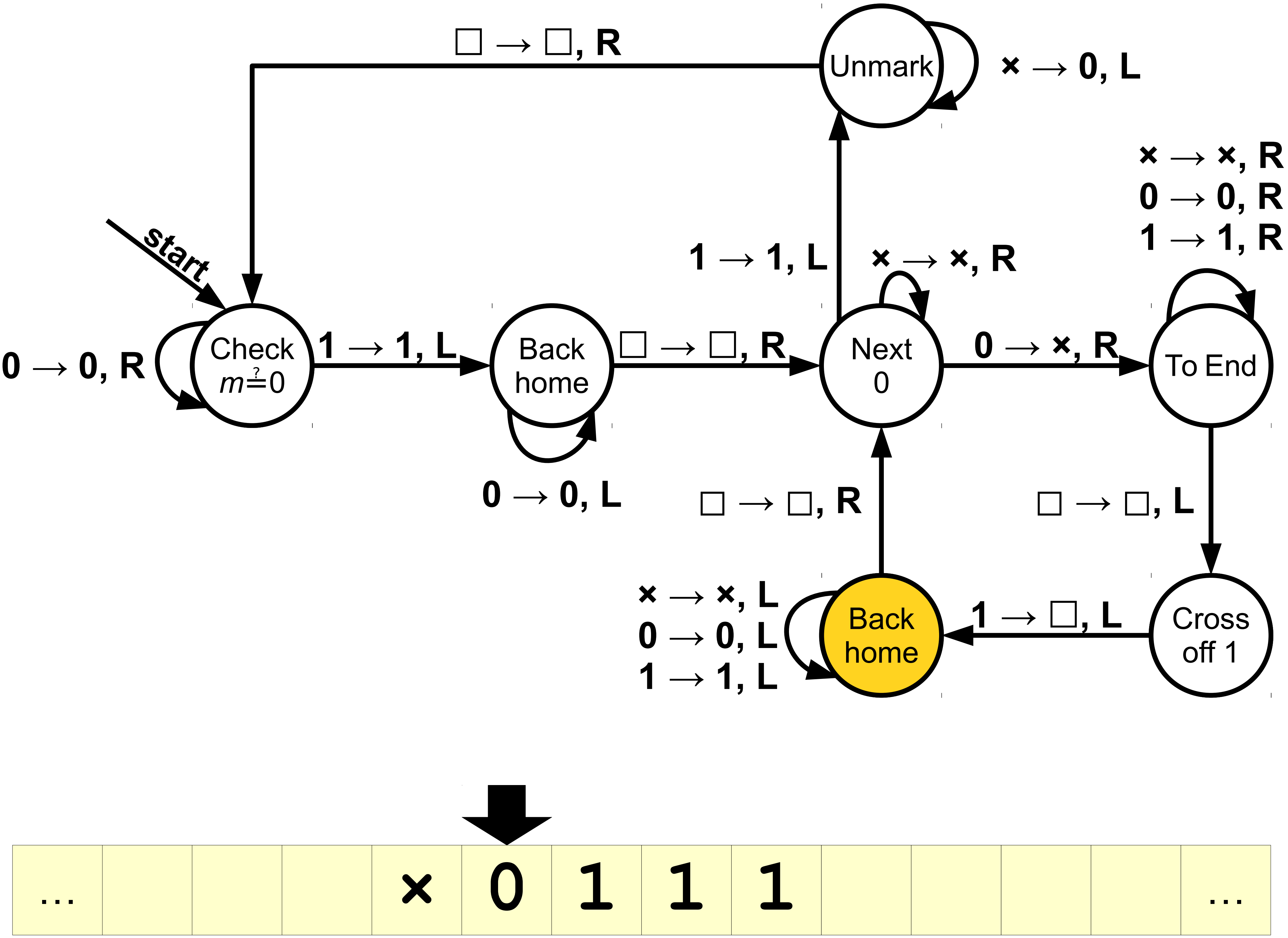

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
1
1
1
…

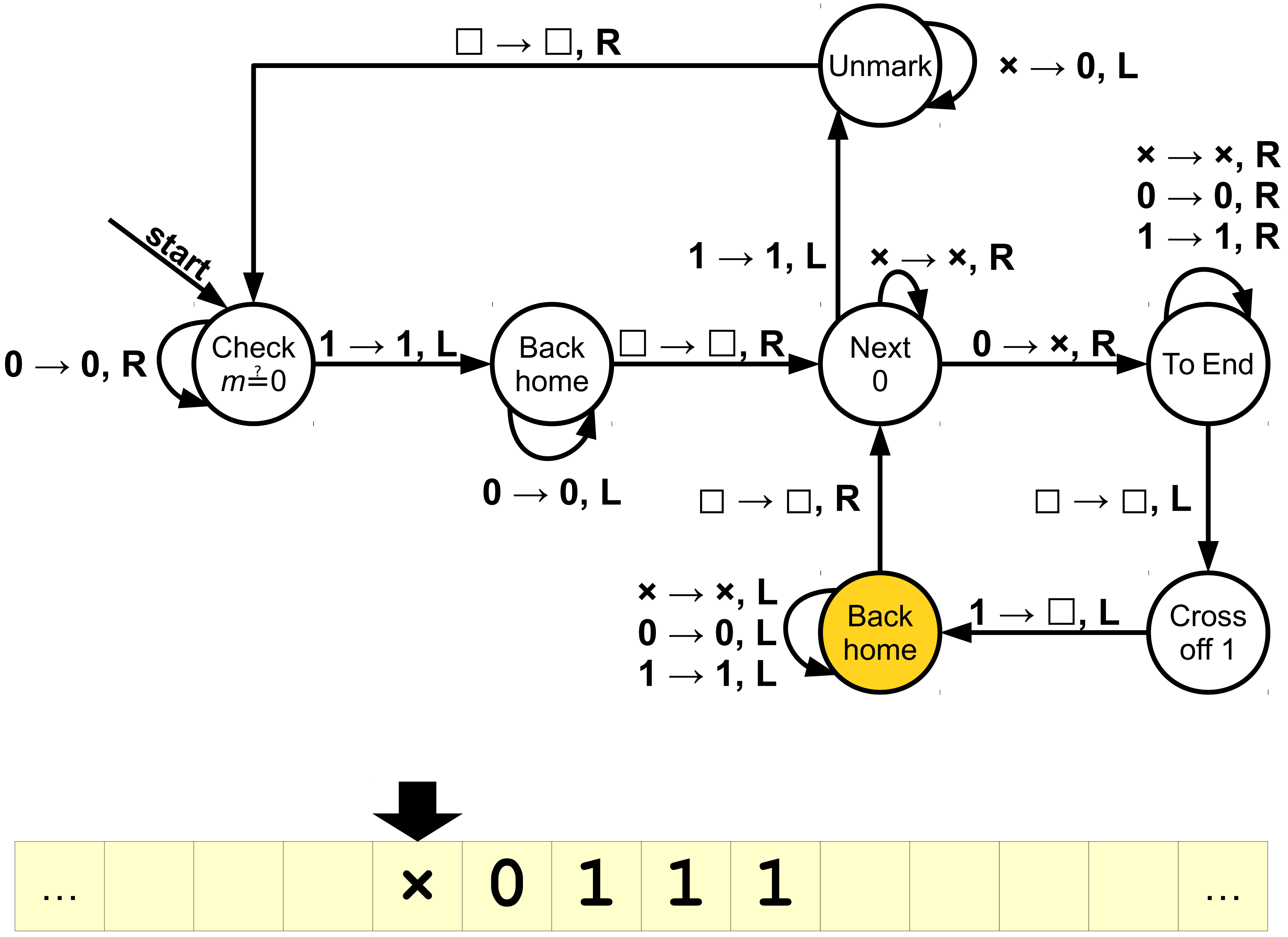

start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
1 → 1, L
× → ×, R
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
0
1
1
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1

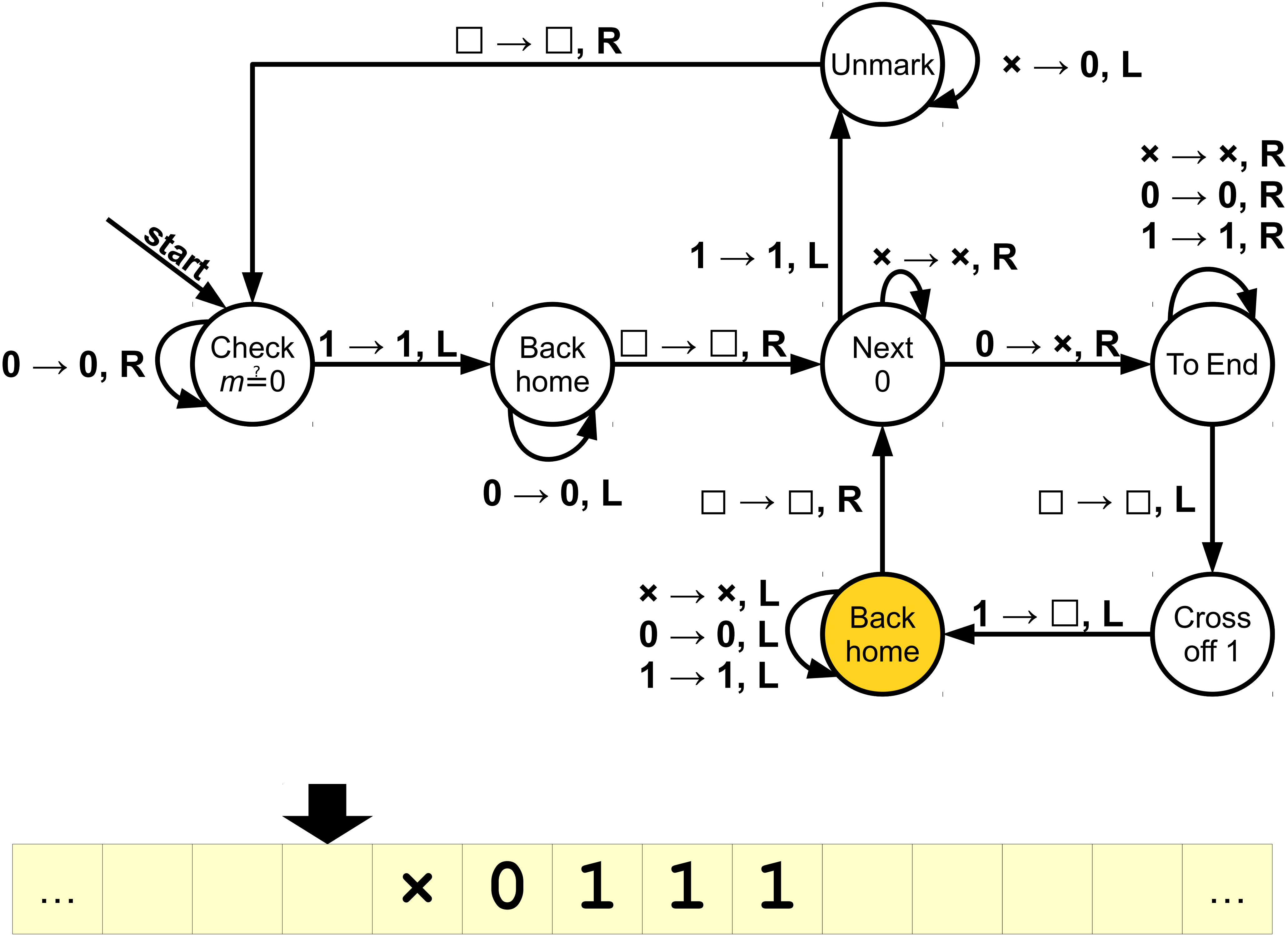

…
×
0
1
1
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
×
0
1
1
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
start
1 → 1, L
× → ×, R
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
1
1
…


□ → □, R
Unmark
× → 0, L
start
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1

…				×	0	1	1	1					…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
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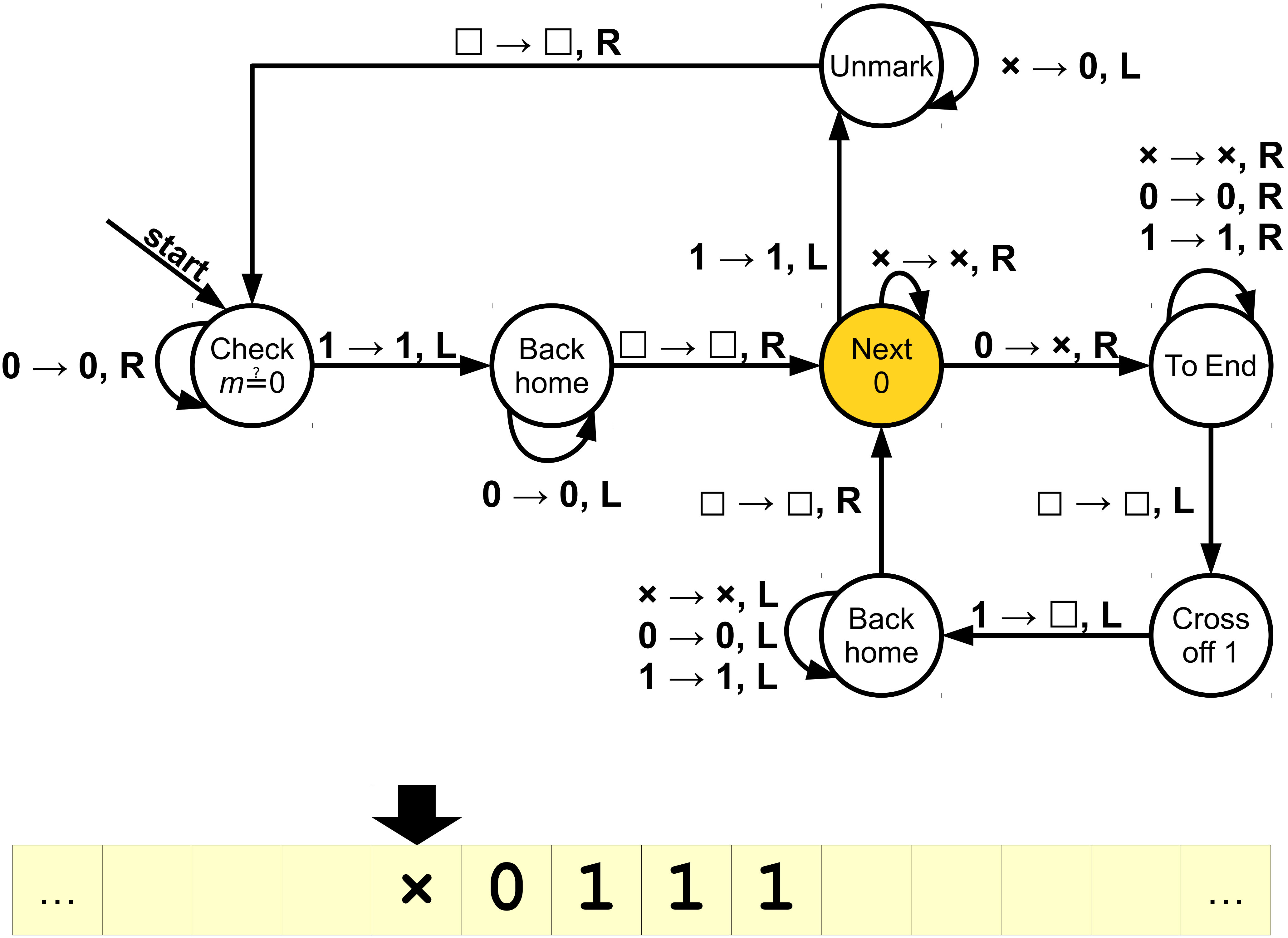
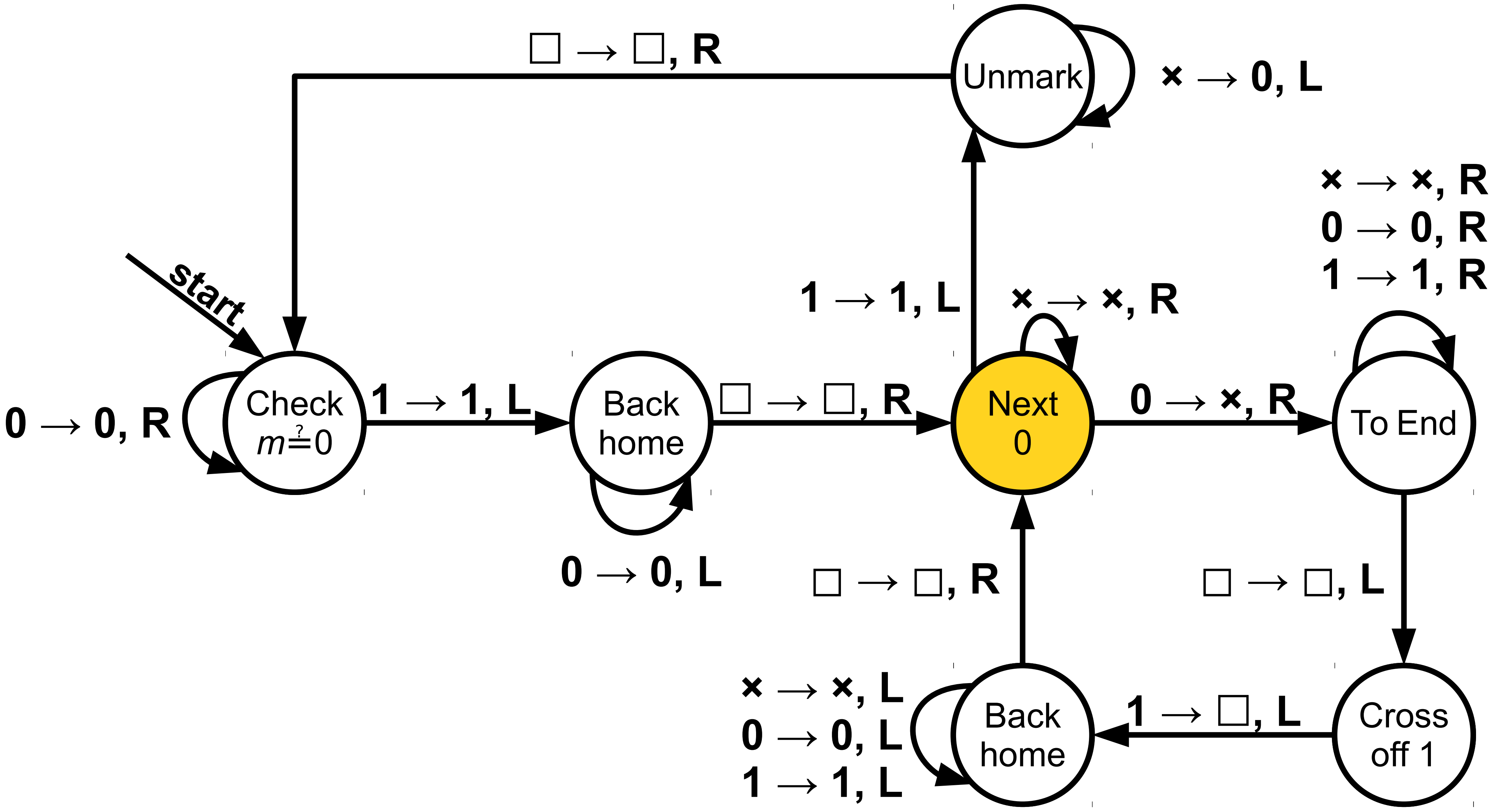
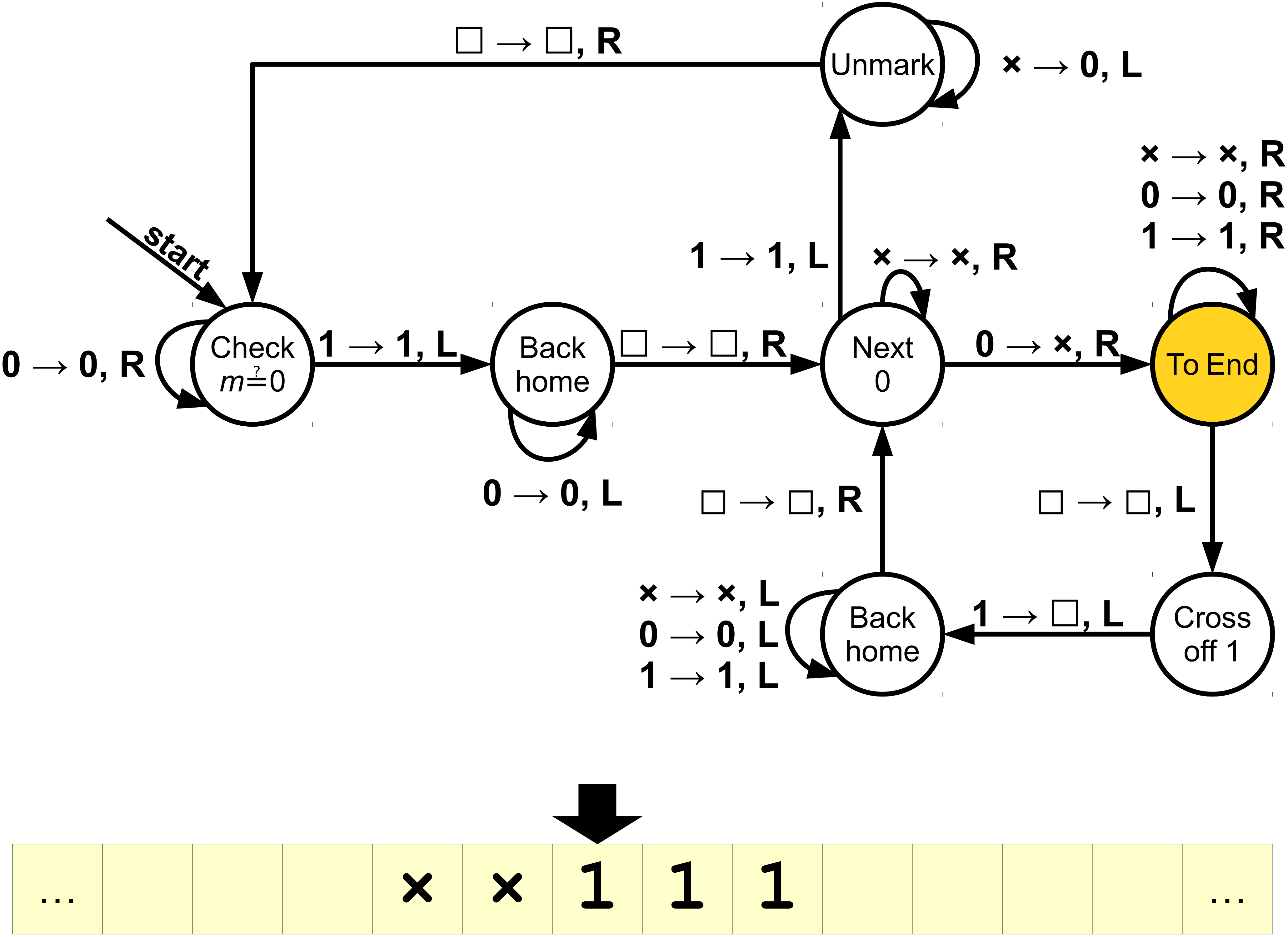
1
1
…



□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
1
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
start
1 → 1, L
× → ×, R
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1

…				×	0	1	1	1					…


□ → □, R
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0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
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Check
$m \overset{?}{=} 0$
1 → 1, L
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home
□ → □, R
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0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
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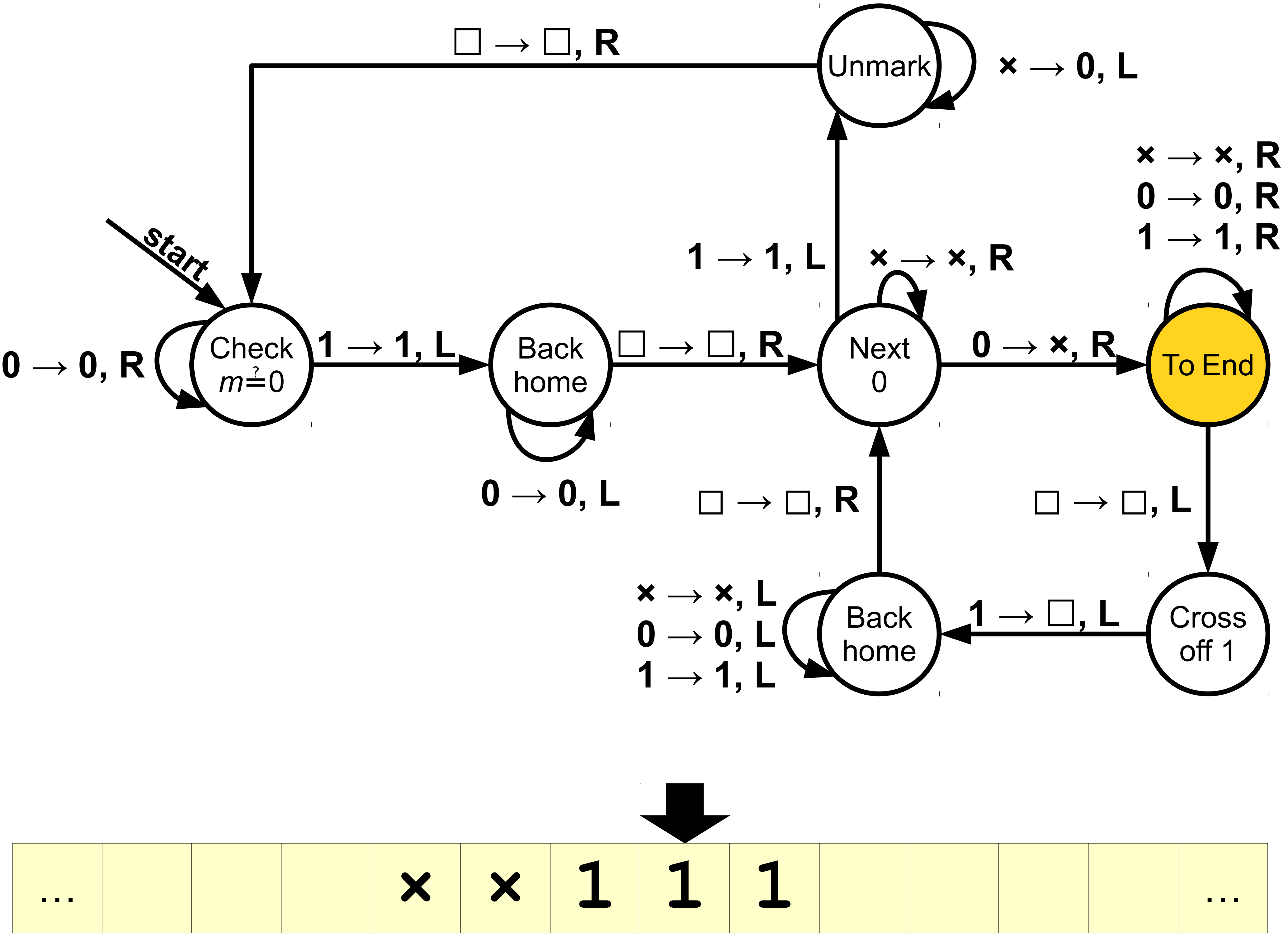
Unmark
× → 0, L
□ → □, R
start
Check
$m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
1 → 1, L
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
□ → □, R
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
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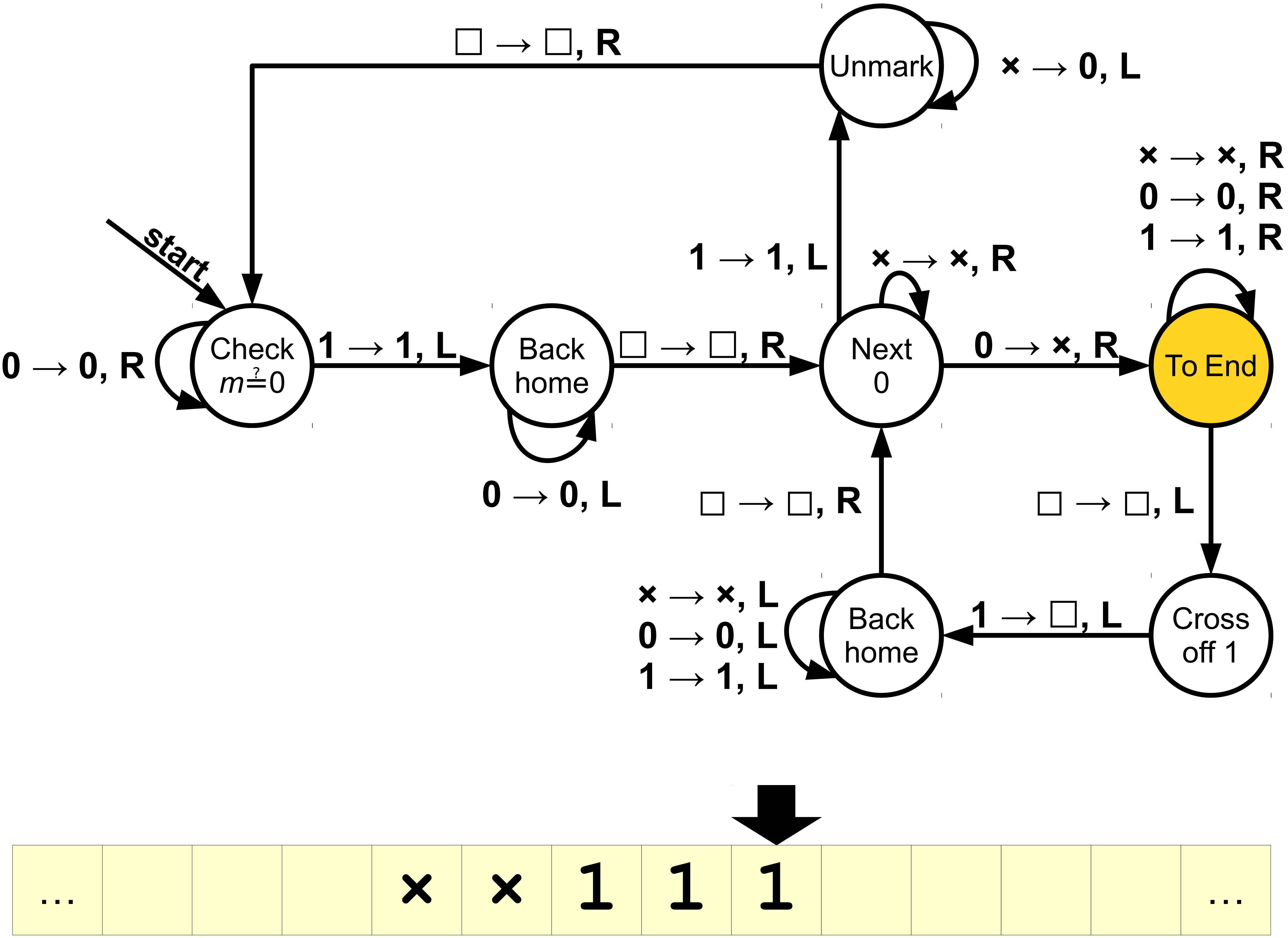
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
start
1 → 1, L
× → ×, R
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
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home
□ → □, R
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0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
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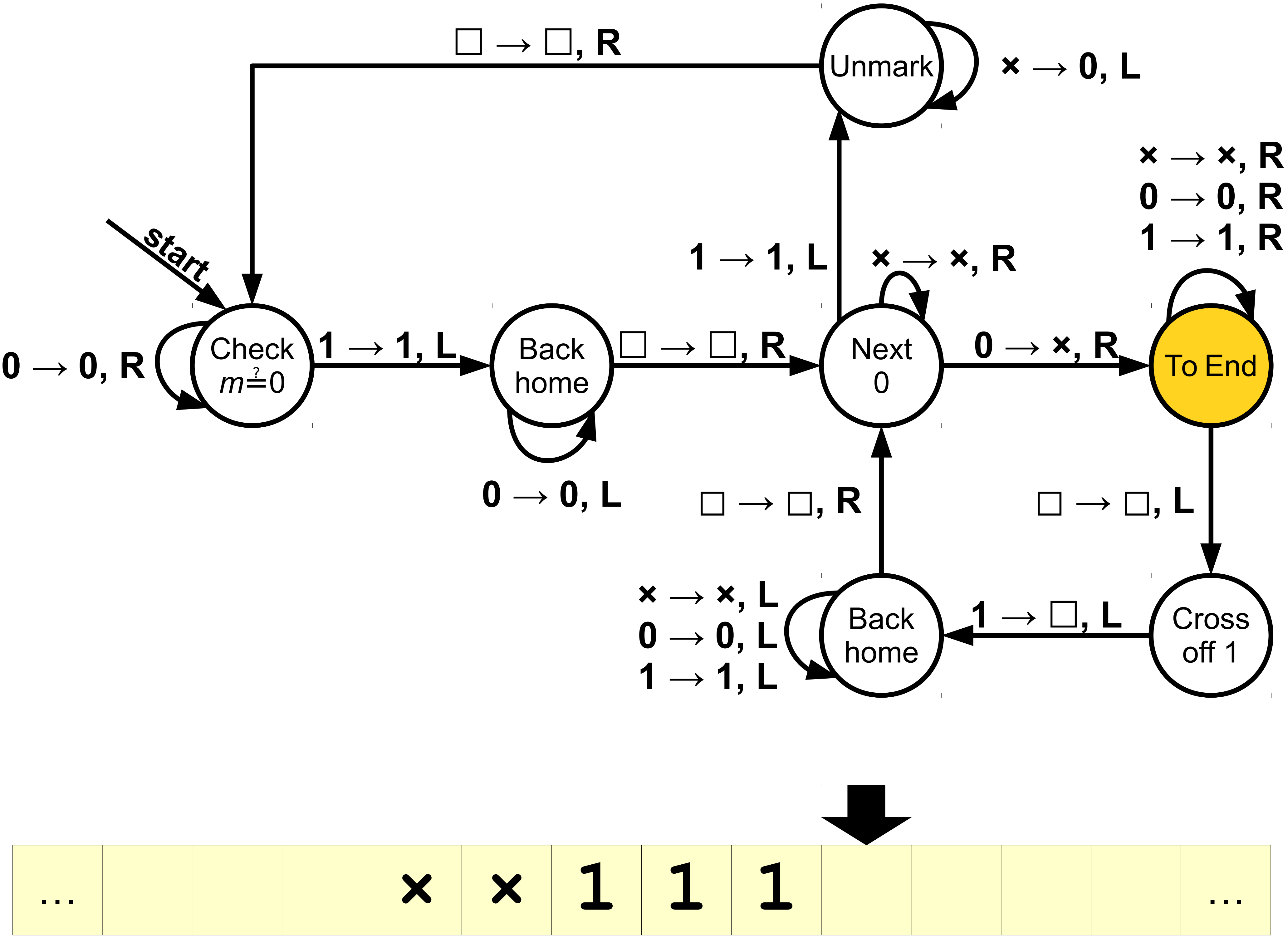
□ → □, R
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× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
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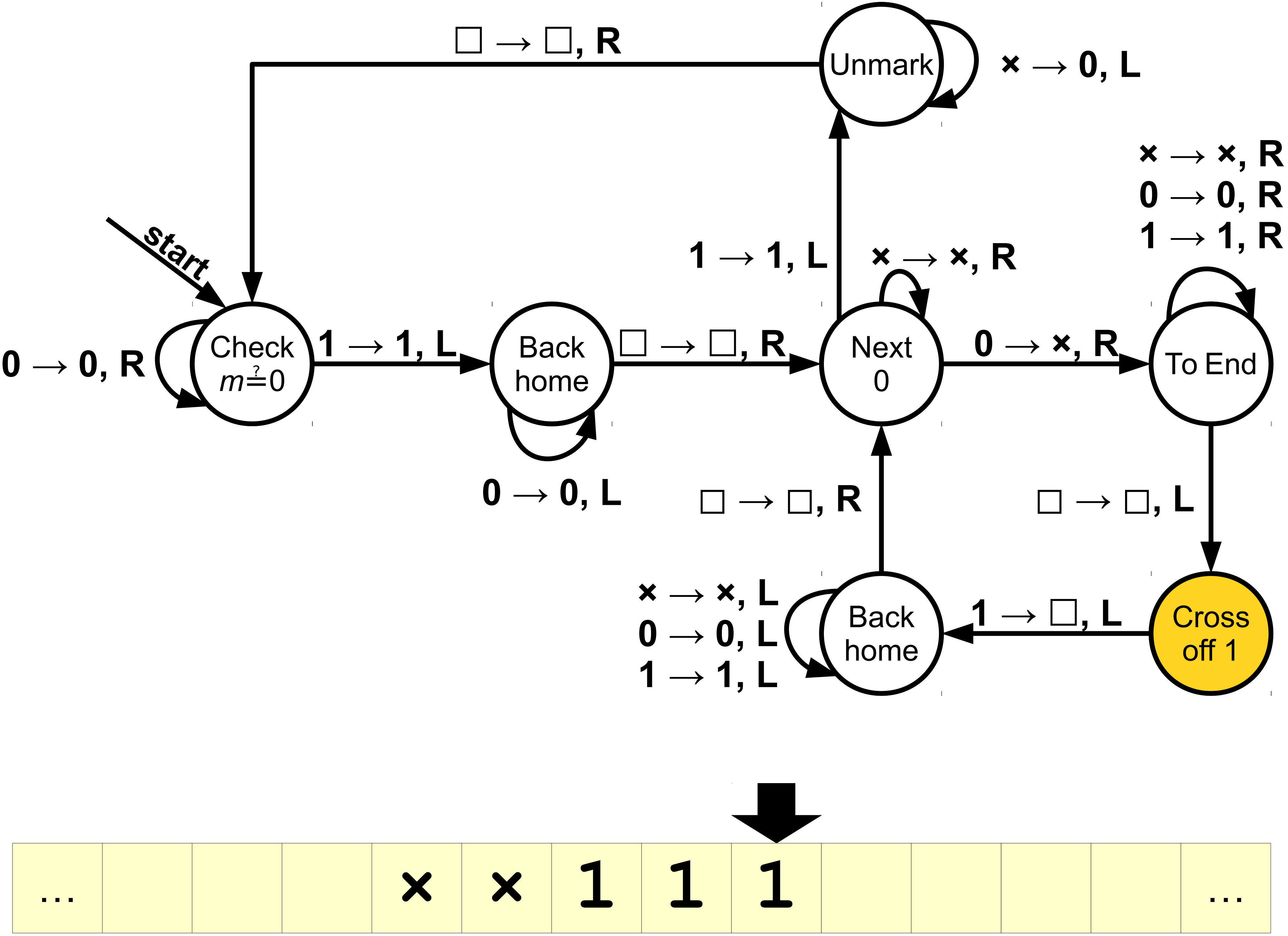
□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
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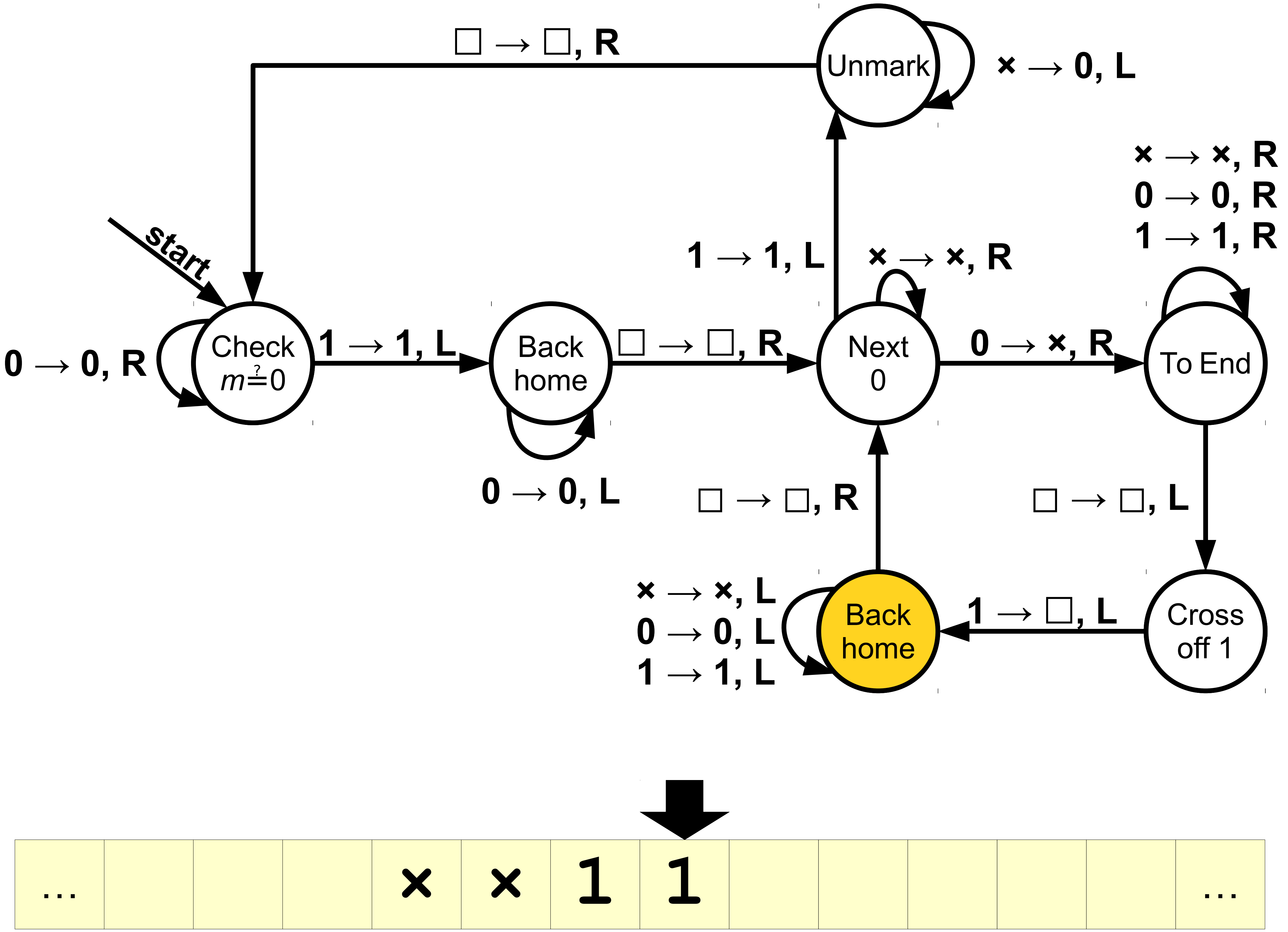
□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
□ → □, R
Next
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0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
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Back
home
1 → □, L
Cross
off 1
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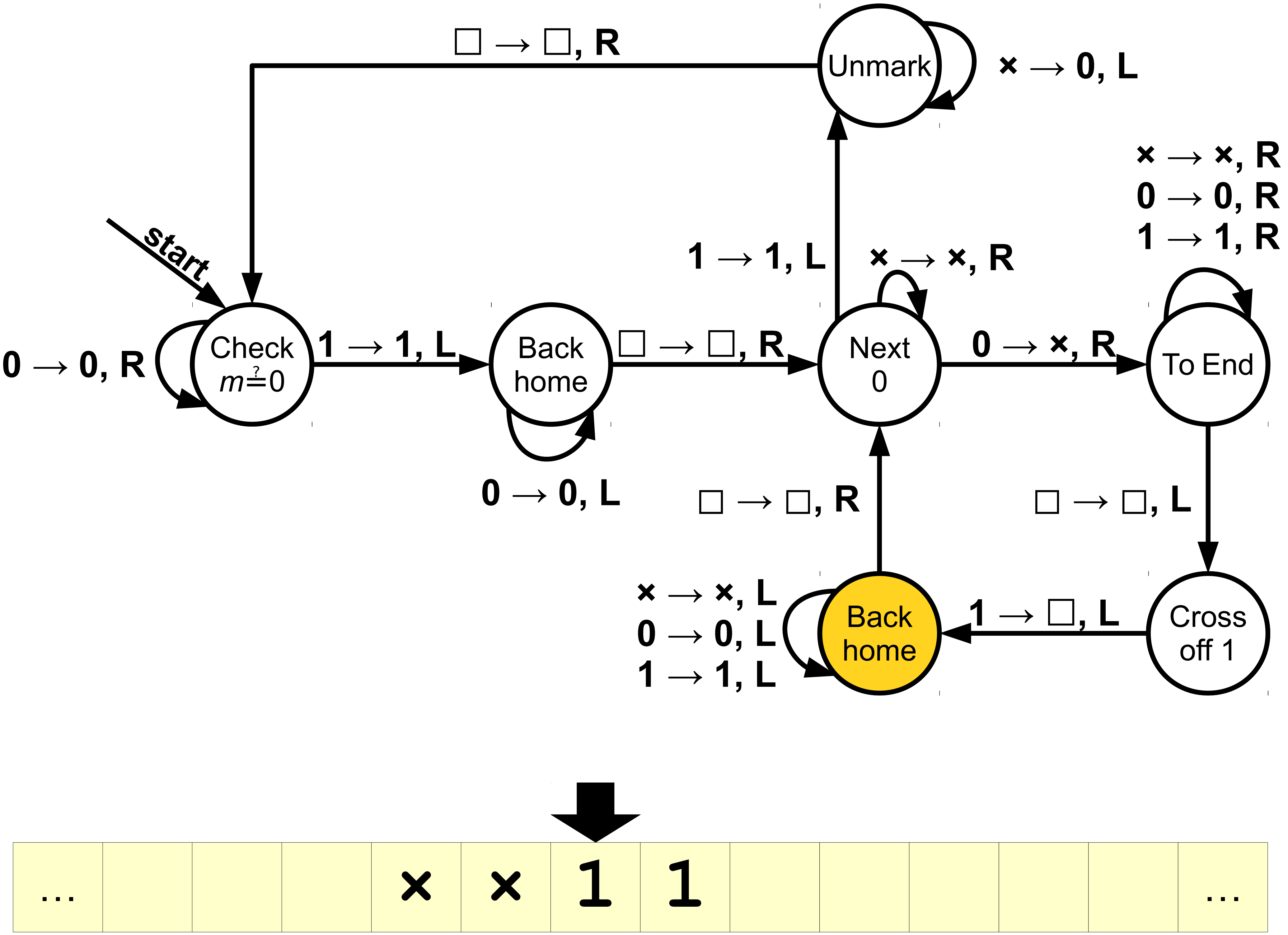
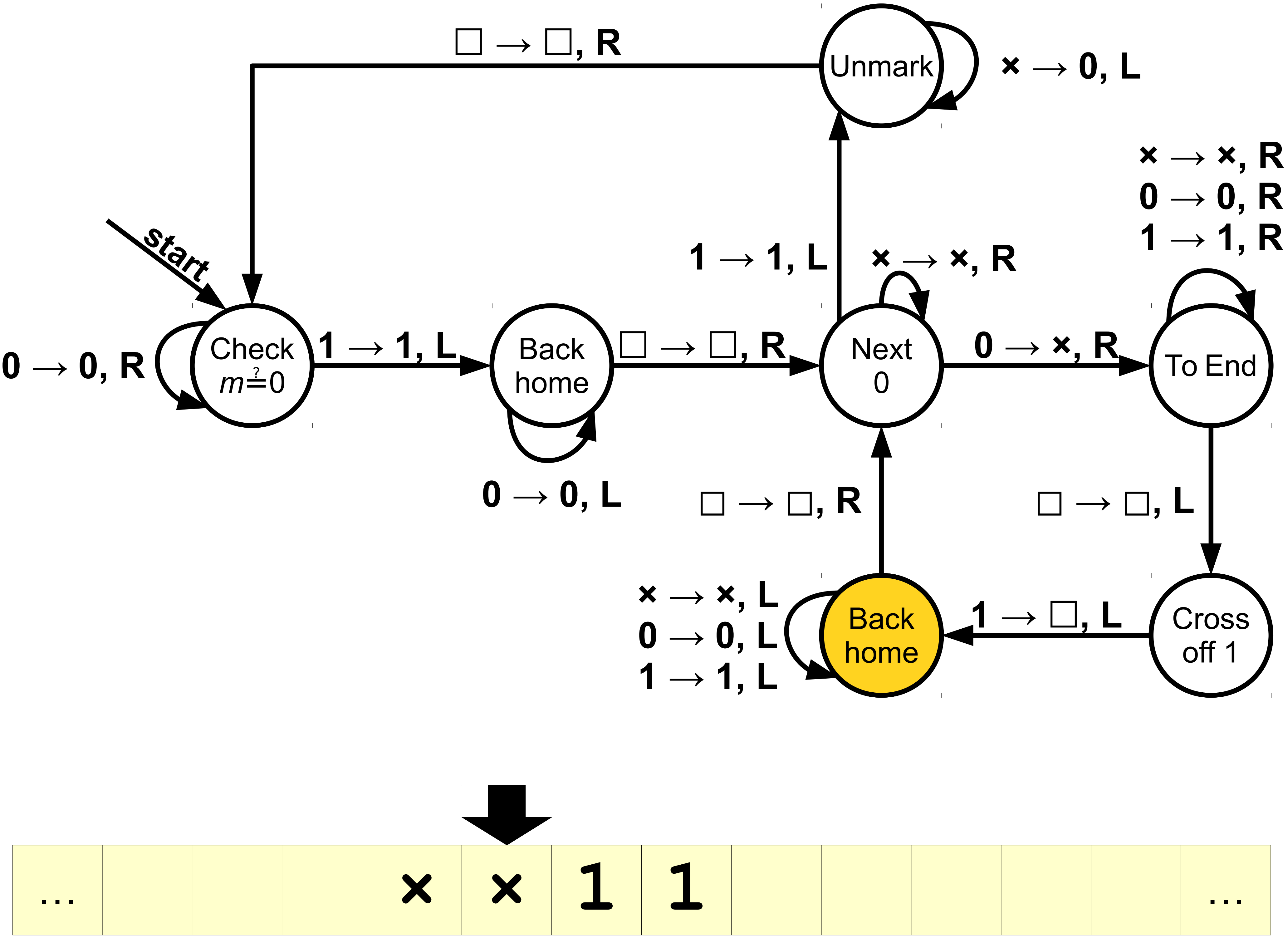
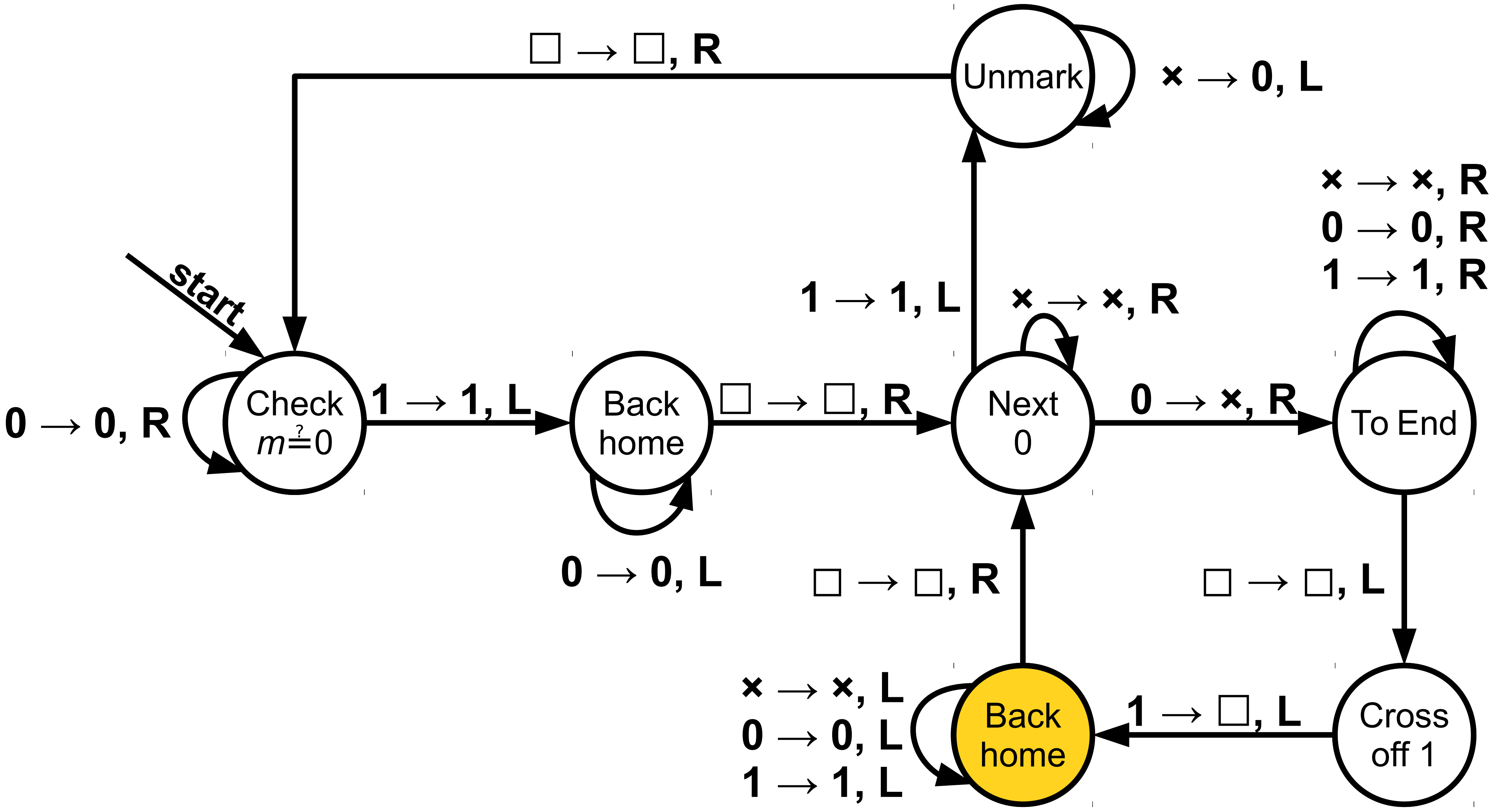
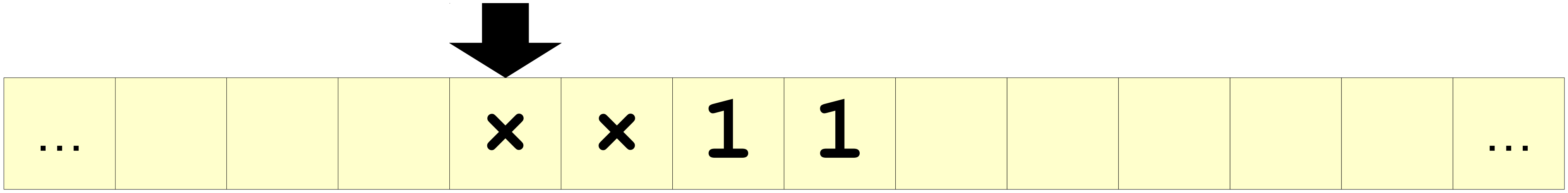

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
start
1 → 1, L
× → ×, R
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
×
×
1
1
…


□ → □, R
Unmark
× → 0, L
start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
1 → 1, L
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
□ → □, R
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
…
×
×
1
1
…


□ → □, R
Unmark
× → 0, L
start
Check
$m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
1 → 1, L
× → ×, R
Next
0
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1


…
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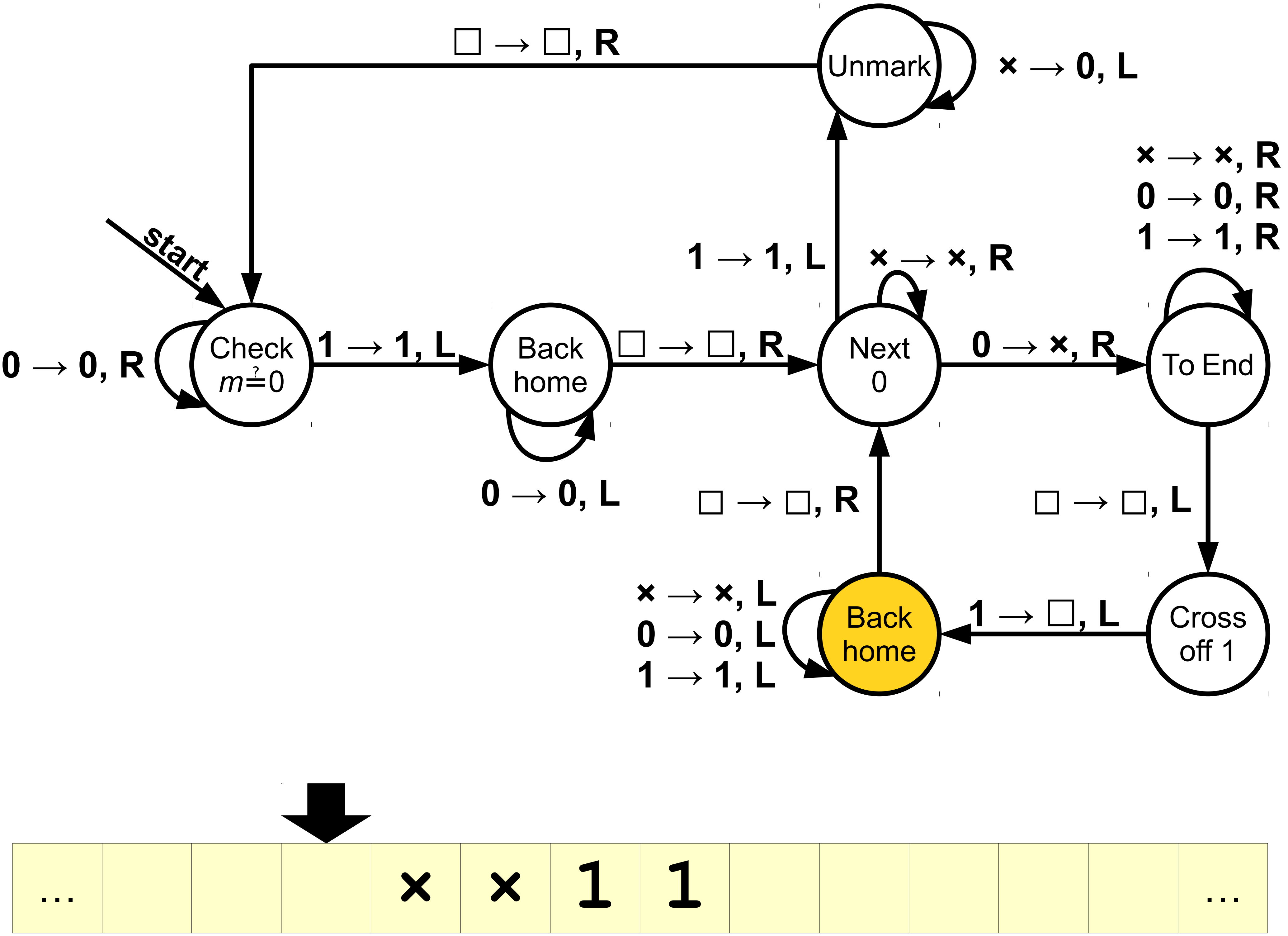
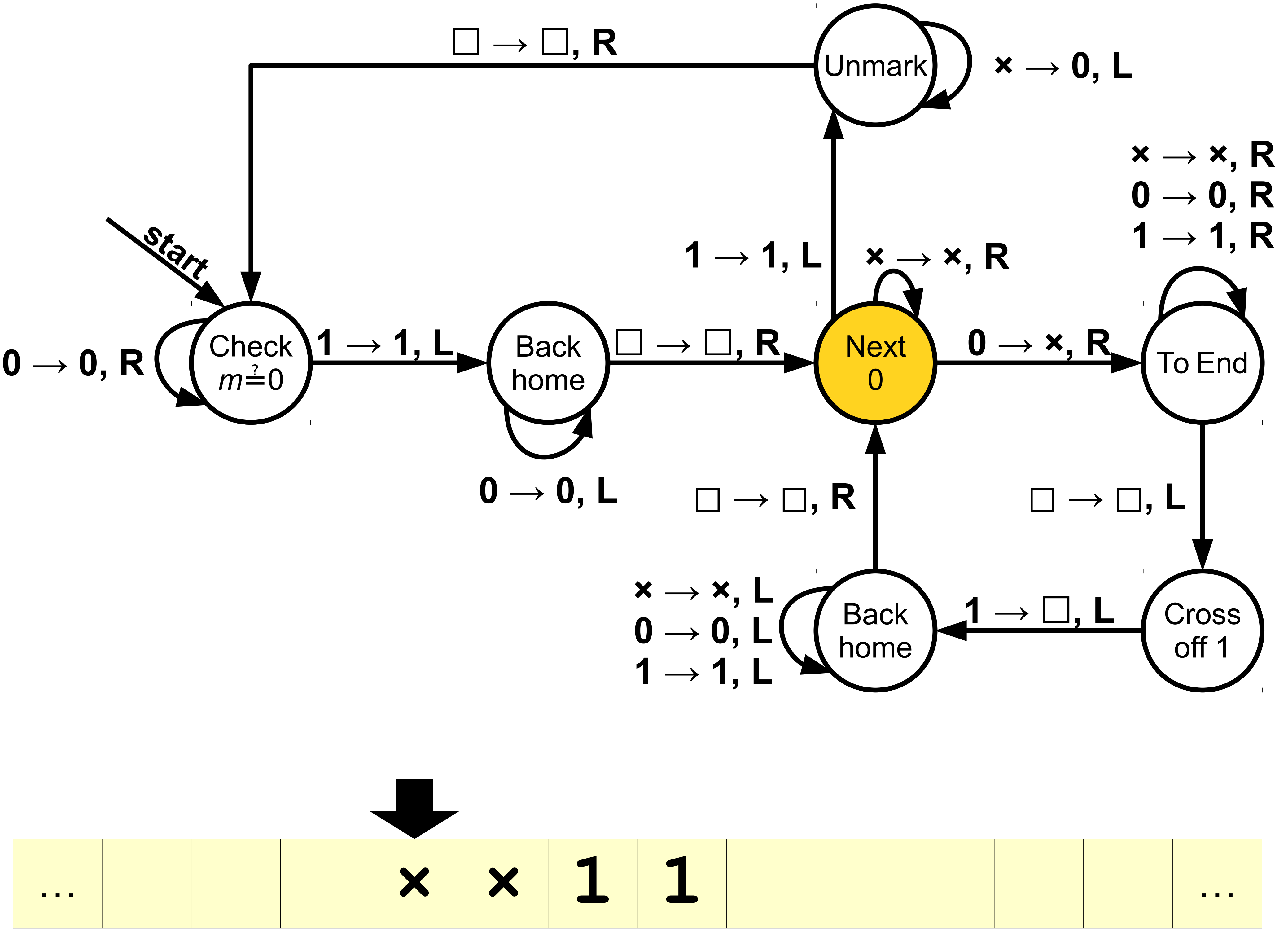
1
…


start
Check $m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
1
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
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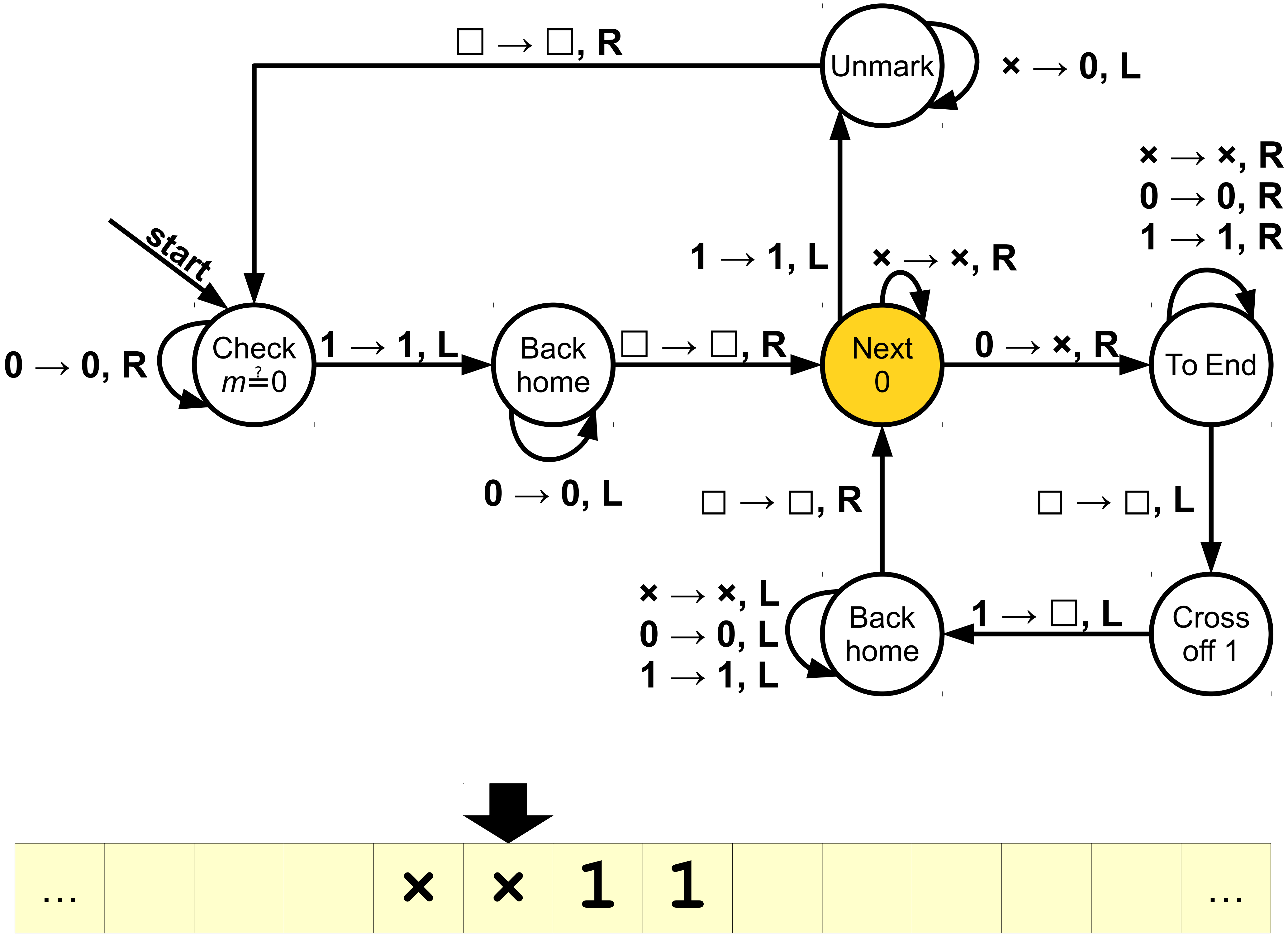
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
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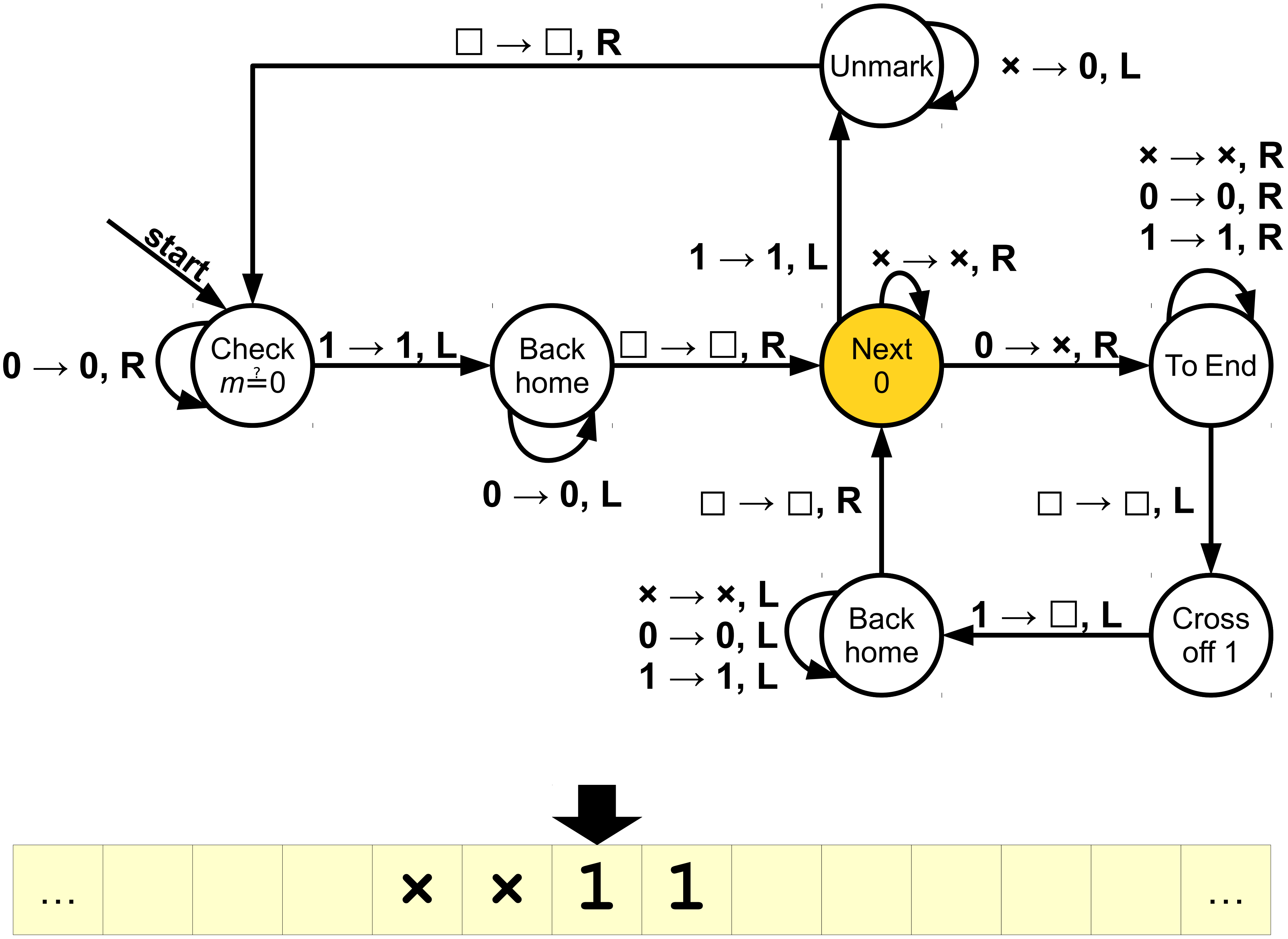

□ → □, R
Unmark
× → 0, L
start
Check
$m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
1 → 1, L
× → ×, R
Next
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0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, L
□ → □, R
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
…
×
×
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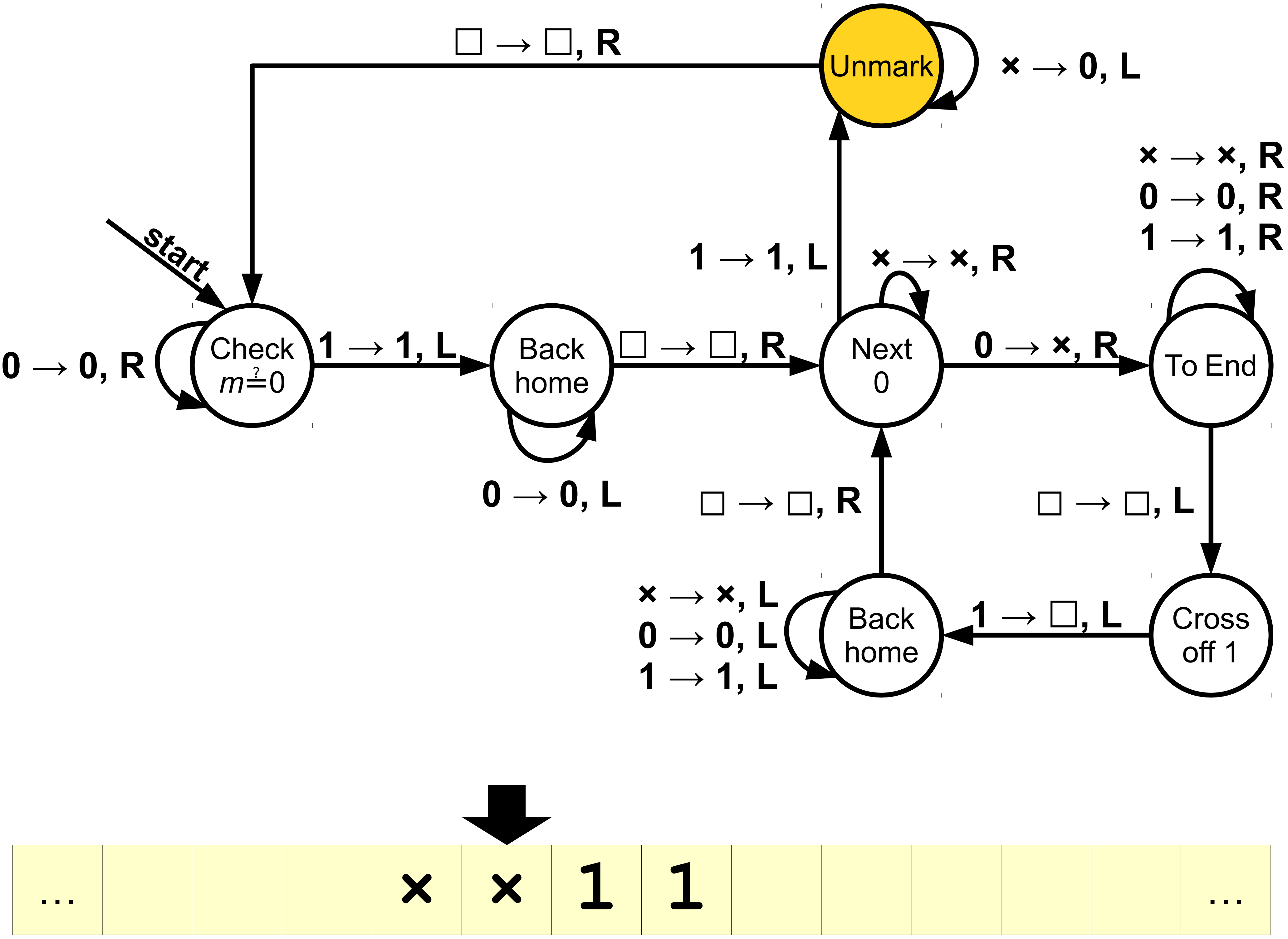
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
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×
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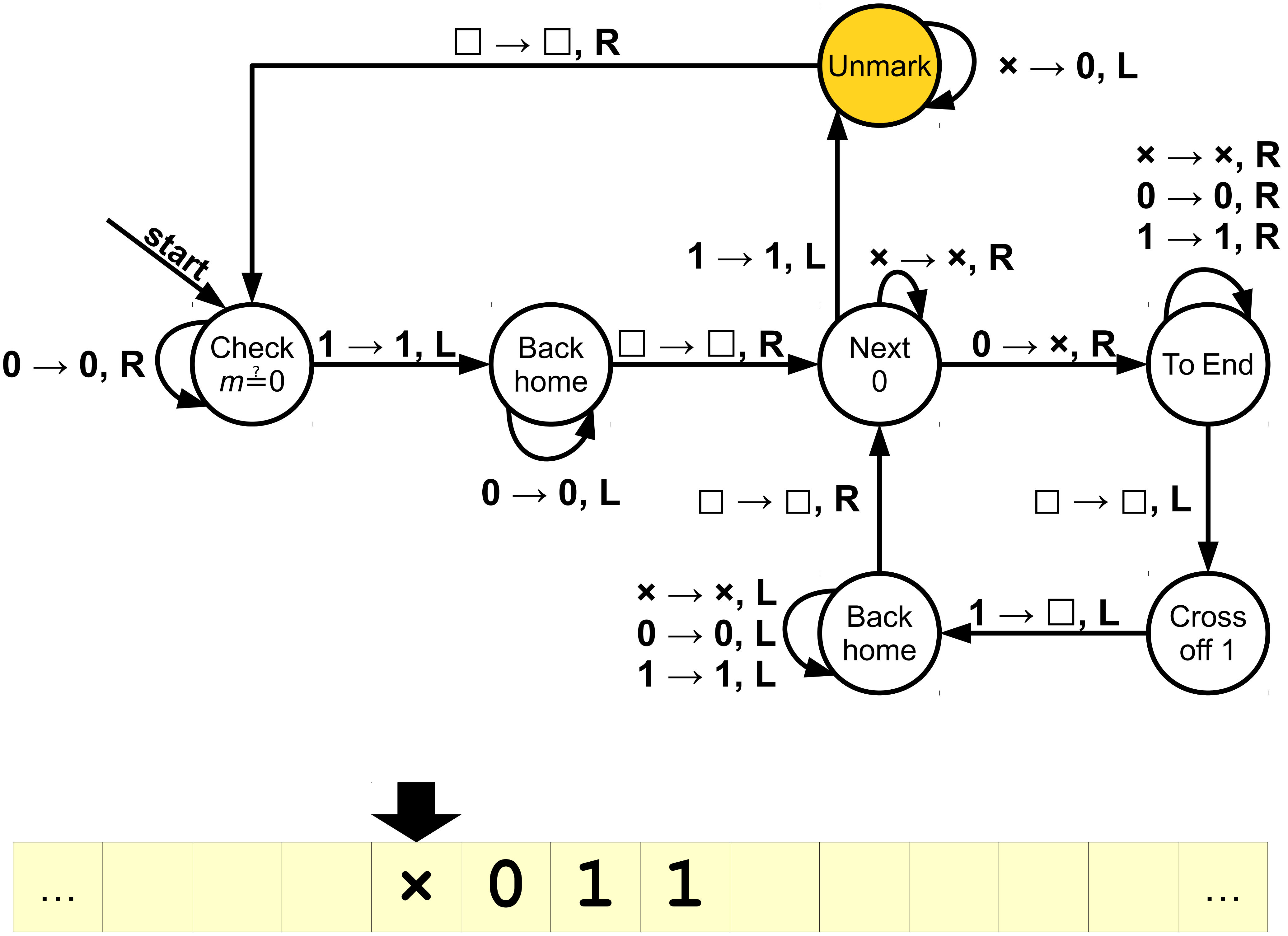
□ → □, R
Unmark
× → 0, L
× → ×, R
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start
1 → 1, L
× → ×, R
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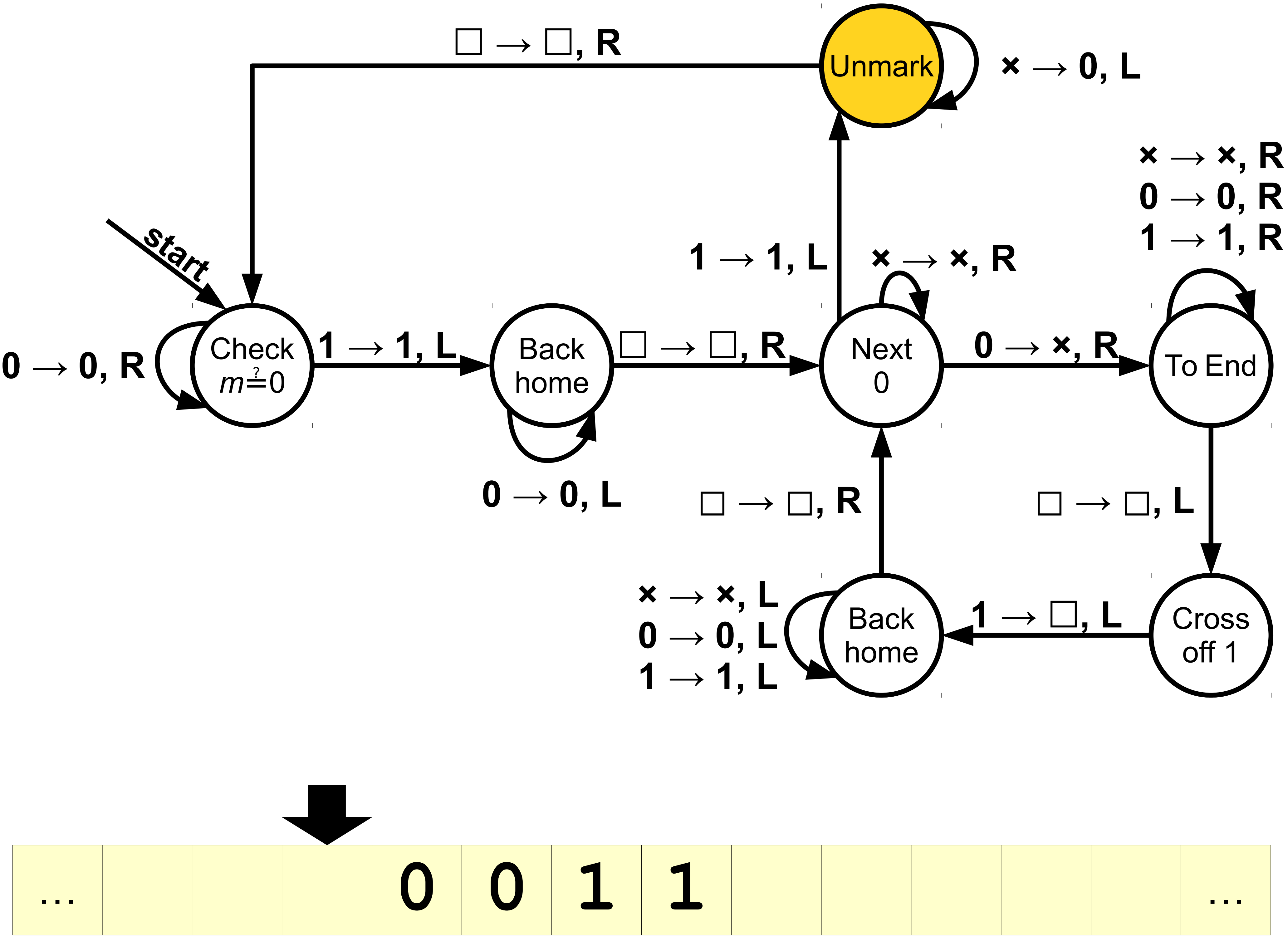
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1

…				×	0	1	1						…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
□ → □, R
Next
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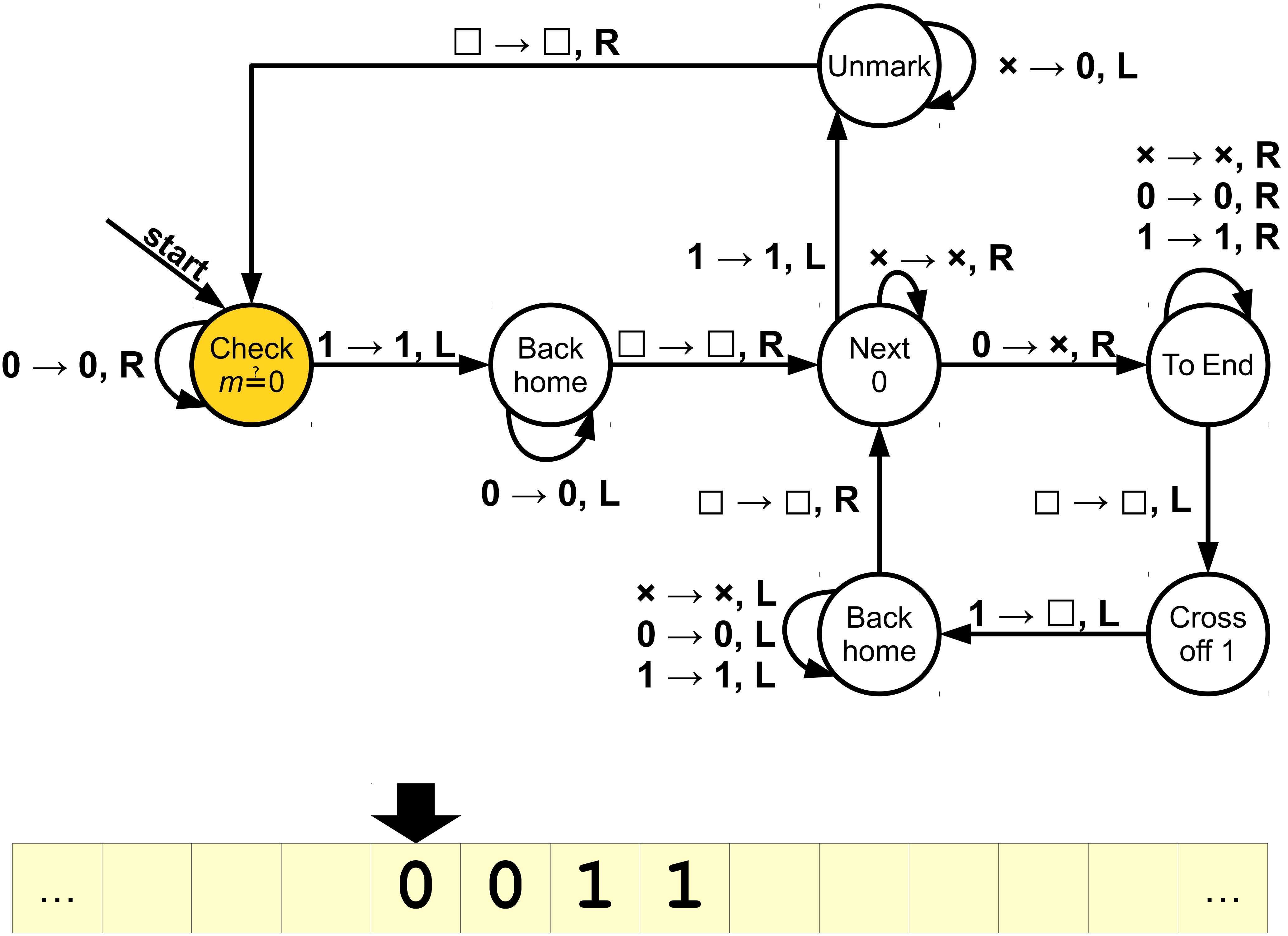
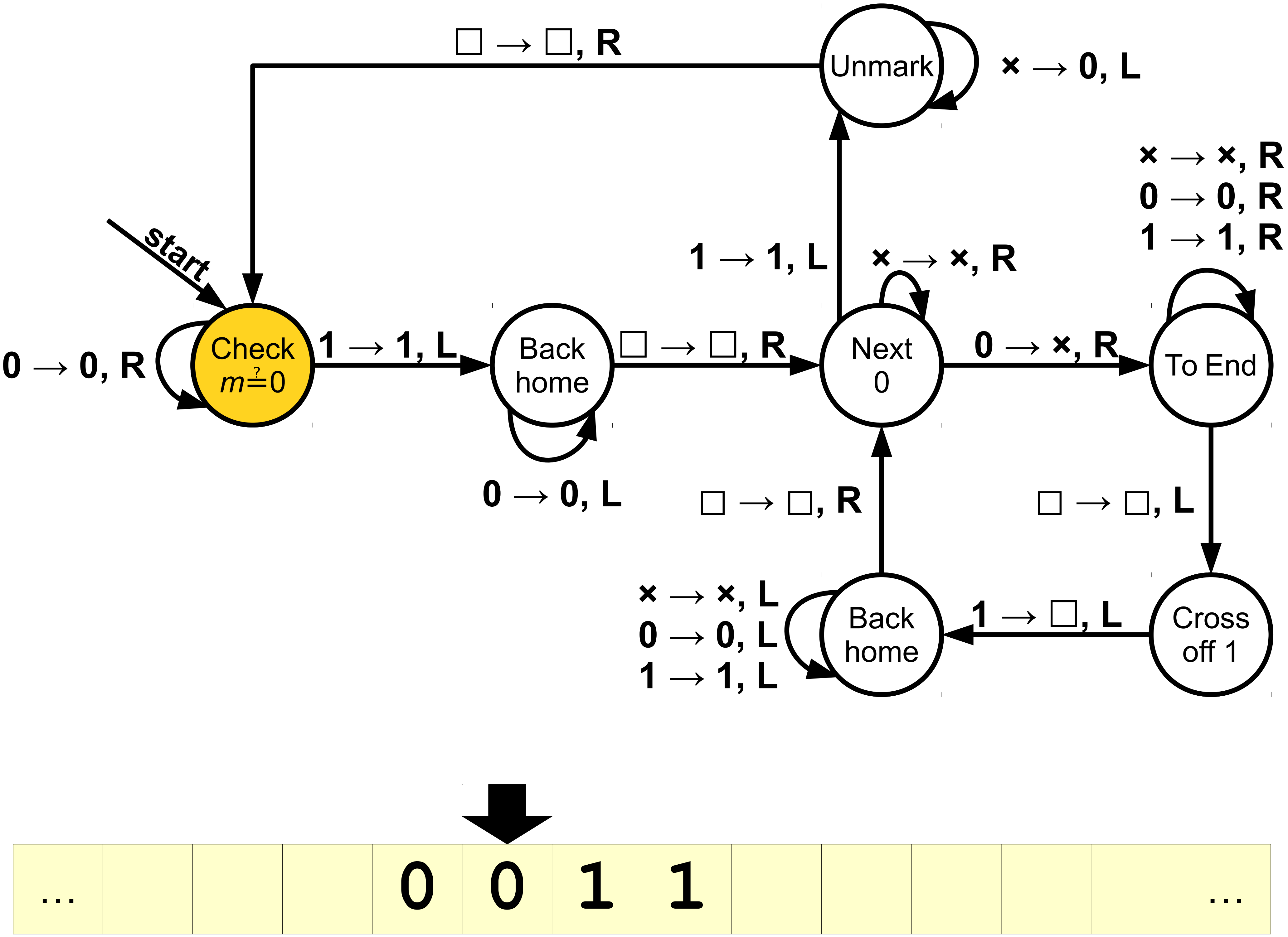
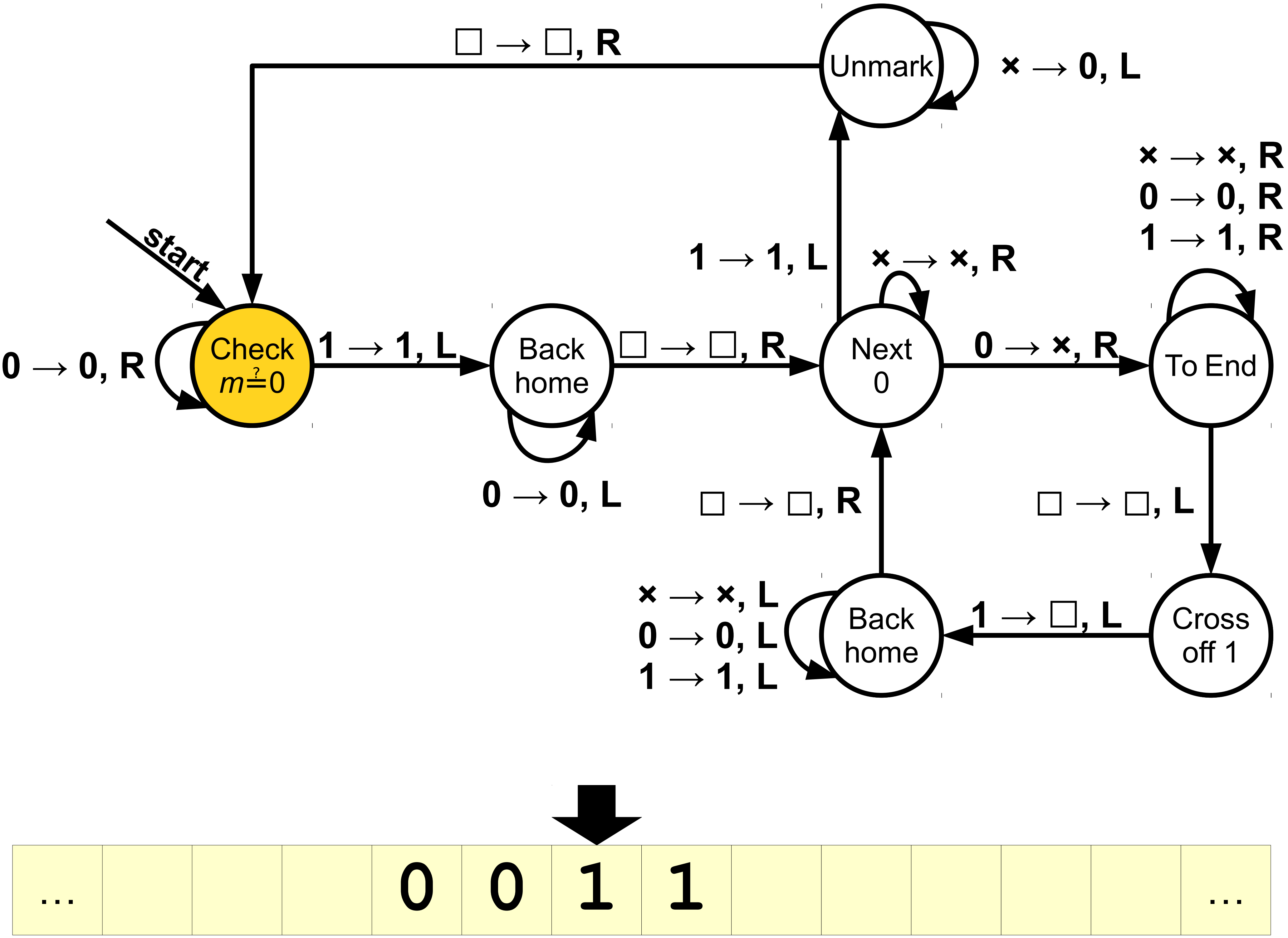
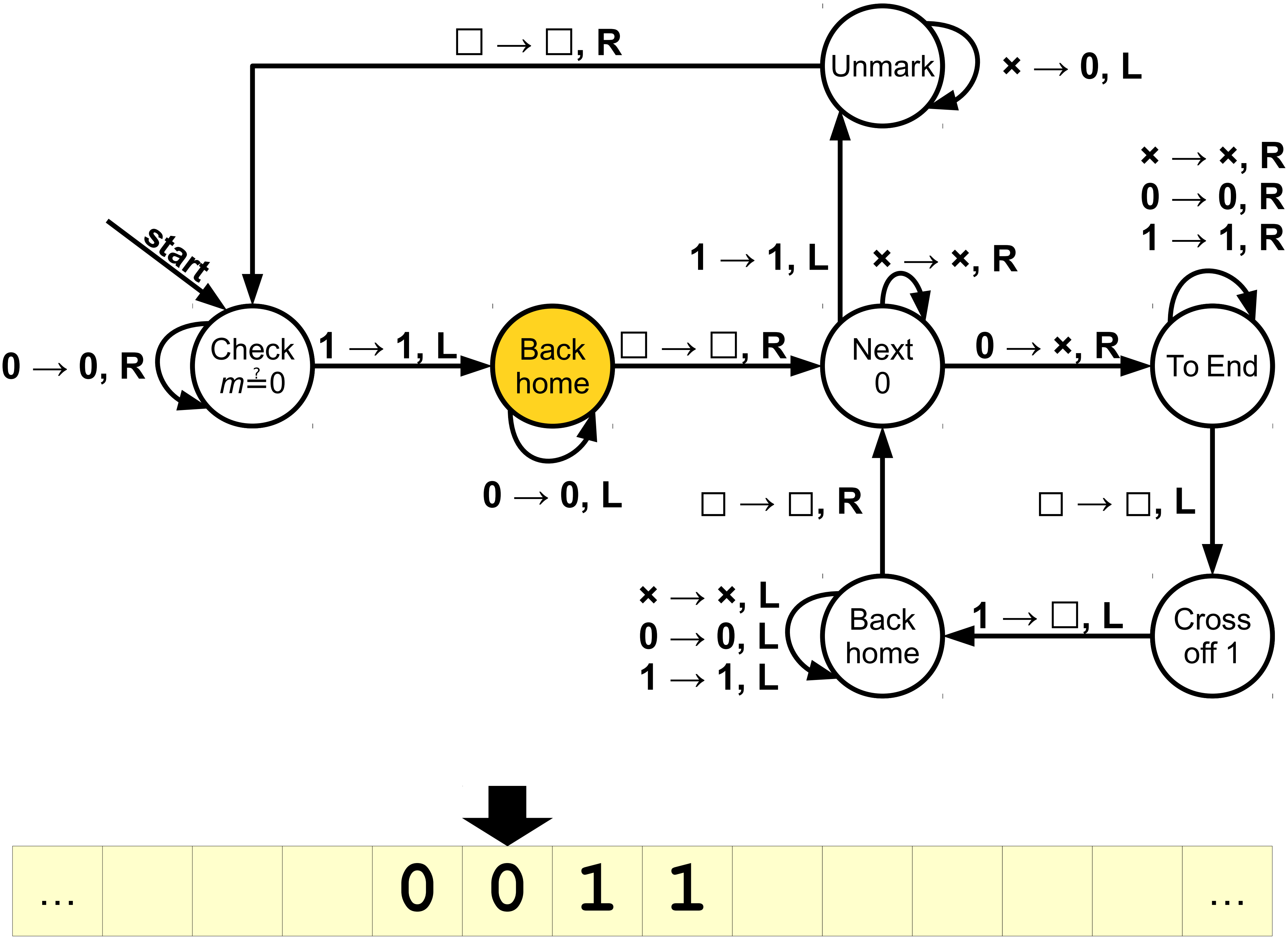
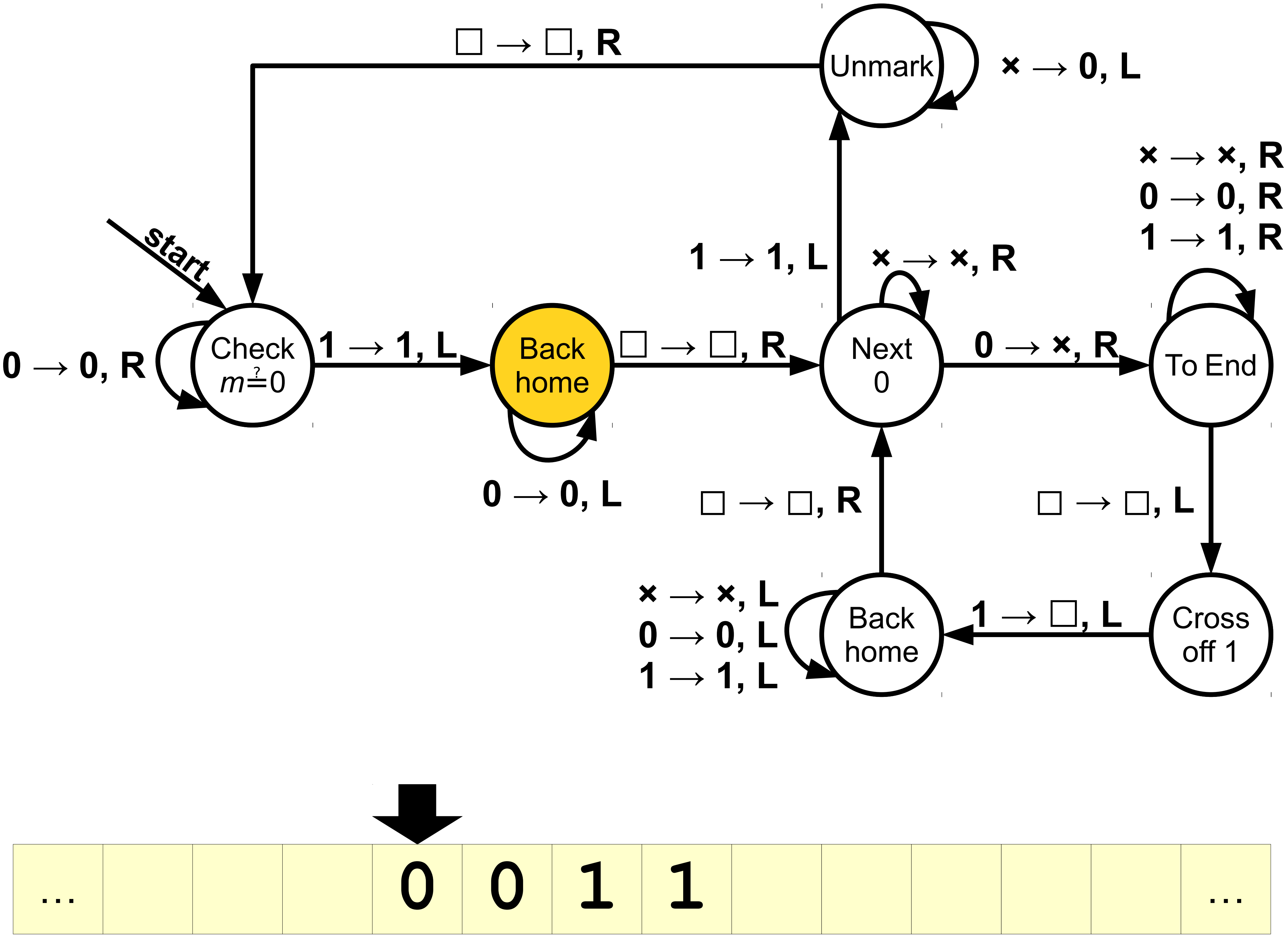
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
0
0
1
1
…

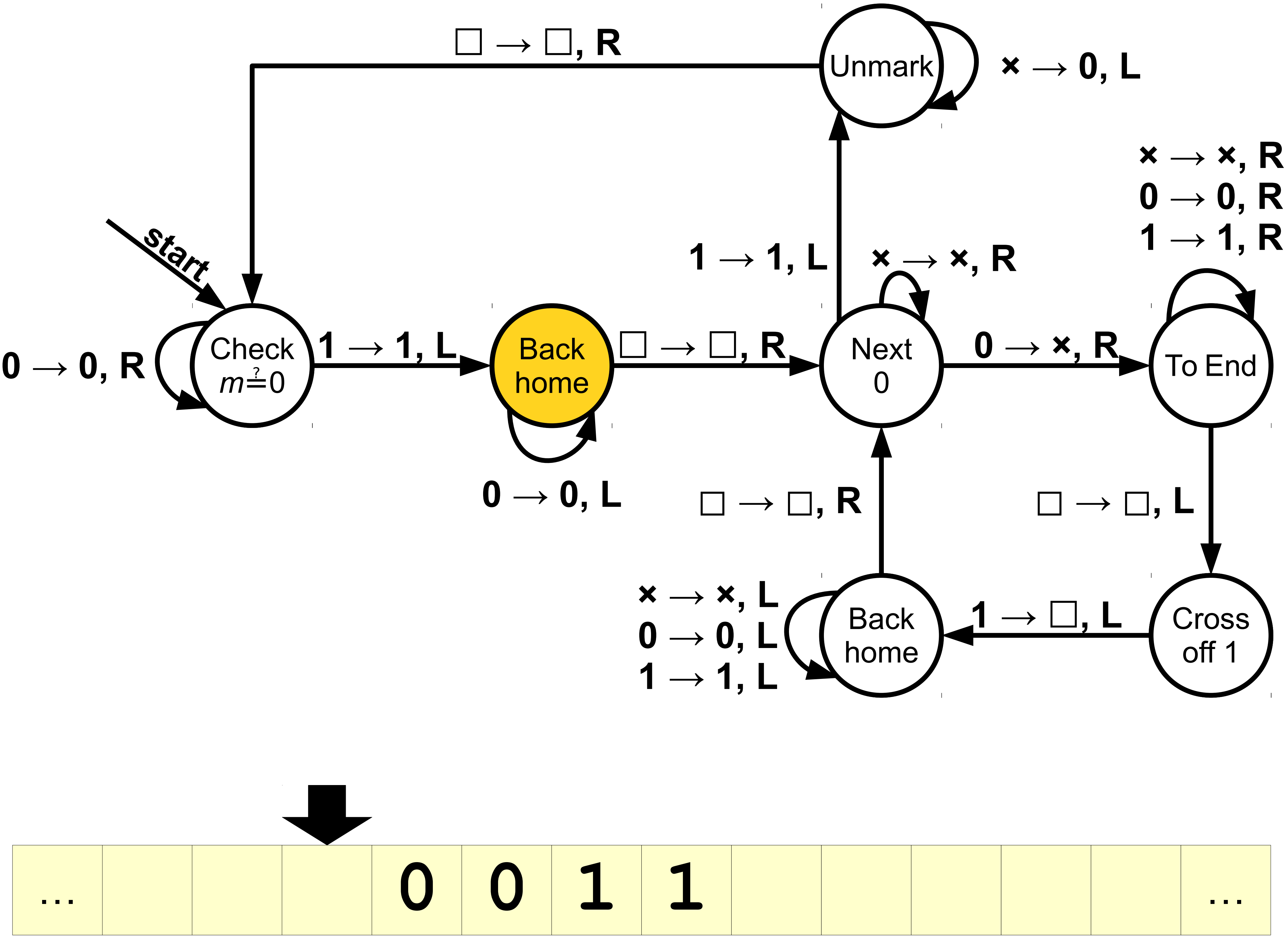

start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
0
0
1
1
…

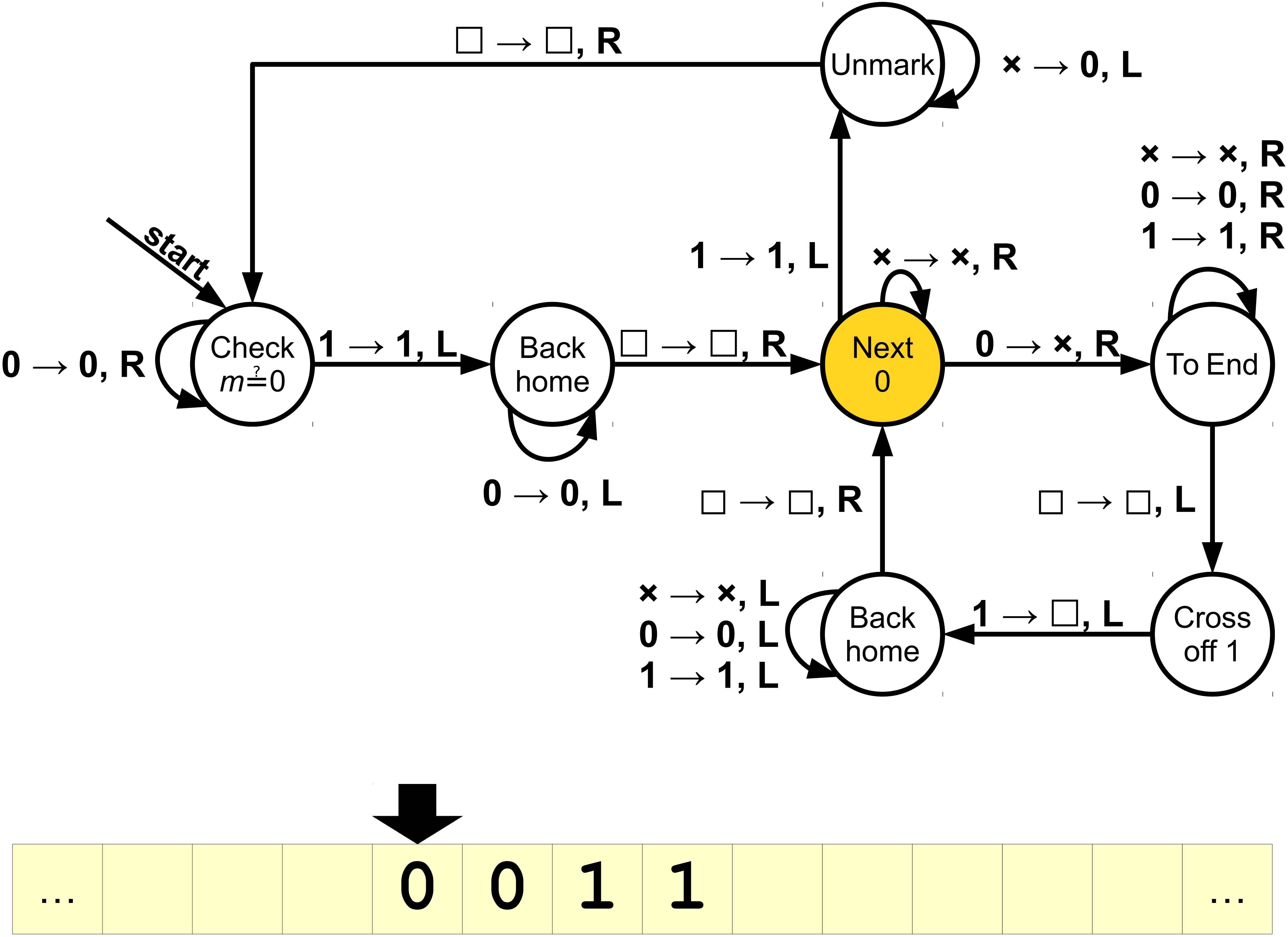

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
0
0
1
1
…

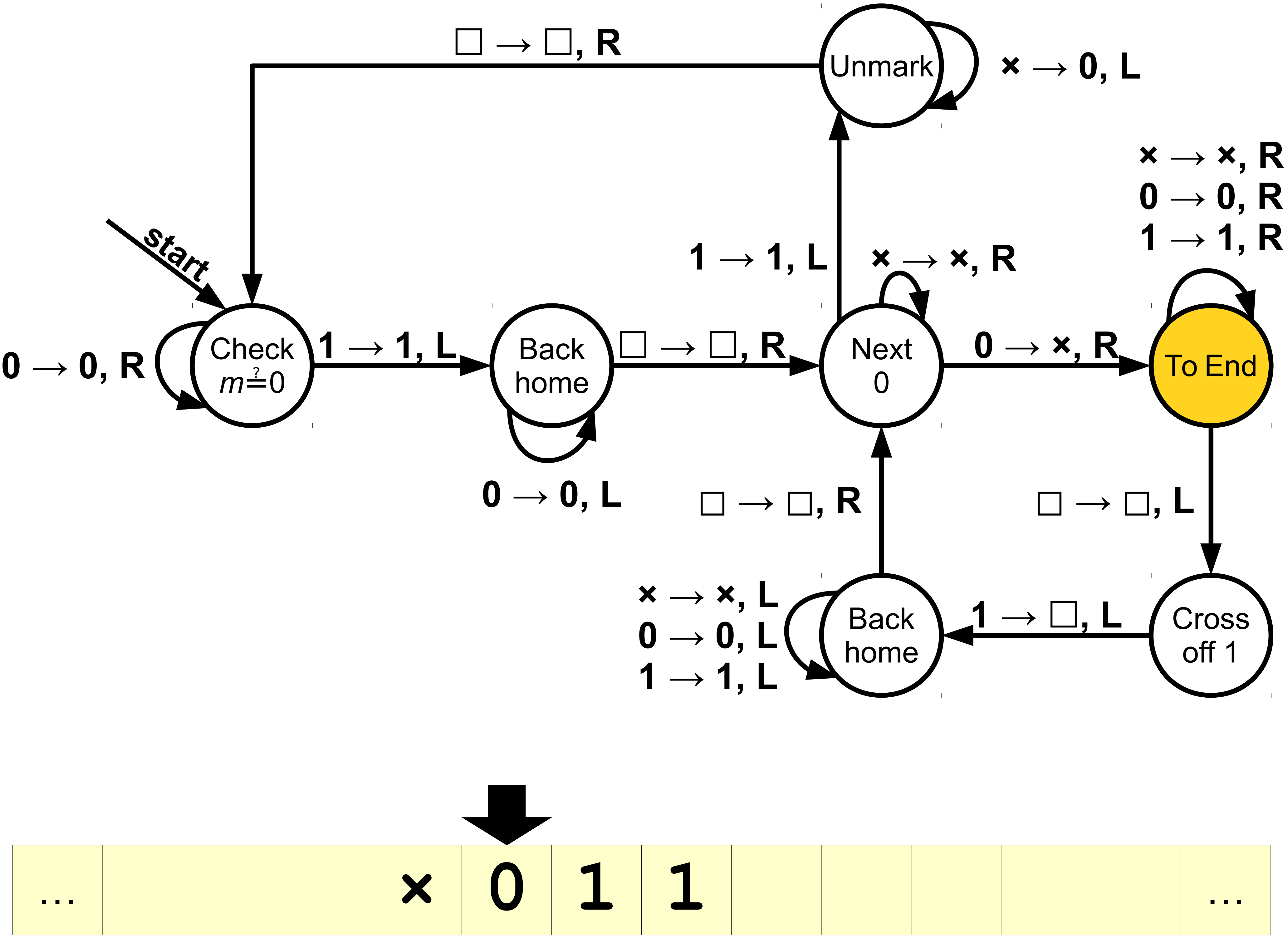

start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
0
0
1
1
…

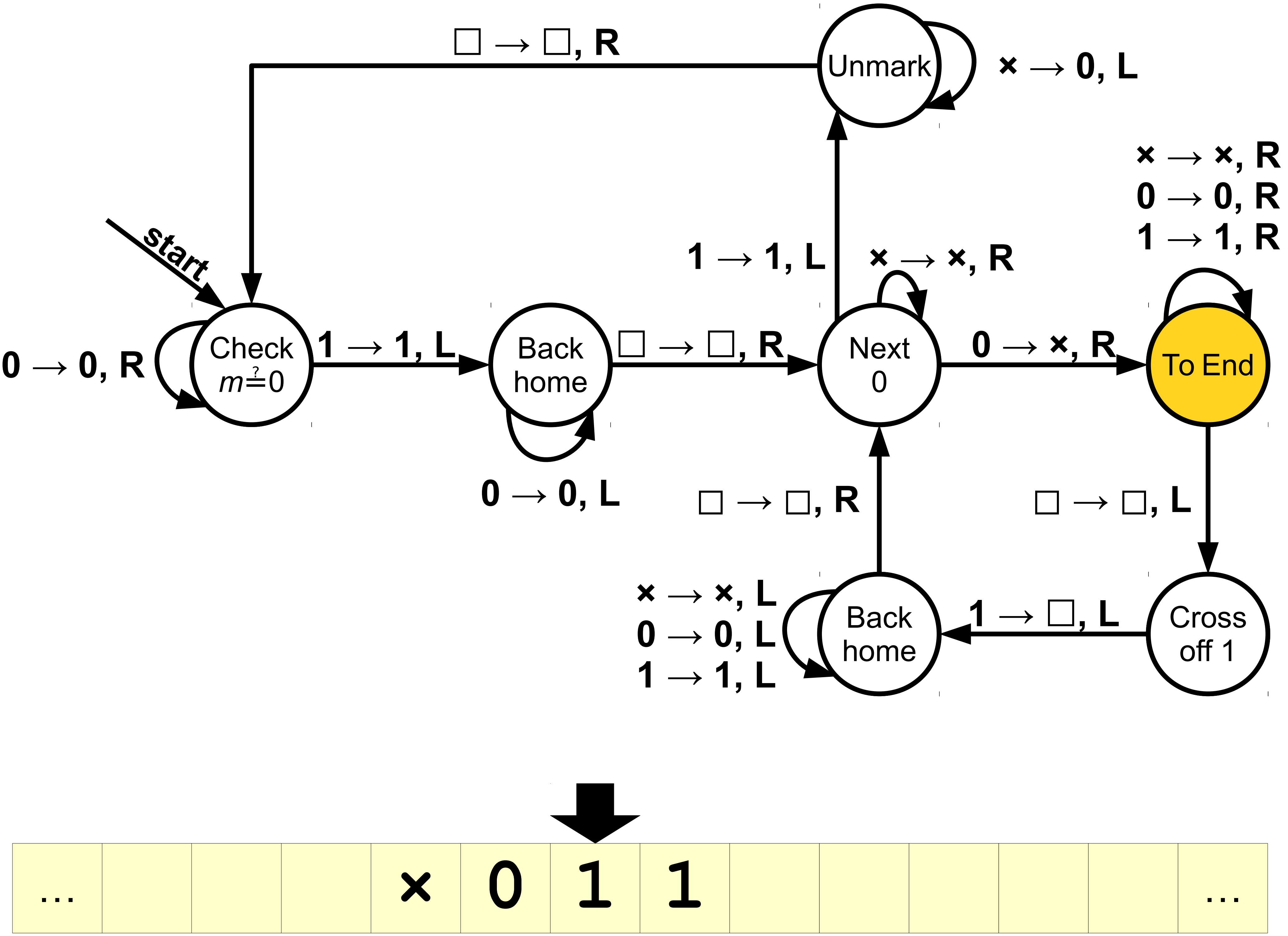

□ → □, R
Unmark
× → 0, L
start
Check
$m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
1 → 1, L
× → ×, R
Next
0
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
0
0
1
1
…

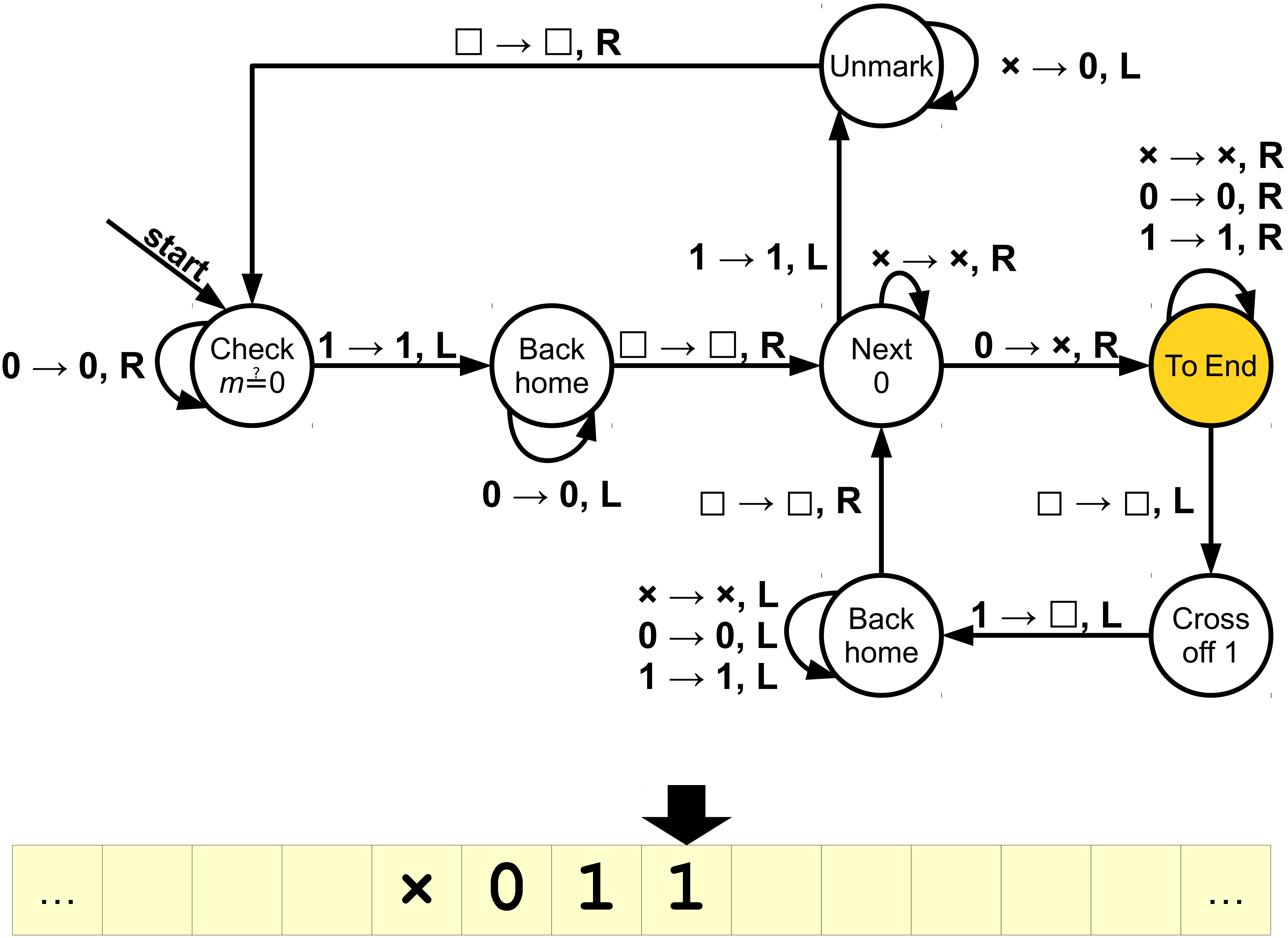

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
0
0
1
1
…

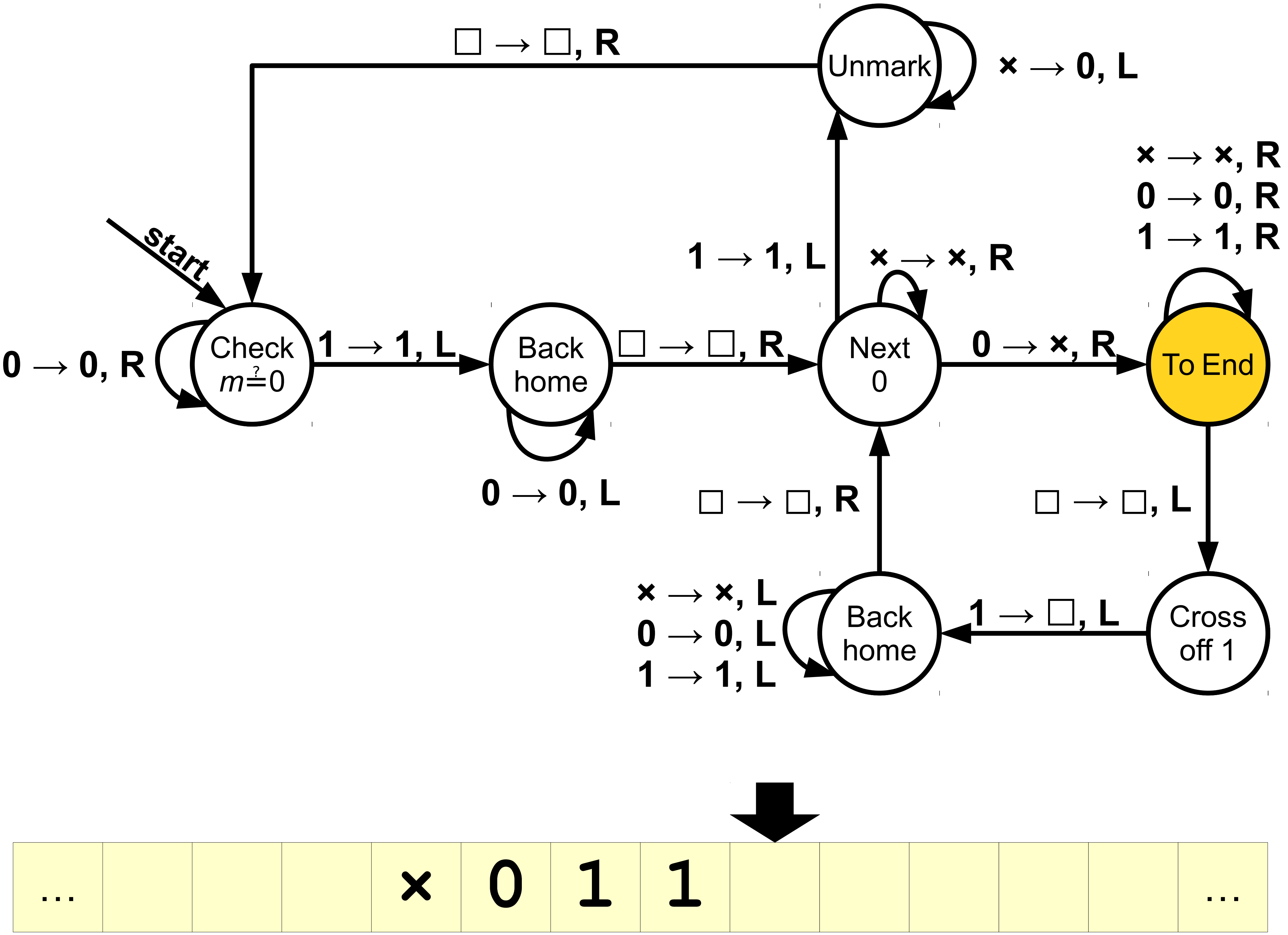

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
0
0
1
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
0
0
1
1
…

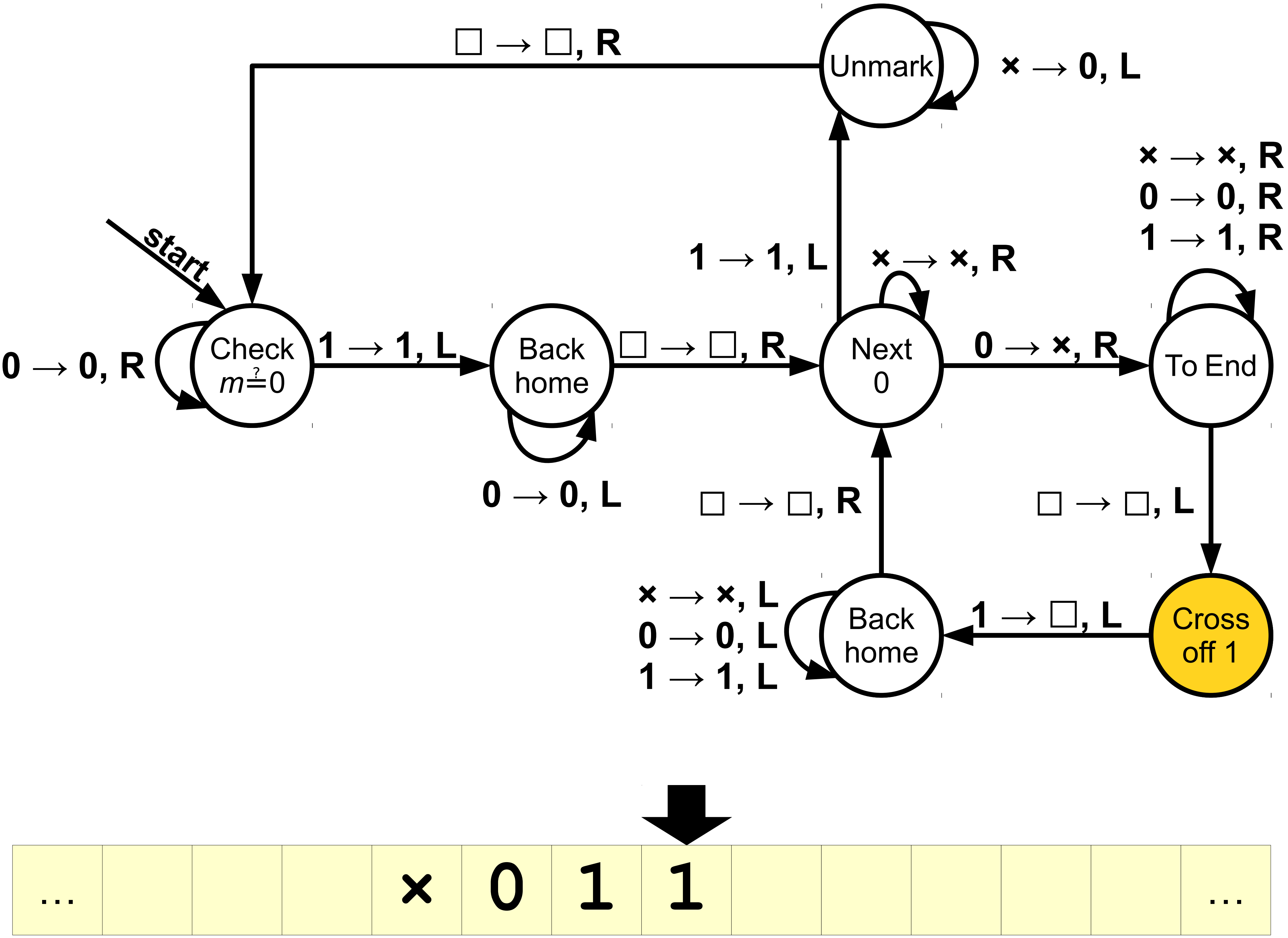

start
Check $m\overset{?}{=}0$
$0 \to 0$, R
$1 \to 1$, L
Back home
$0 \to 0$, L
$\square \to \square$, R
Next 0
$\times \to \times$, R
$1 \to 1$, L
Unmark
$\times \to 0$, L
$\square \to \square$, R
$0 \to \times$, R
To End
$\times \to \times$, R
$0 \to 0$, R
$1 \to 1$, R
$\square \to \square$, L
Cross off 1
$1 \to \square$, L
Back home
$\times \to \times$, L
$0 \to 0$, L
$1 \to 1$, L
$\square \to \square$, R
…
×
0
1
1
…

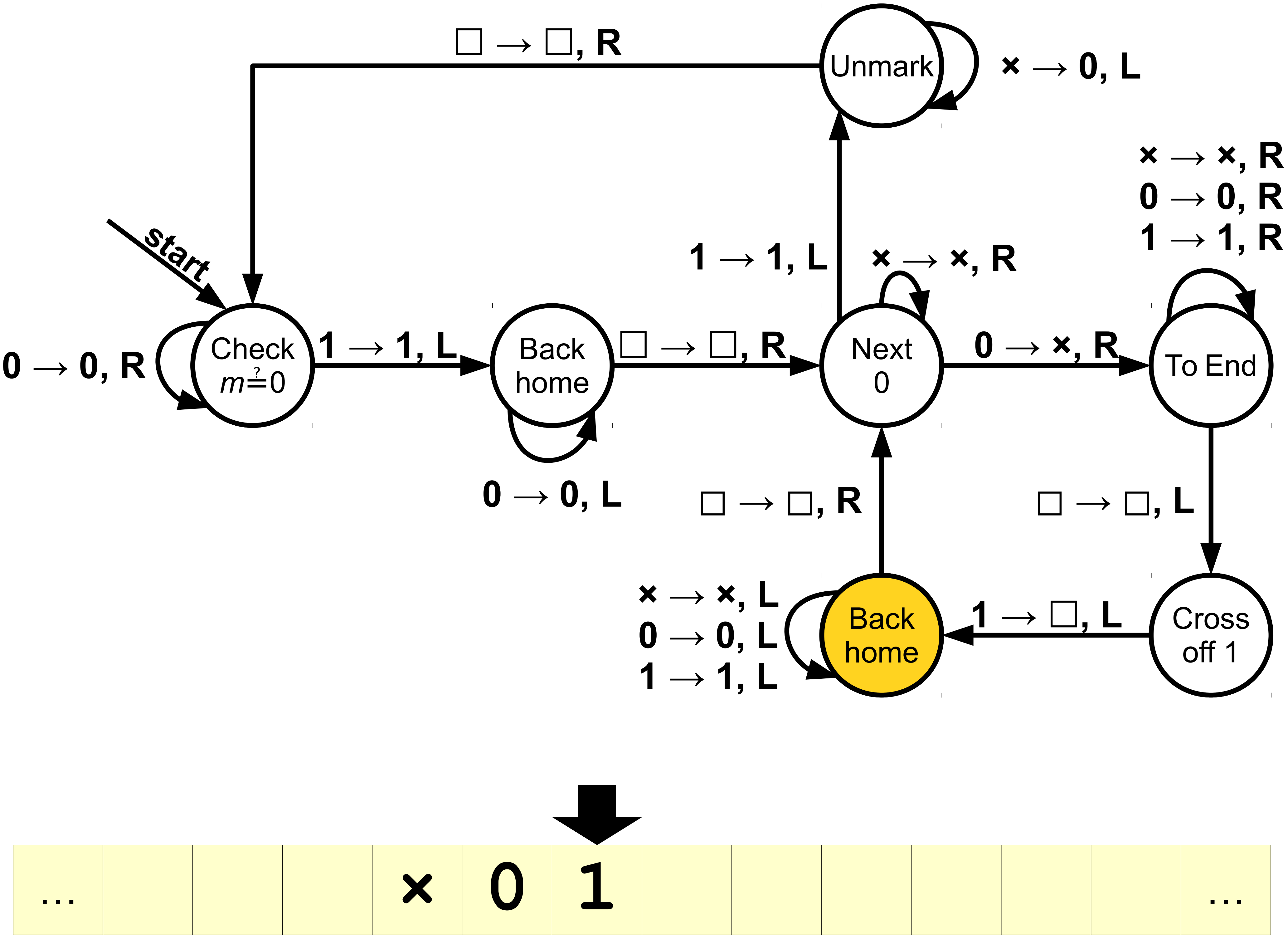

start
Check $m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
1 → 1, L
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
Unmark
× → 0, L
□ → □, R
…
×
0
1
1
…

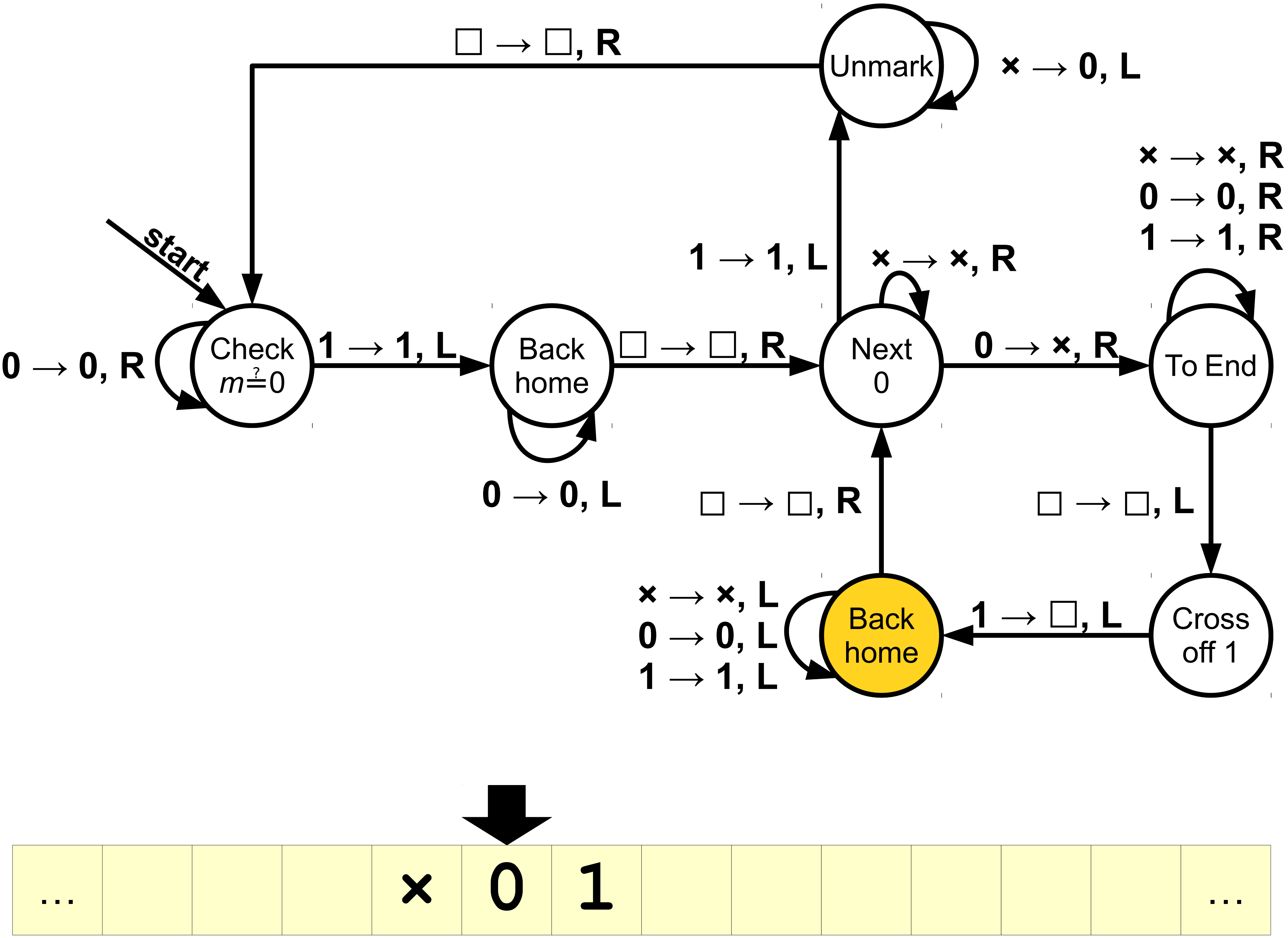

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
start
1 → 1, L
× → ×, R
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
1
…

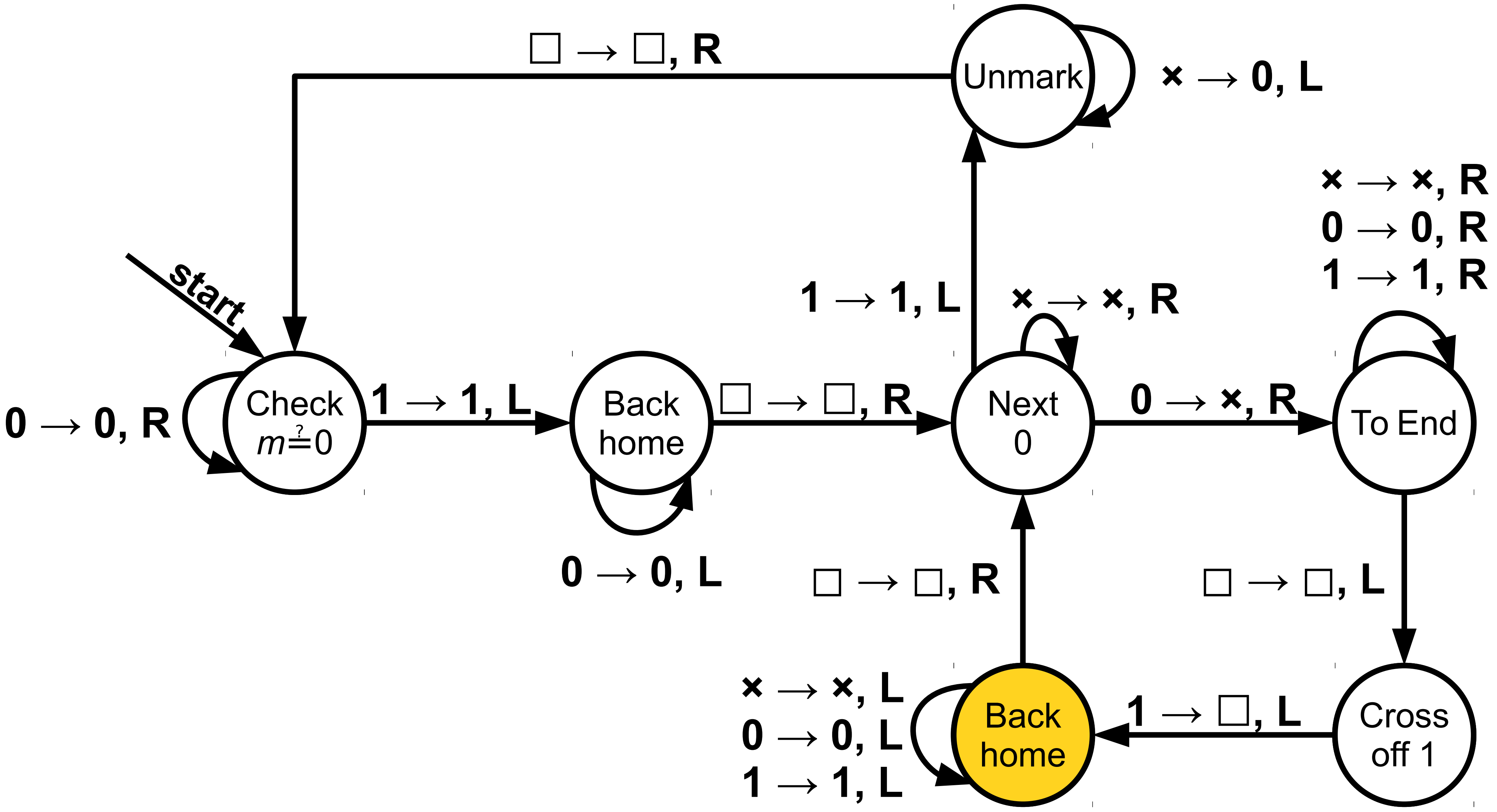


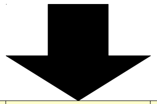
□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
1
…

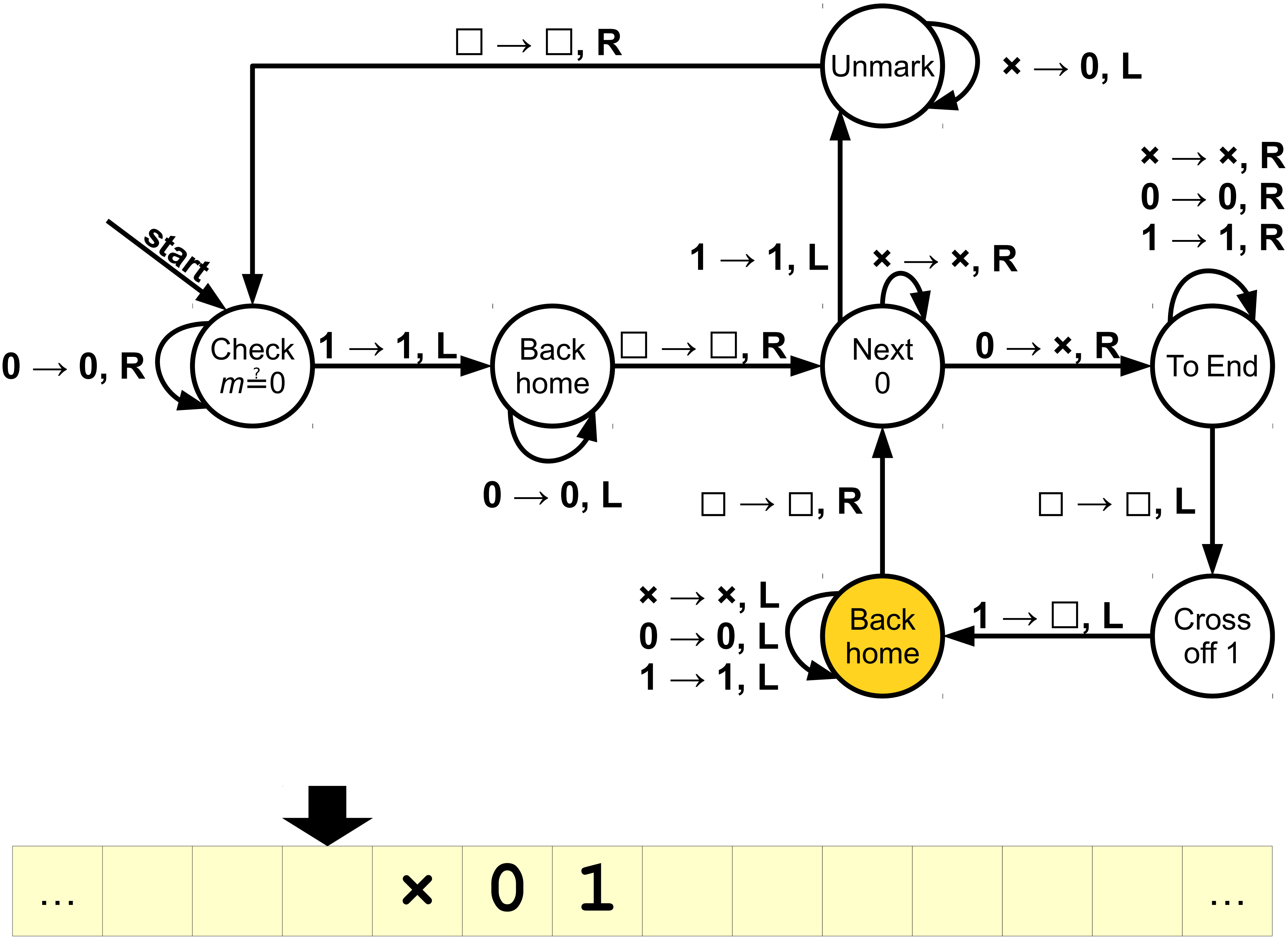

start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
0
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
start
1 → 1, L
× → ×, R
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1



…				×	0	1							…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
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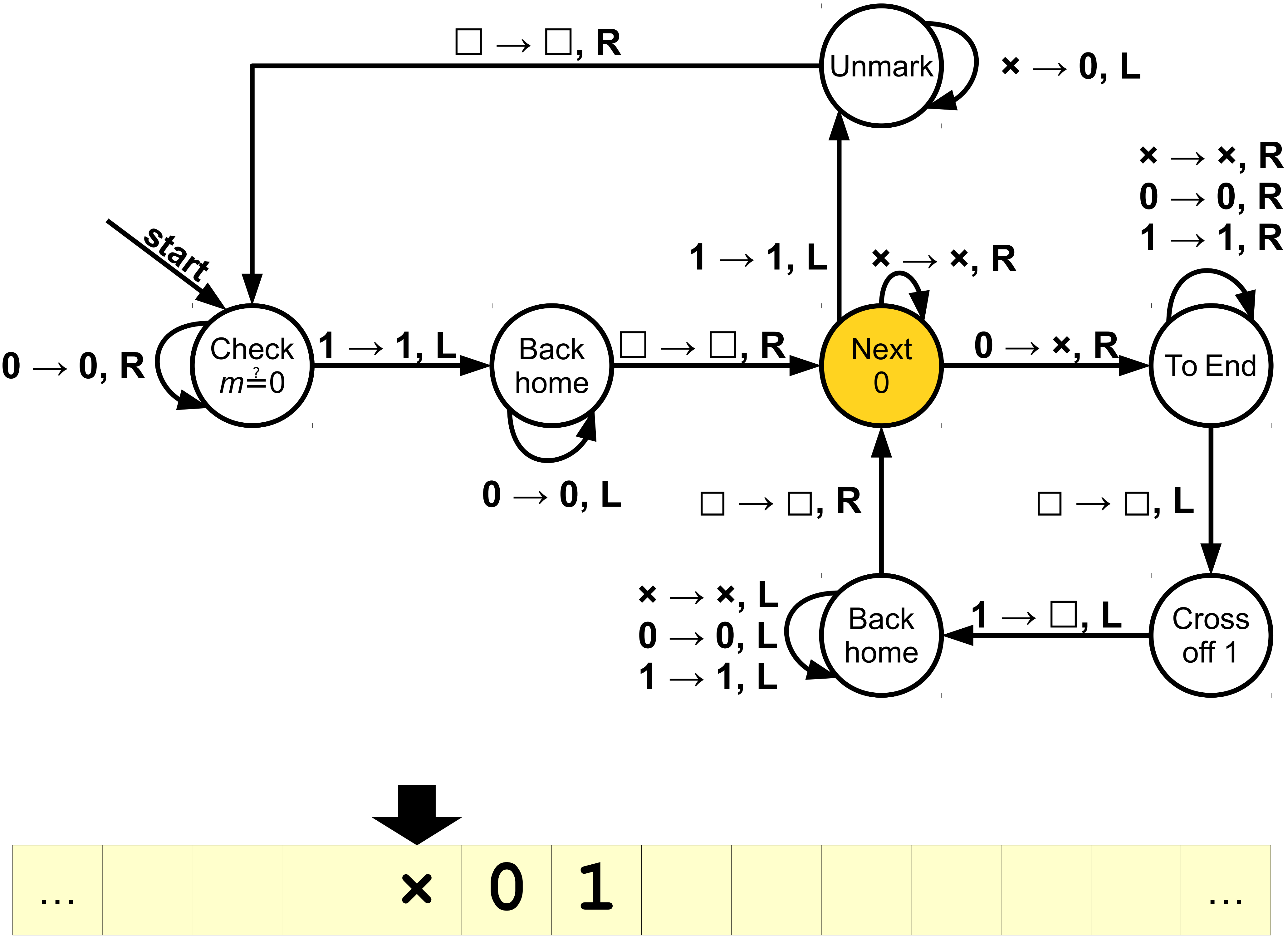
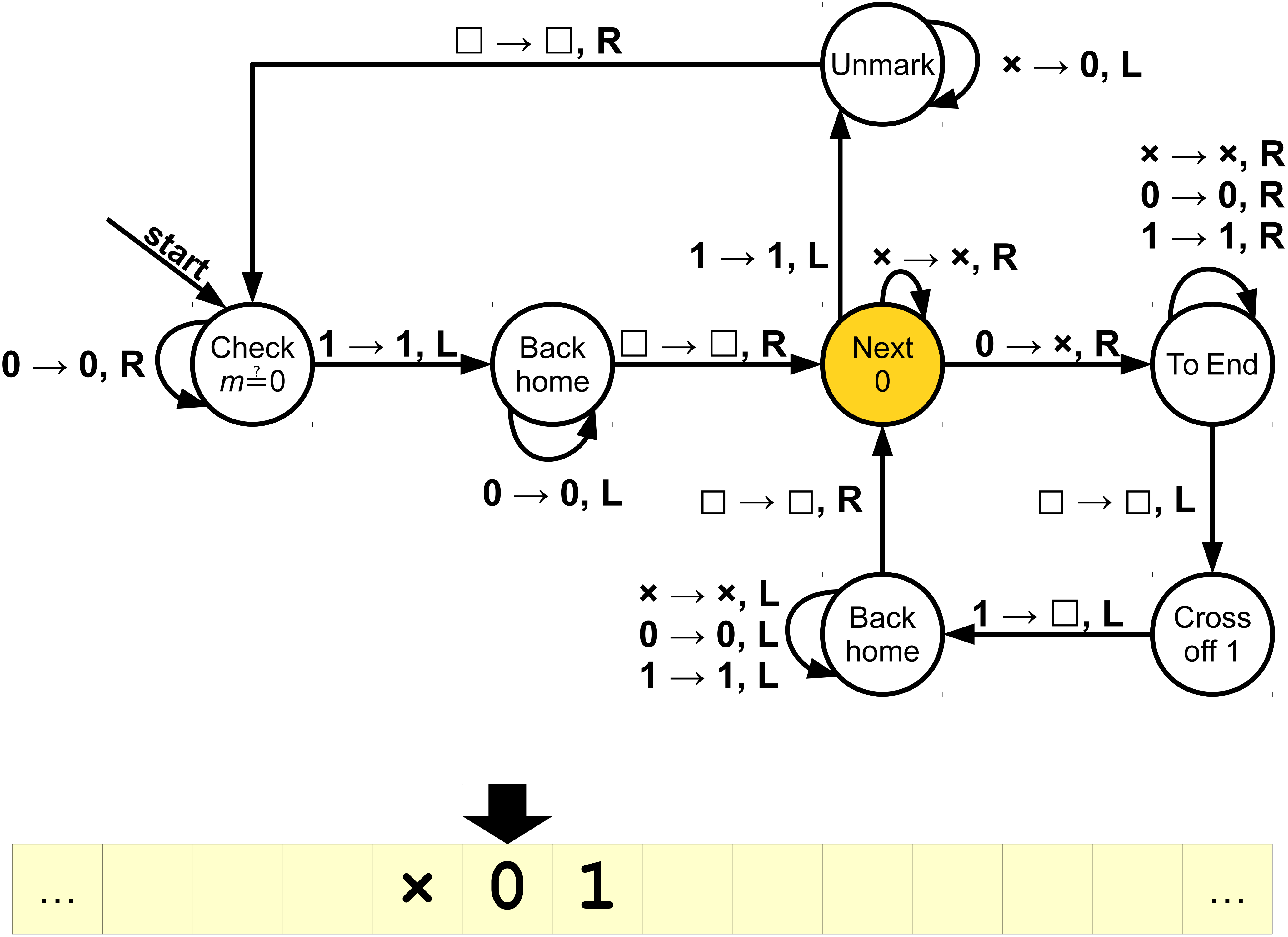
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
start
1 → 1, L
× → ×, R
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
…


□ → □, R
Unmark
× → 0, L
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
0 → 0, L
1 → 1, L
× → ×, R
Next
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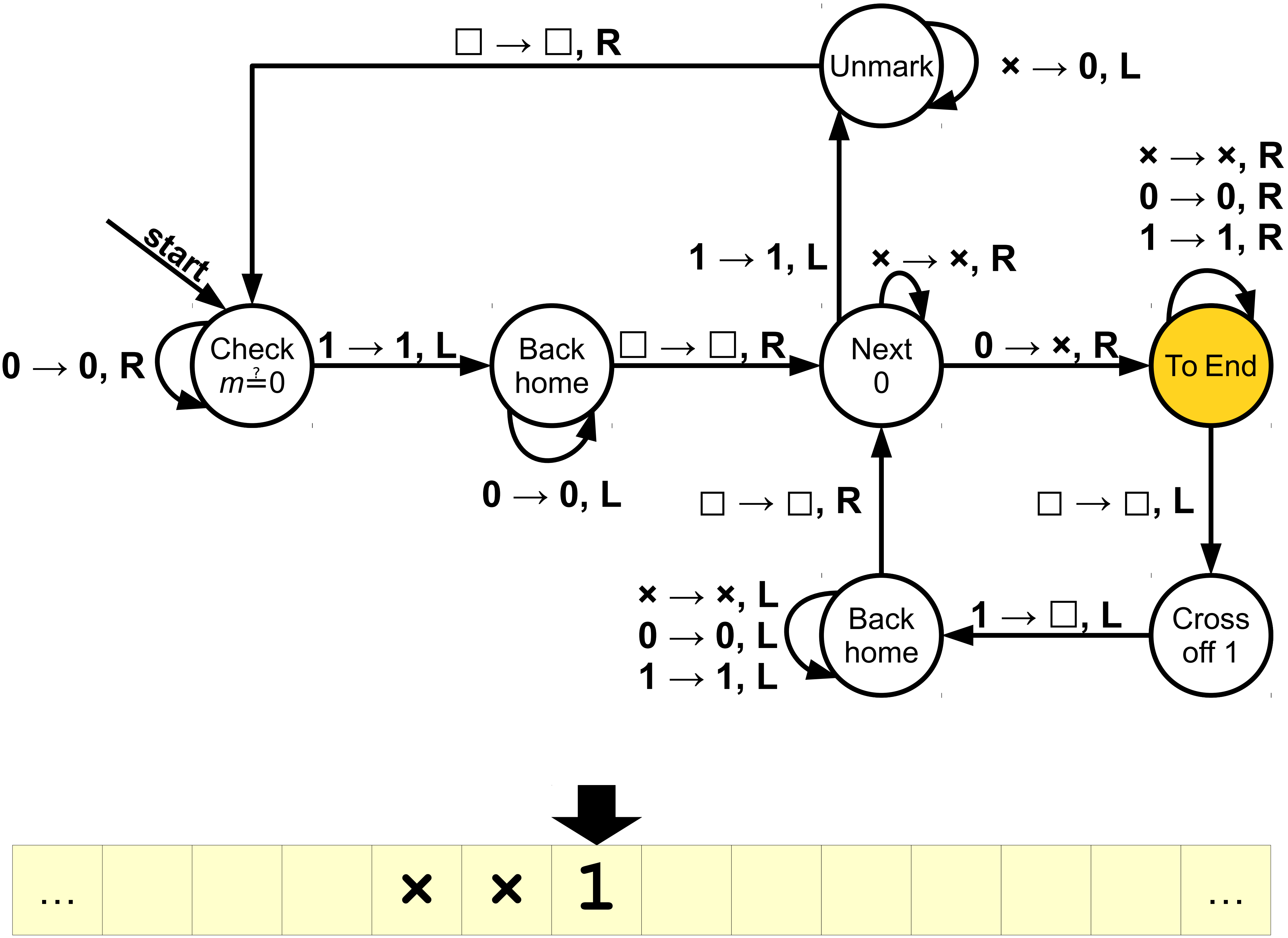
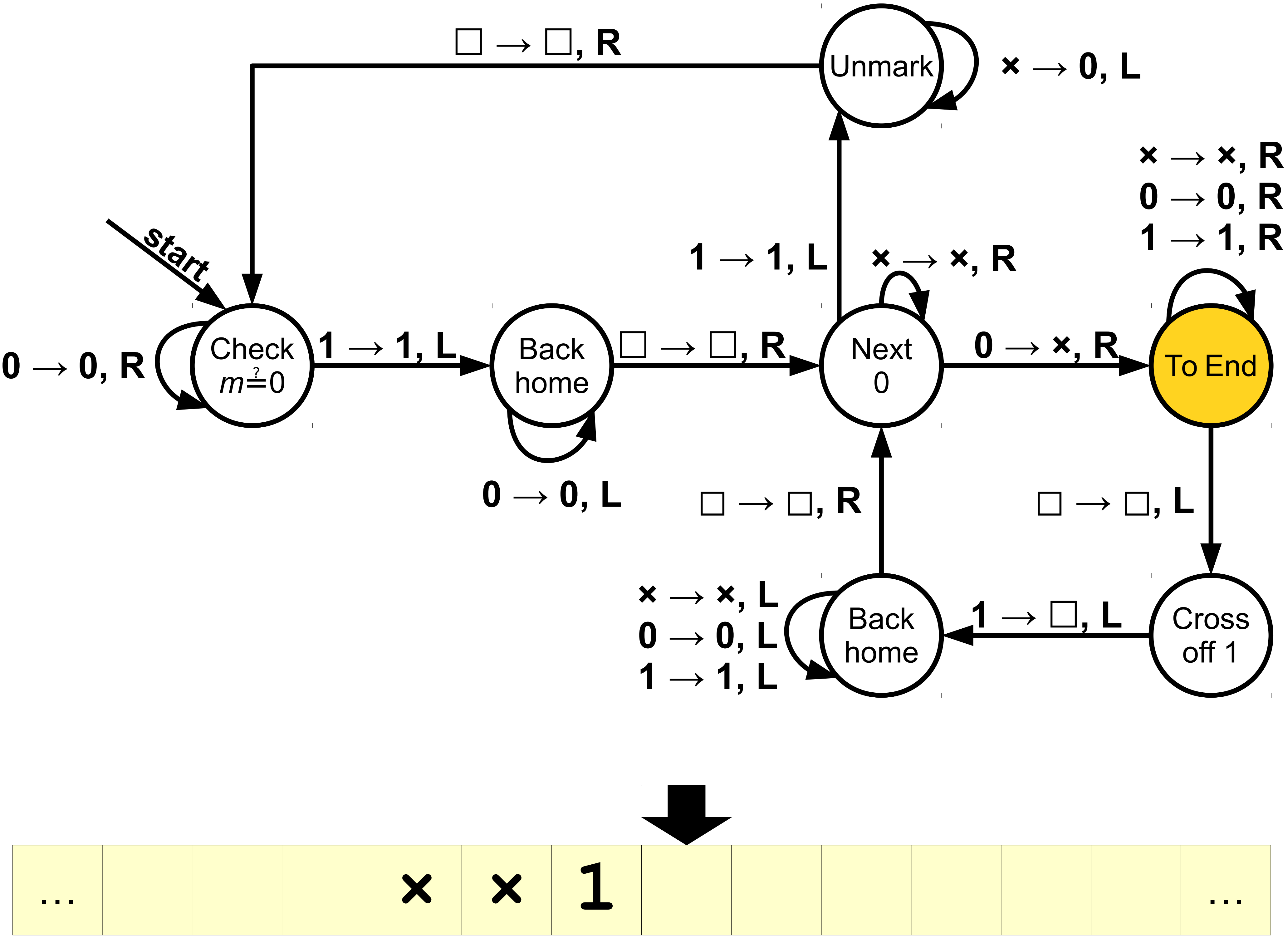
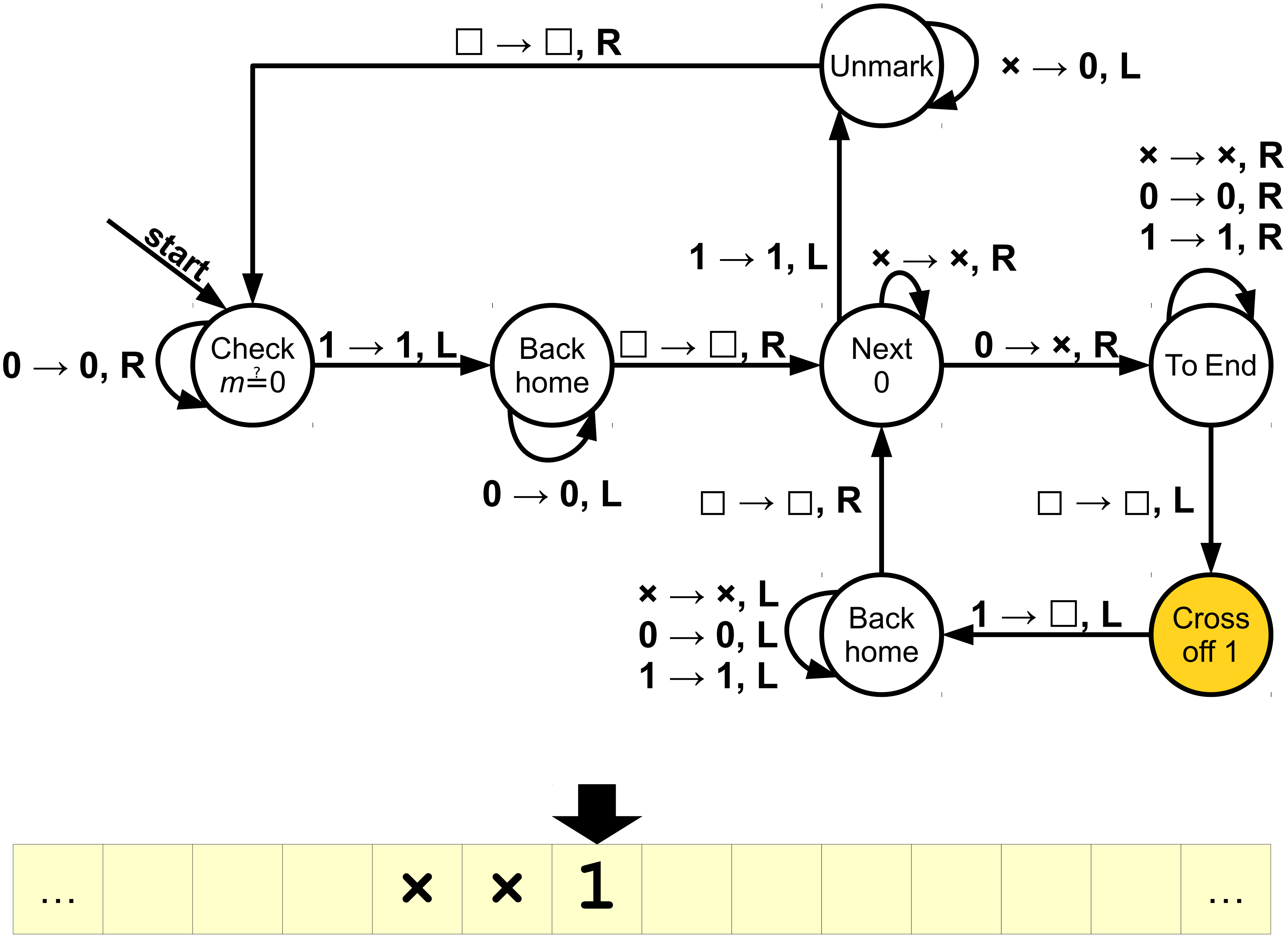
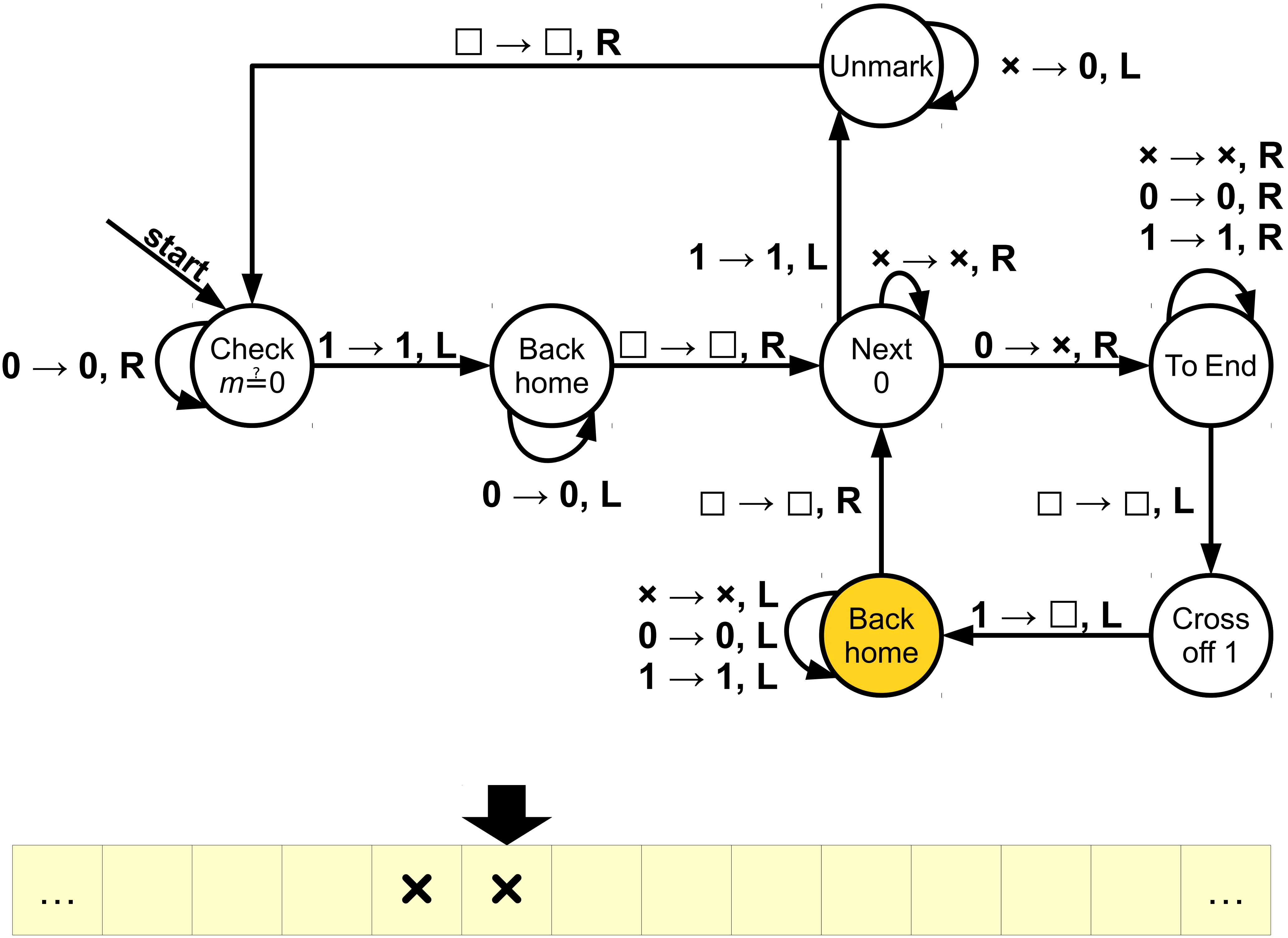
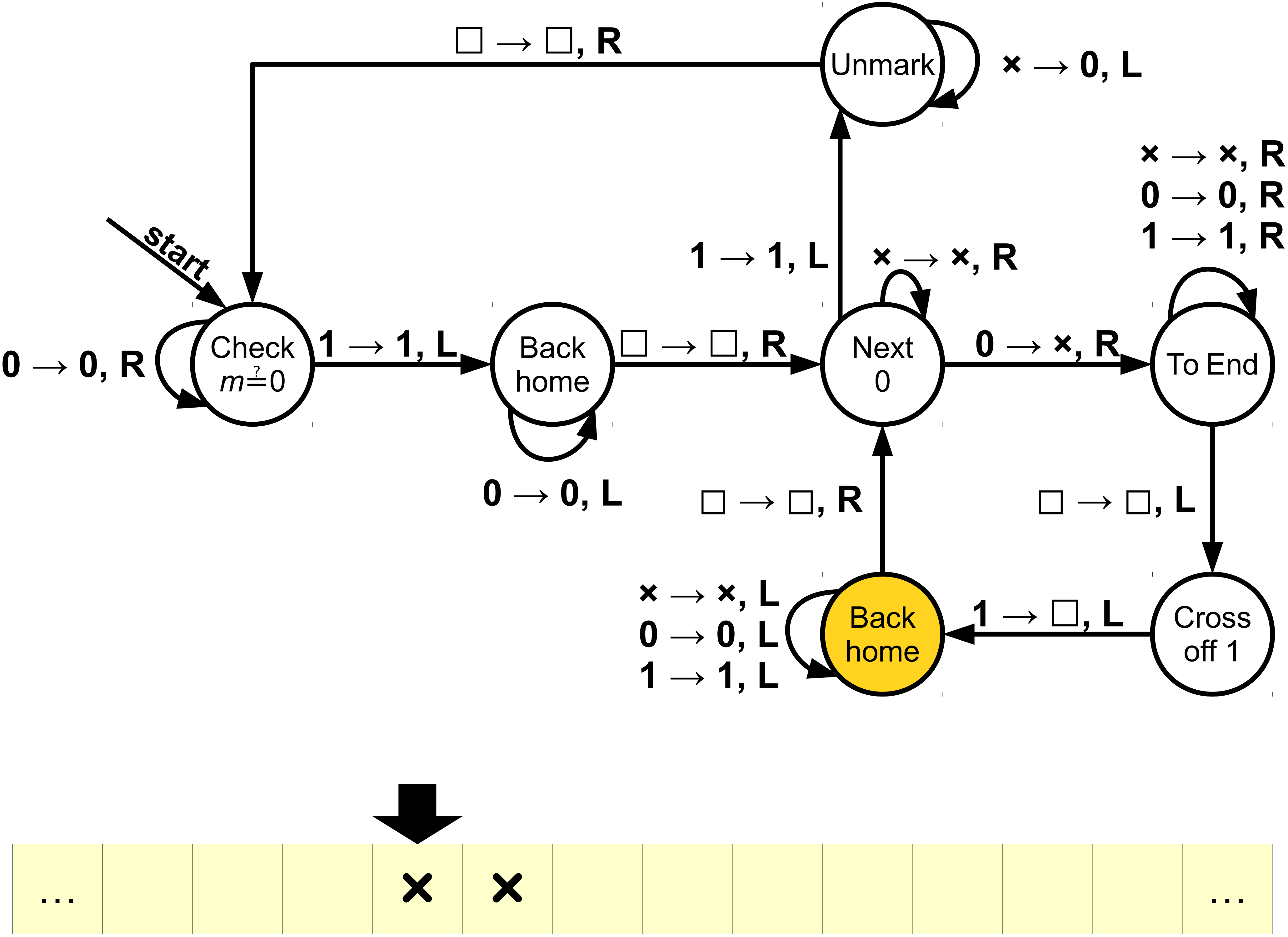
0 → ×, R
× → ×, R
0 → 0, R
1 → 1, R
To End
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
0
1
…

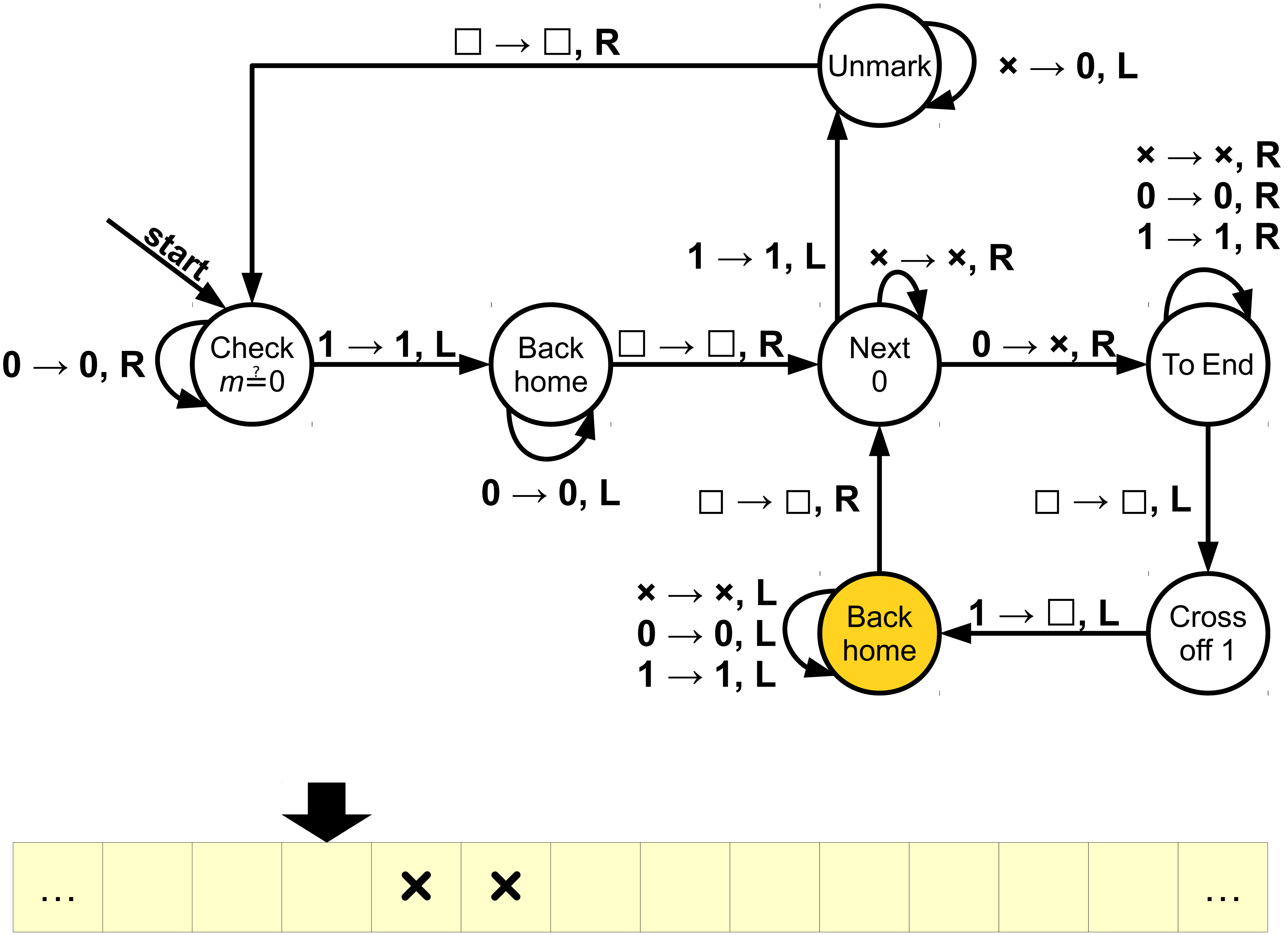

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
1
…

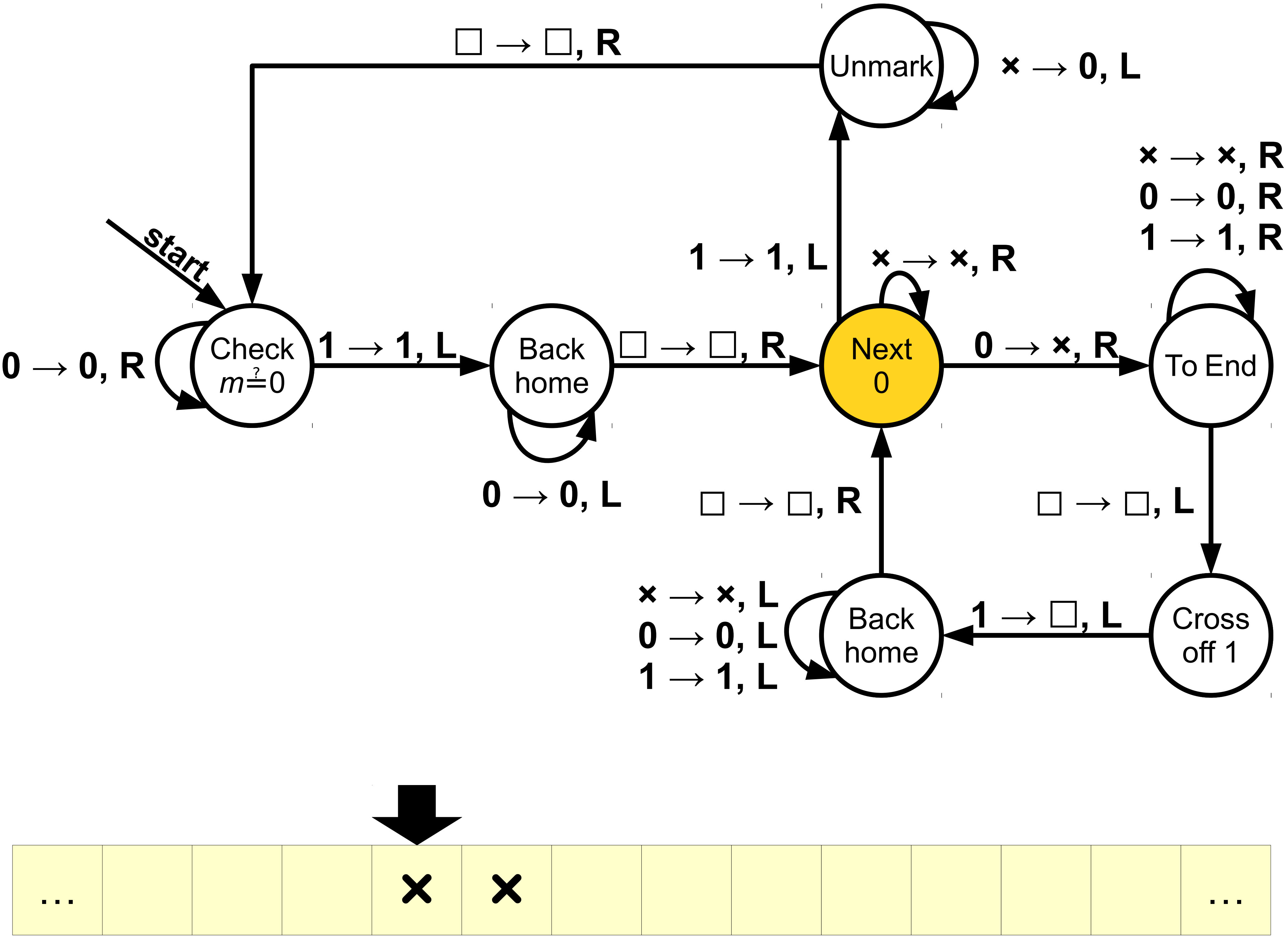

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
1
…

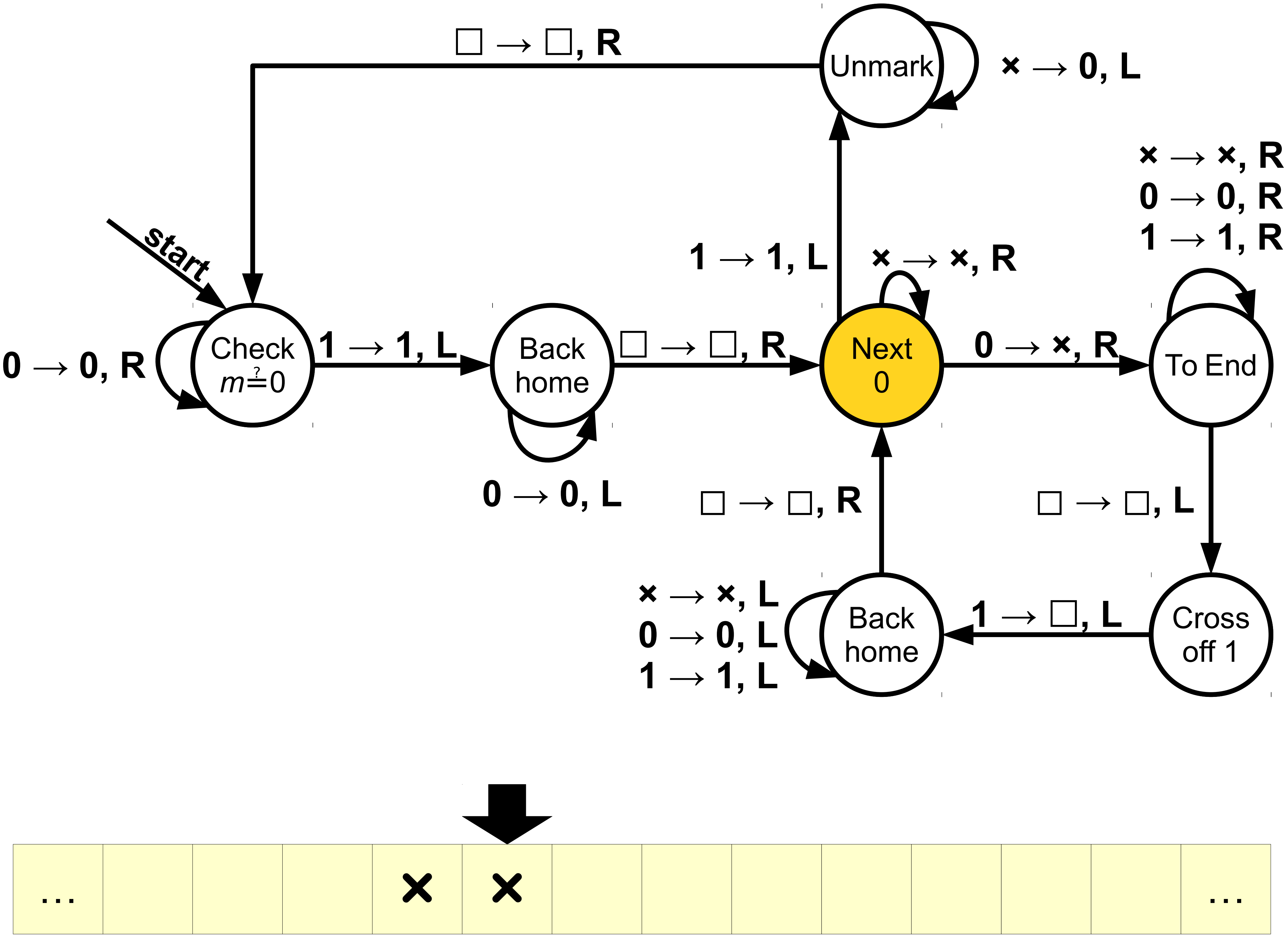

start
Check $m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
1
…

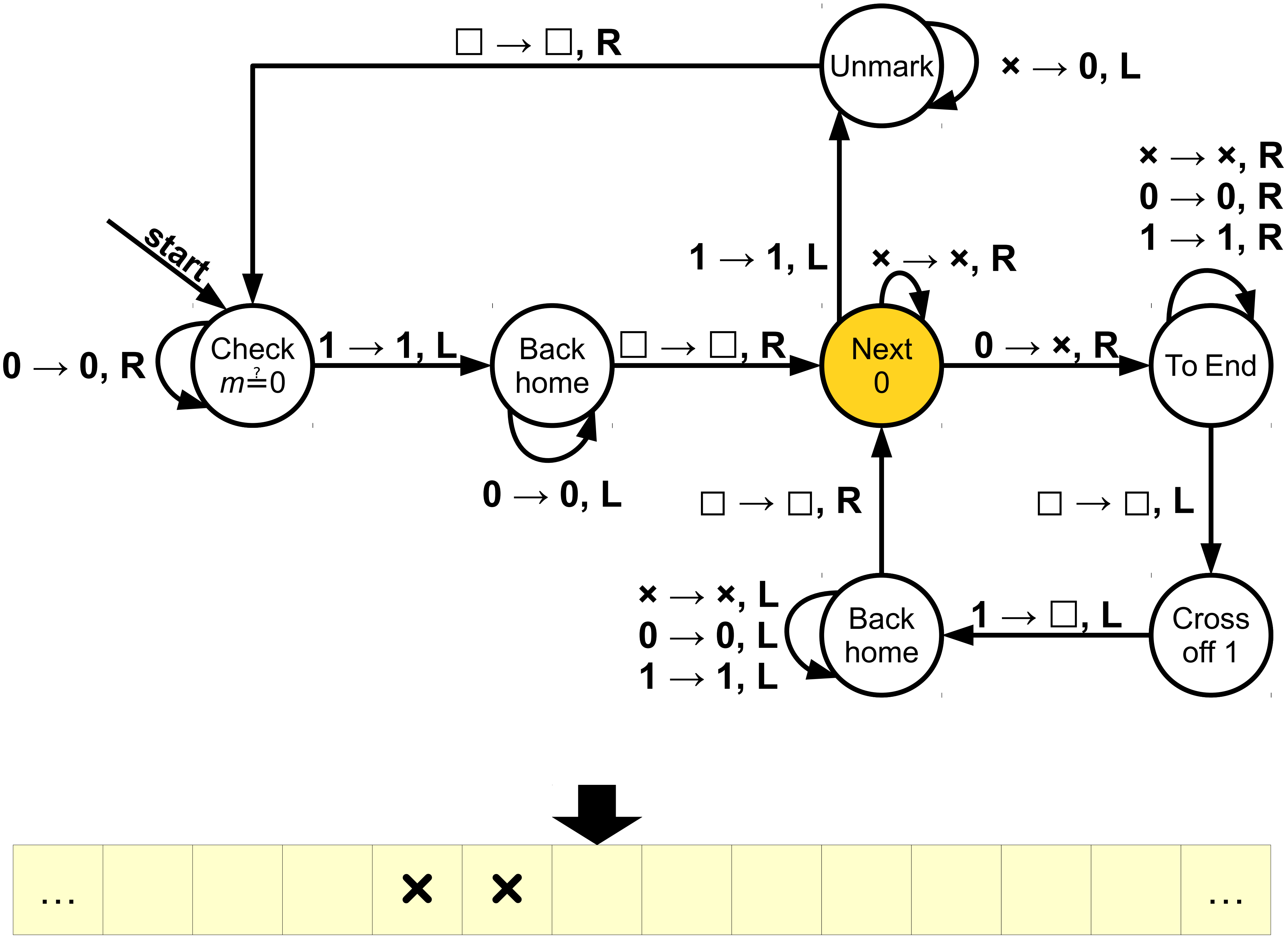

start
Check $m \stackrel{?}{=} 0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
1 → 1, L
× → ×, R
0 → ×, R
Unmark
× → 0, L
□ → □, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
…

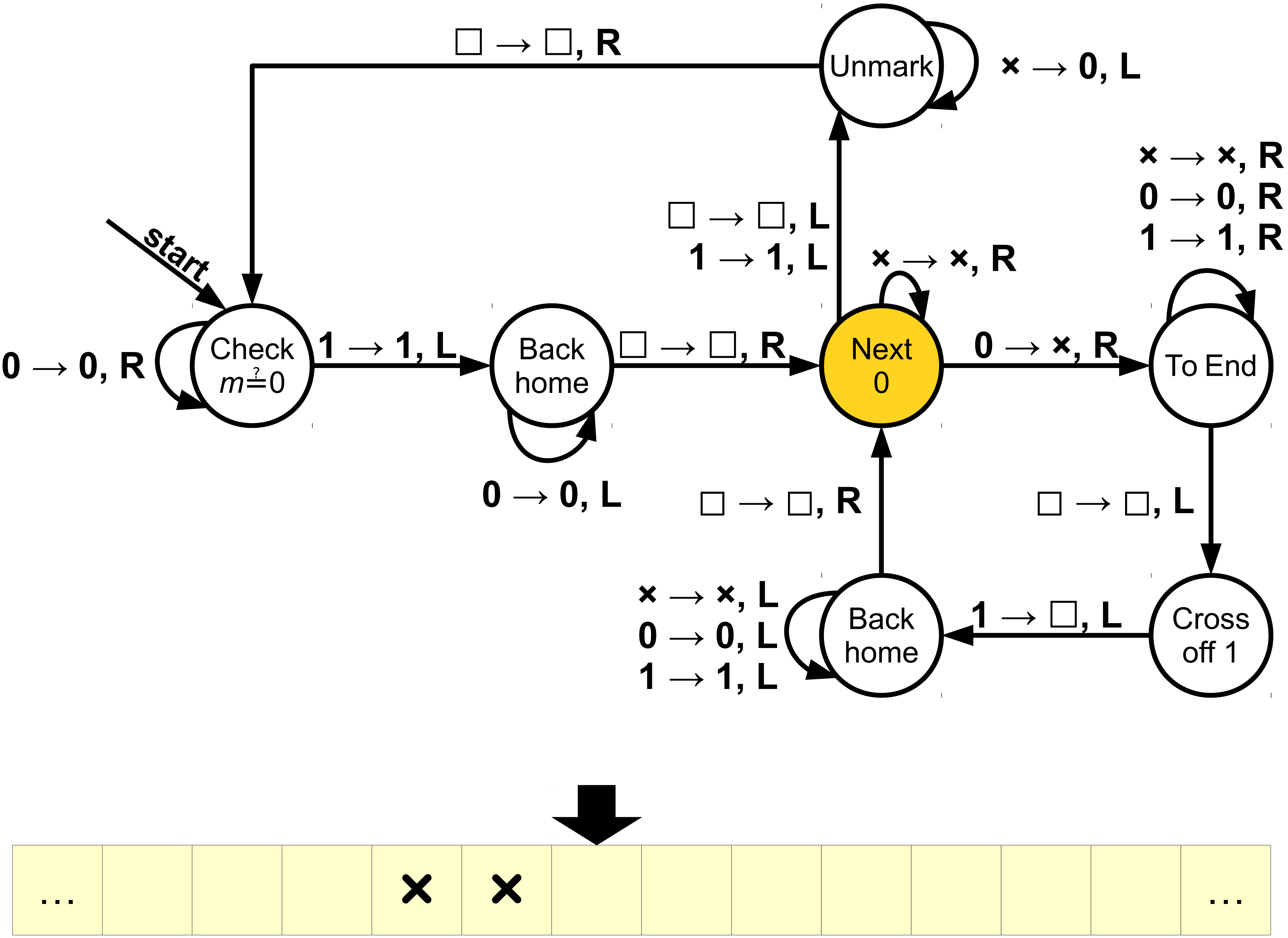

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
…

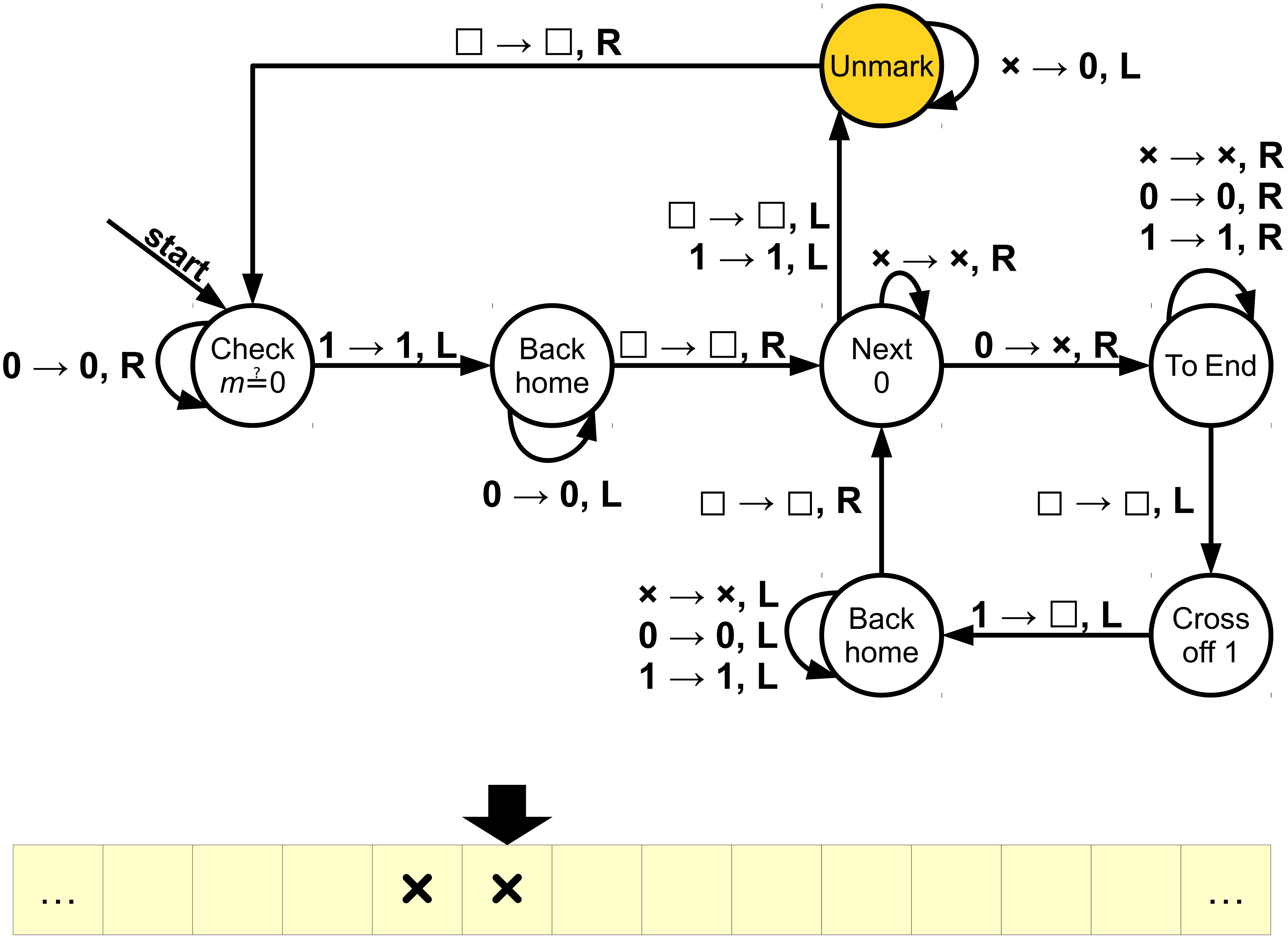

start
Check $m\overset{?}{=}0$
0 → 0, R
1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
…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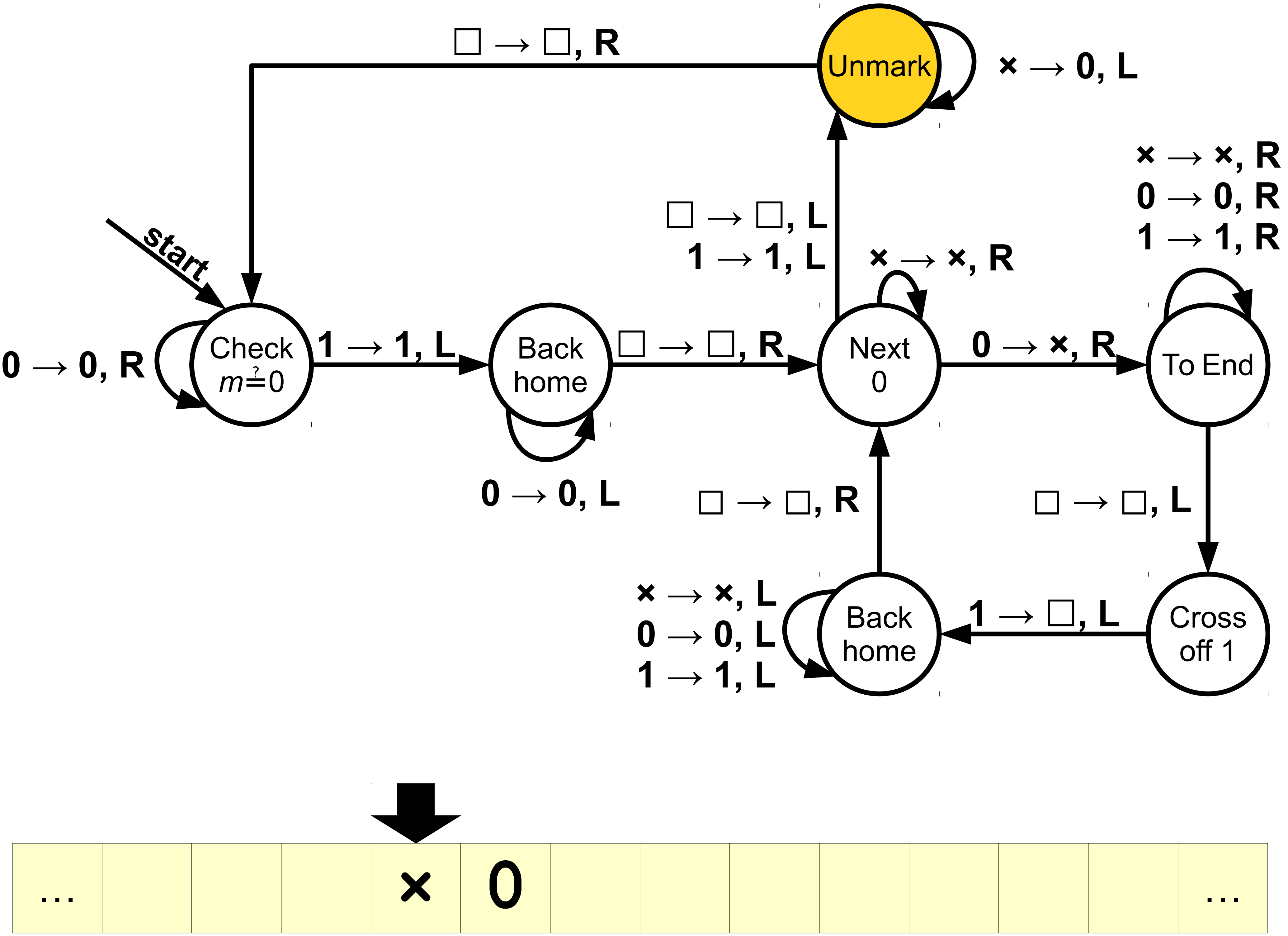
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m≟0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
…
×
×
…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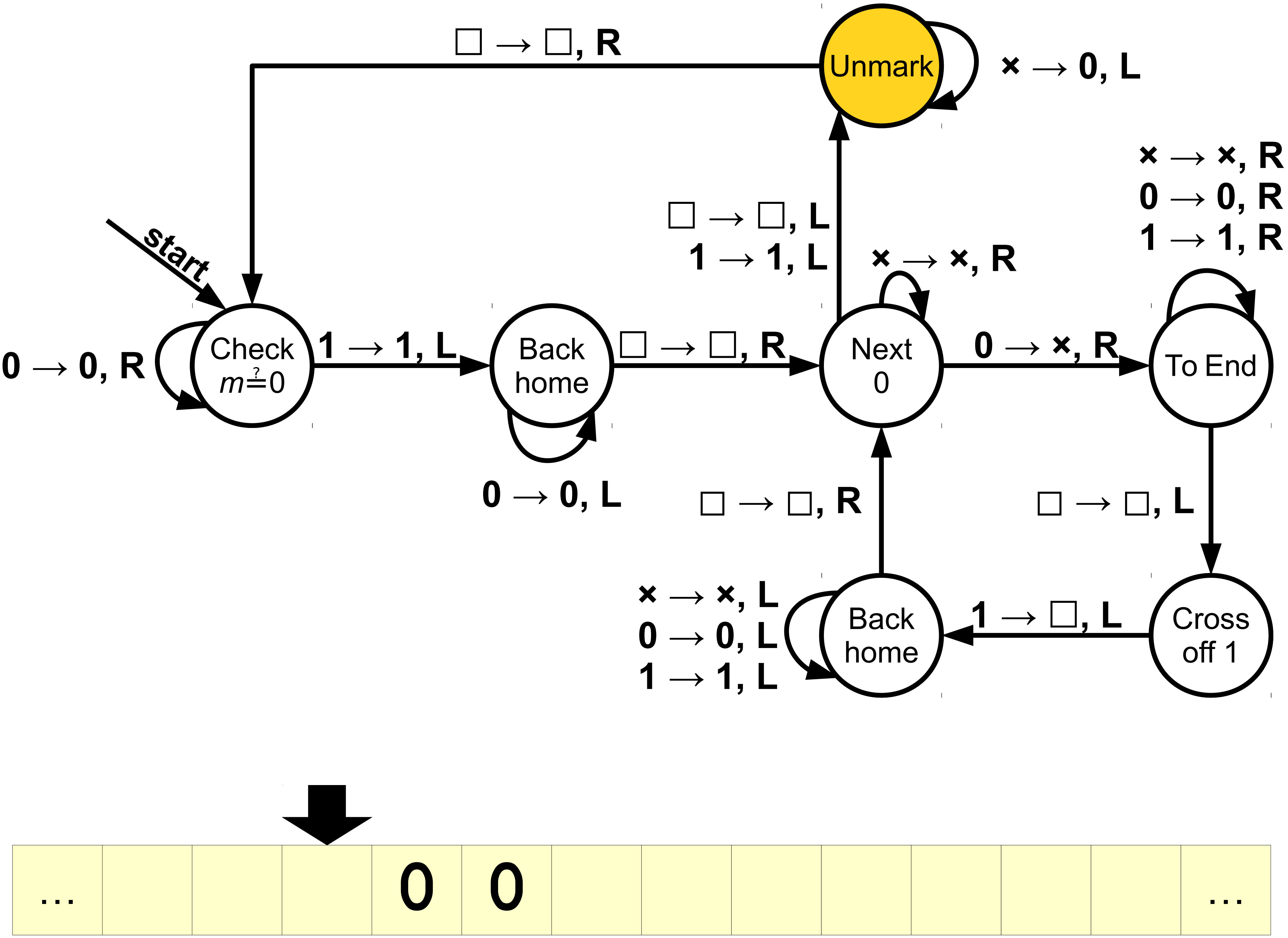
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1

…				×	0								…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× → ×, R
0 → 0, R
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1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \stackrel{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
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0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
× → ×, L
0 → 0, L
1 → 1, L
Back
home
1 → □, L
Cross
off 1
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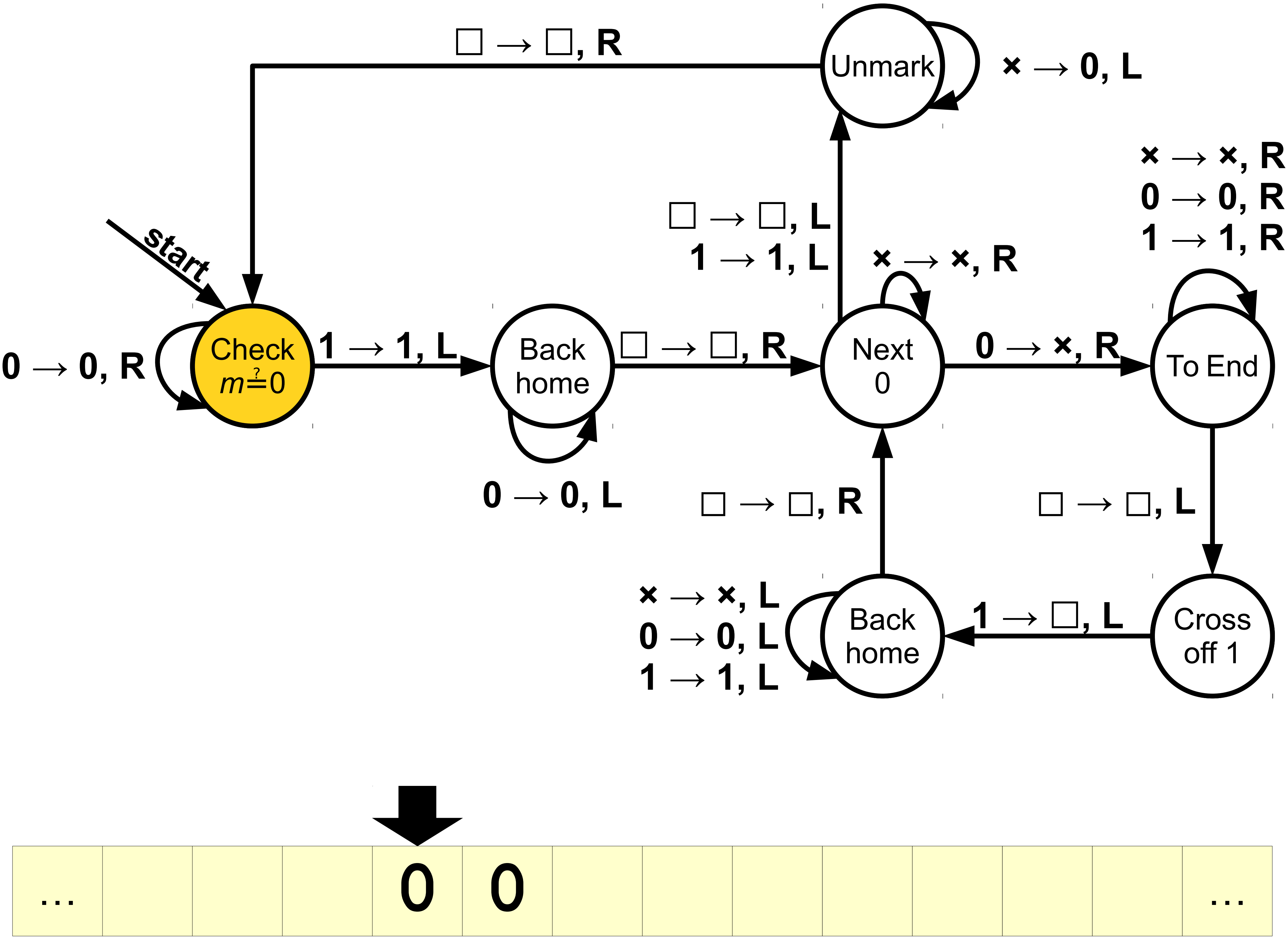
start
Check
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1 → 1, L
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
□ → □, L
1 → 1, L
Unmark
× → 0, L
□ → □, R
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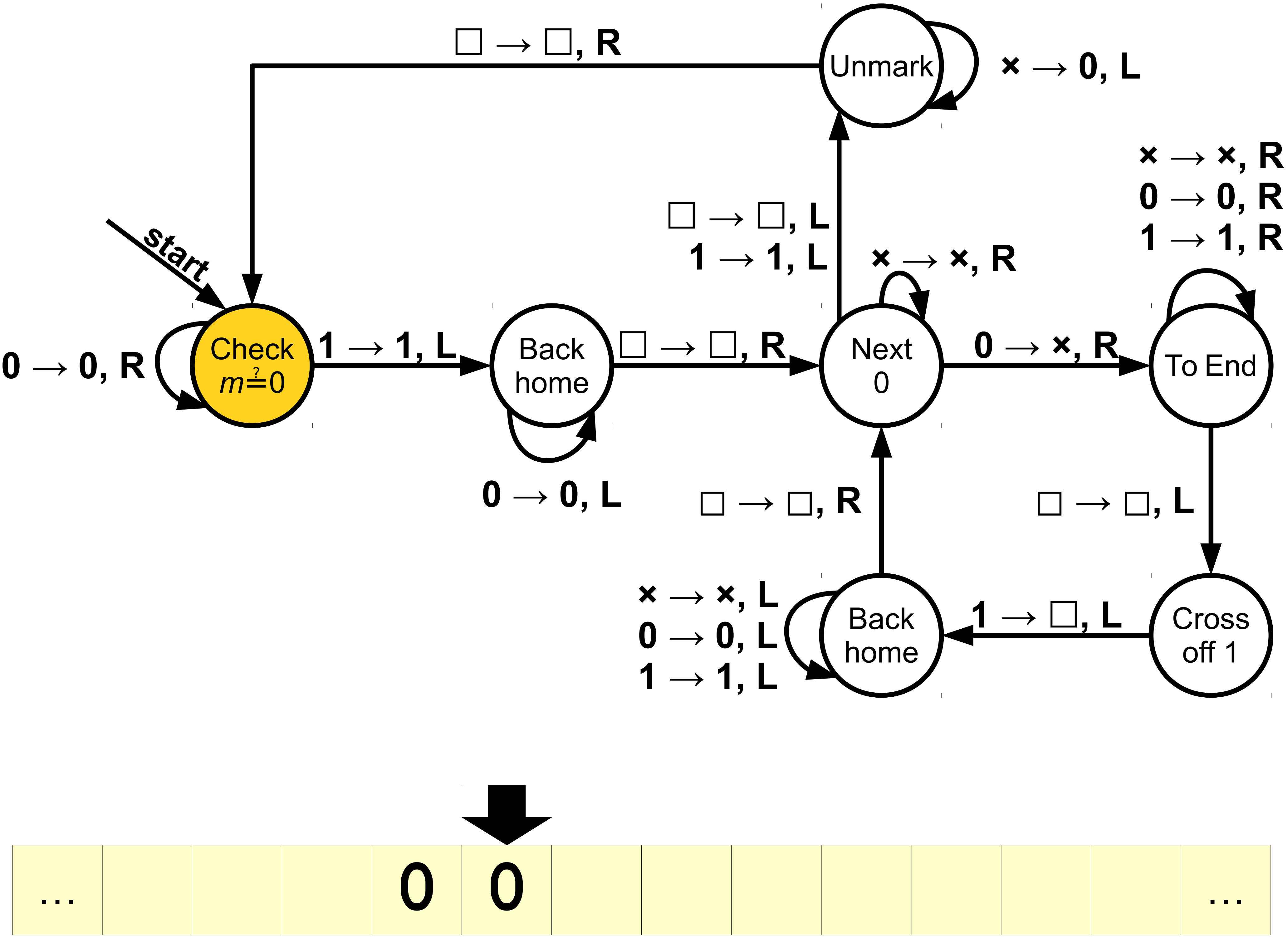
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Unmark
× → 0, L
× → ×, R
0 → 0, R
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1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
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Cross
off 1
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0
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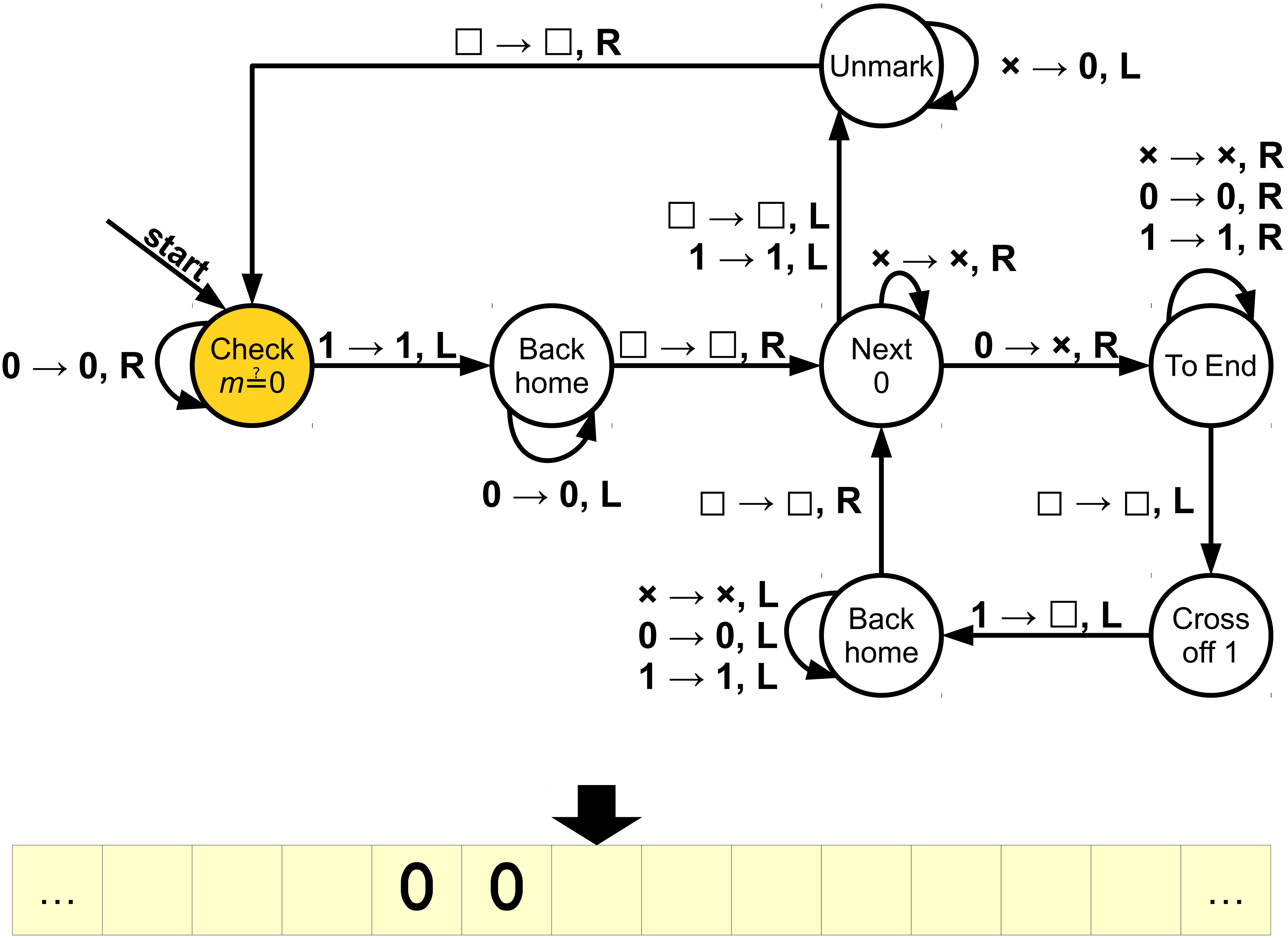
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start
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× → ×, R
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1 → 1, R
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
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Back
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Cross
off 1
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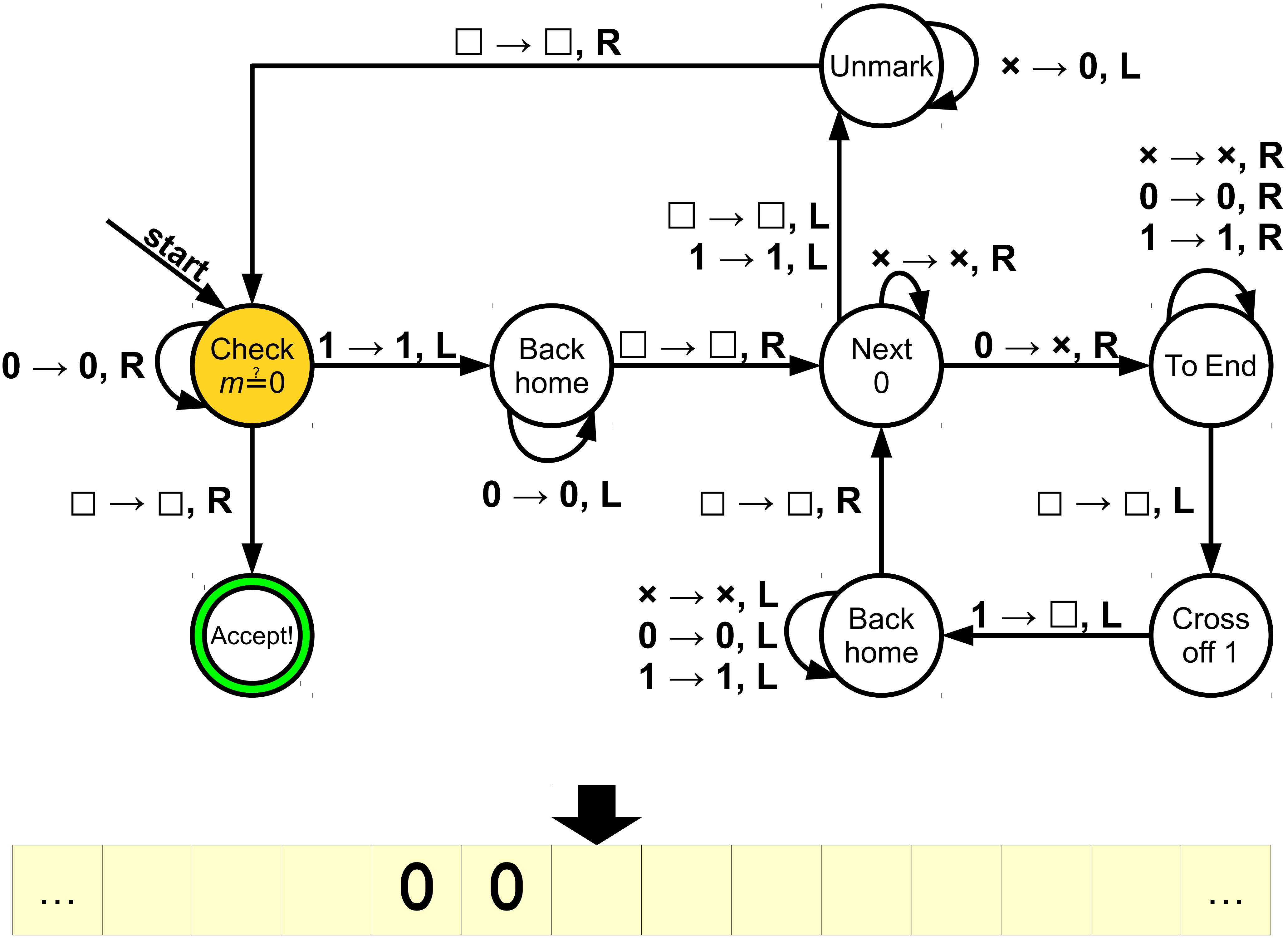
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Unmark
× → 0, L
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1 → 1, L
× → ×, R
start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back
home
□ → □, R
Next
0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, R
□ → □, L
Accept!
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1 → 1, L
Back
home
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Cross
off 1
…
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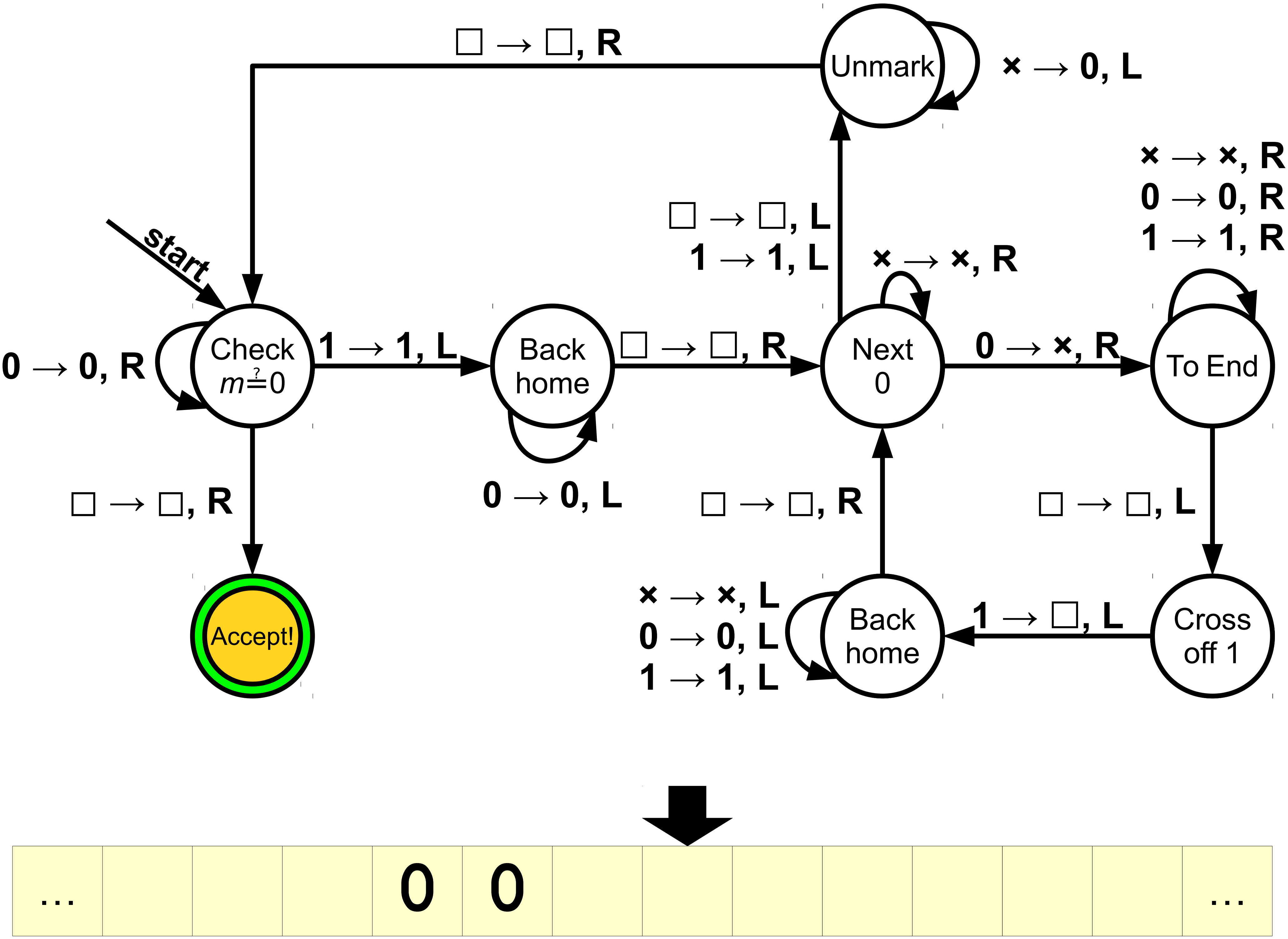
start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
□ → □, R
Accept!
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
□ → □, L
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
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Back home
× → ×, L
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1 → 1, L
□ → □, R
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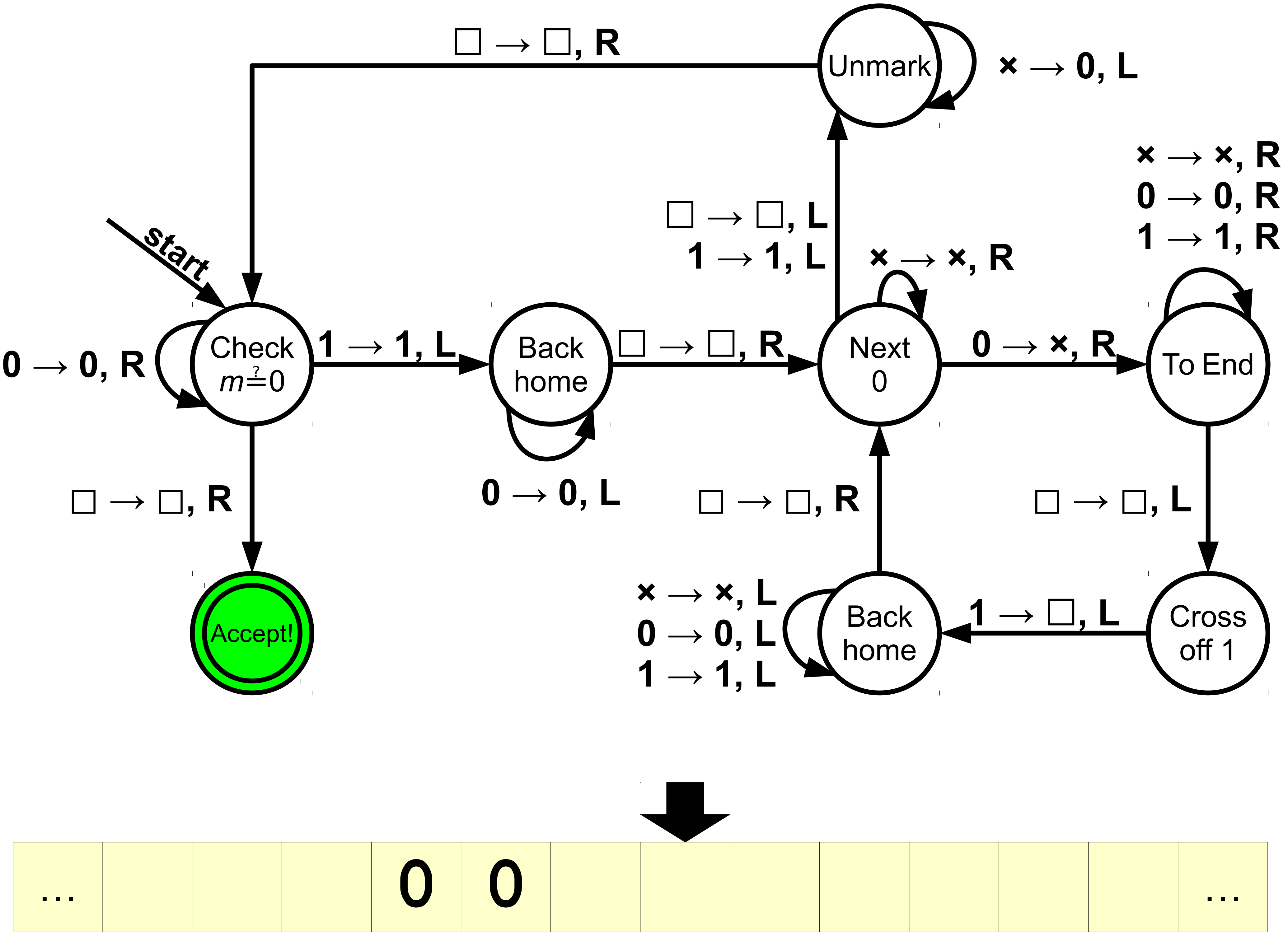
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0 → 0, R
Check
m ≟ 0
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Back home
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Next 0
0 → ×, R
To End
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□ → □, R
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Cross off 1
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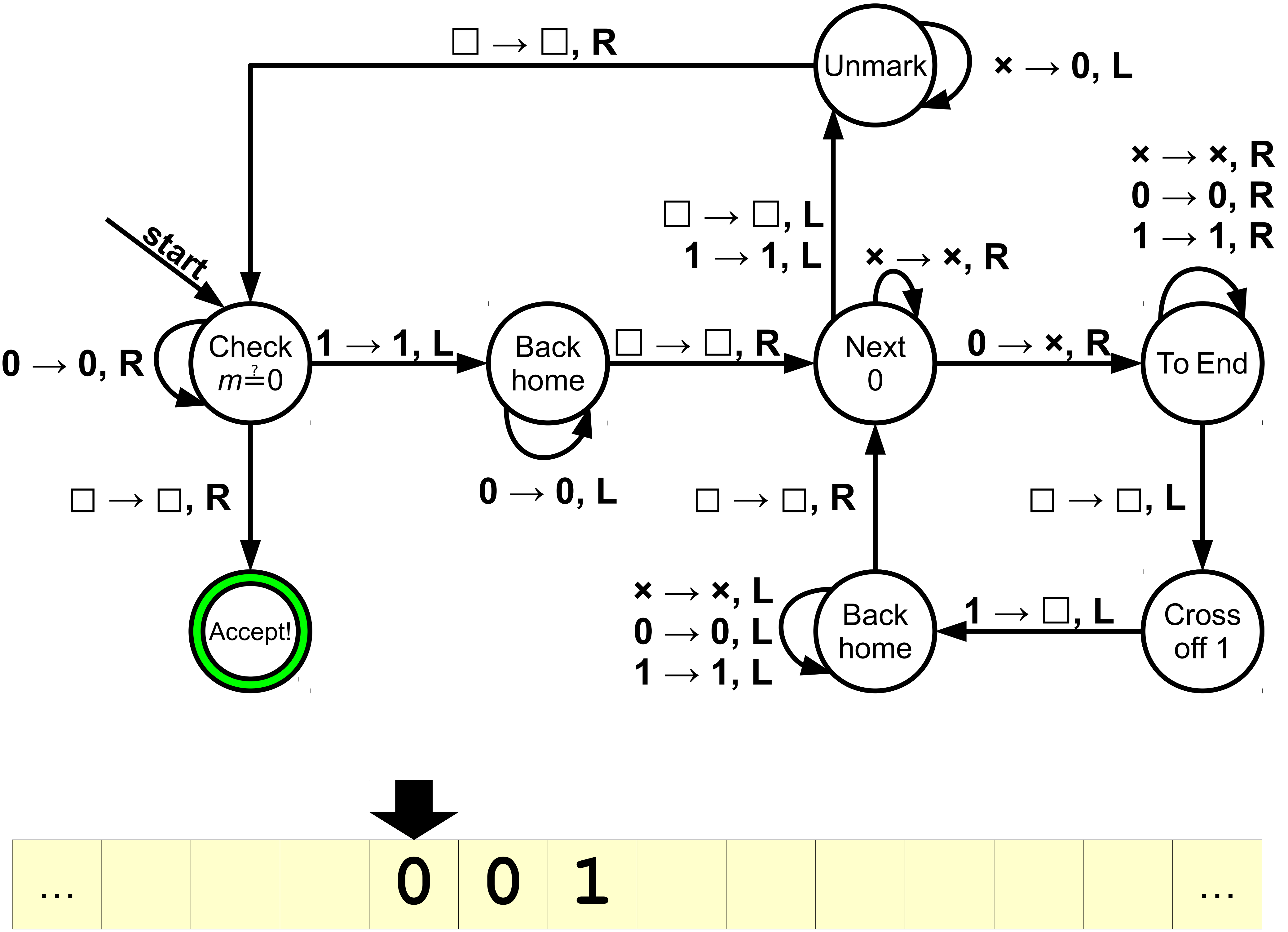
start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
□ → □, R
Accept!
Back home
0 → 0, L
□ → □, R
Next 0
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× → 0, L
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× → ×, R
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1 → 1, R
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Back home
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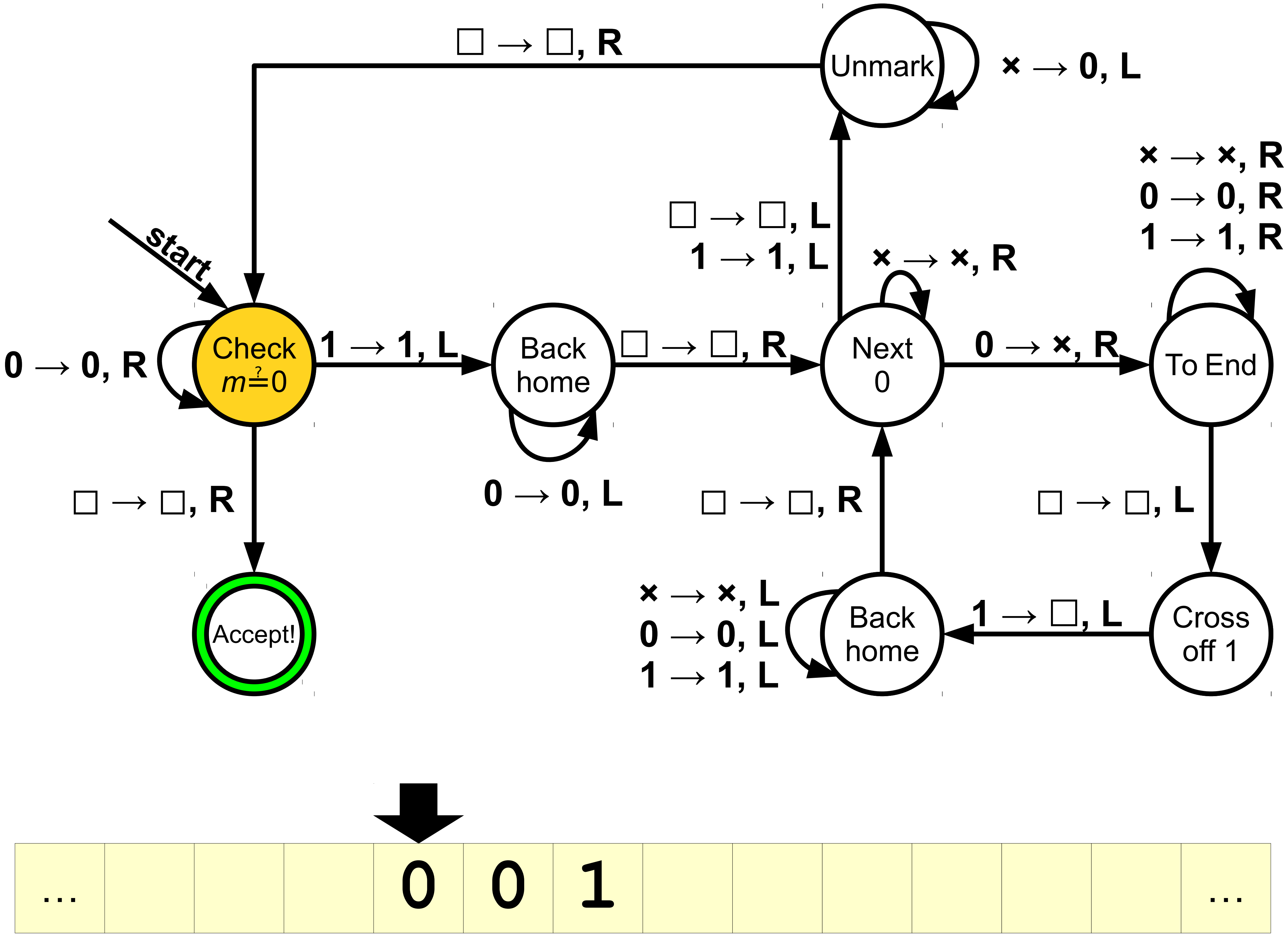
□ → □, R
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0 → 0, R
Check
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1 → 1, L
Back home
□ → □, R
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0 → ×, R
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Accept!
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Back home
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Cross off 1
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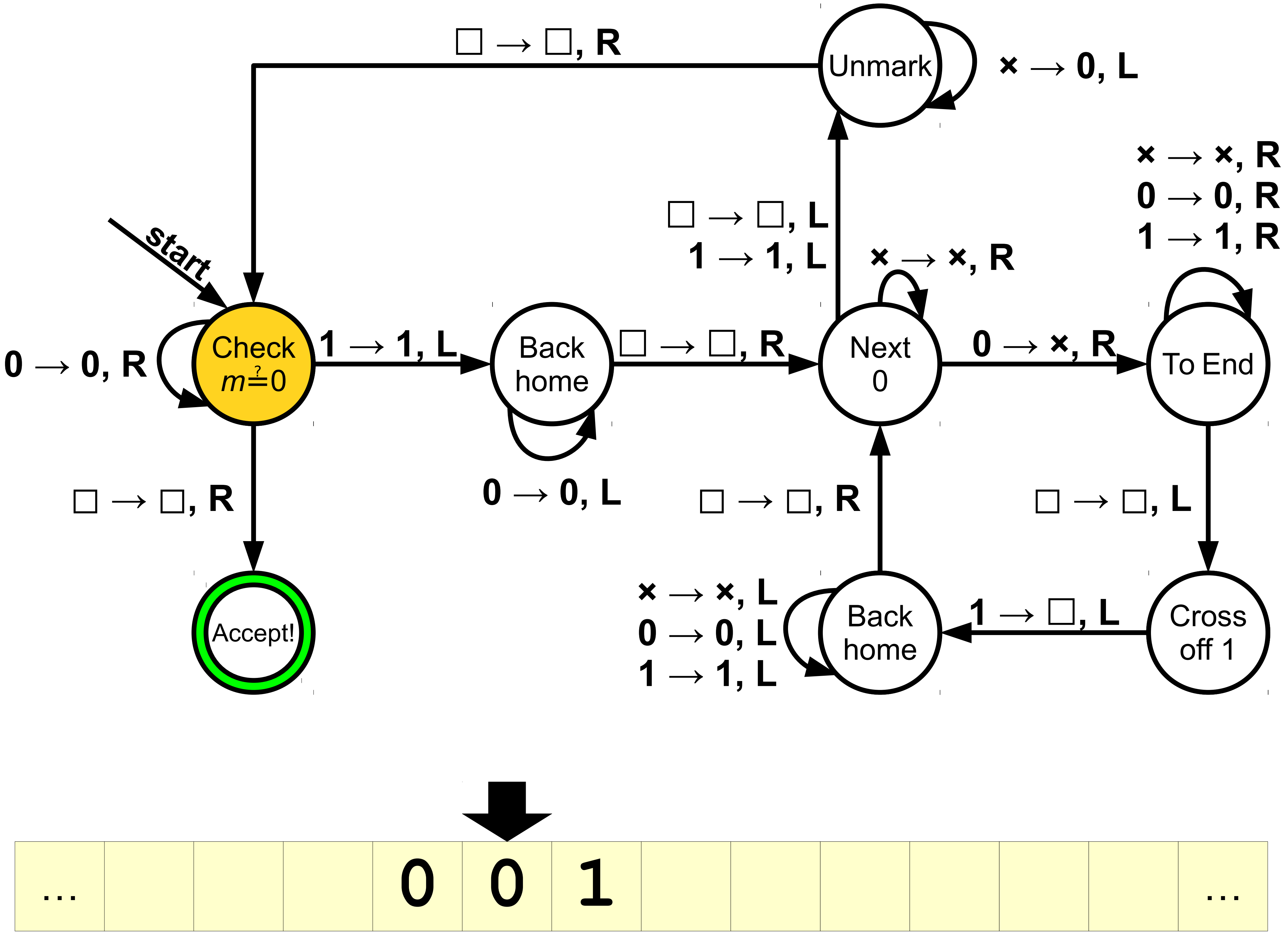
start
Check $m\overset{?}{=}0$
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Accept!
Back home
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□ → □, L
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× → 0, L
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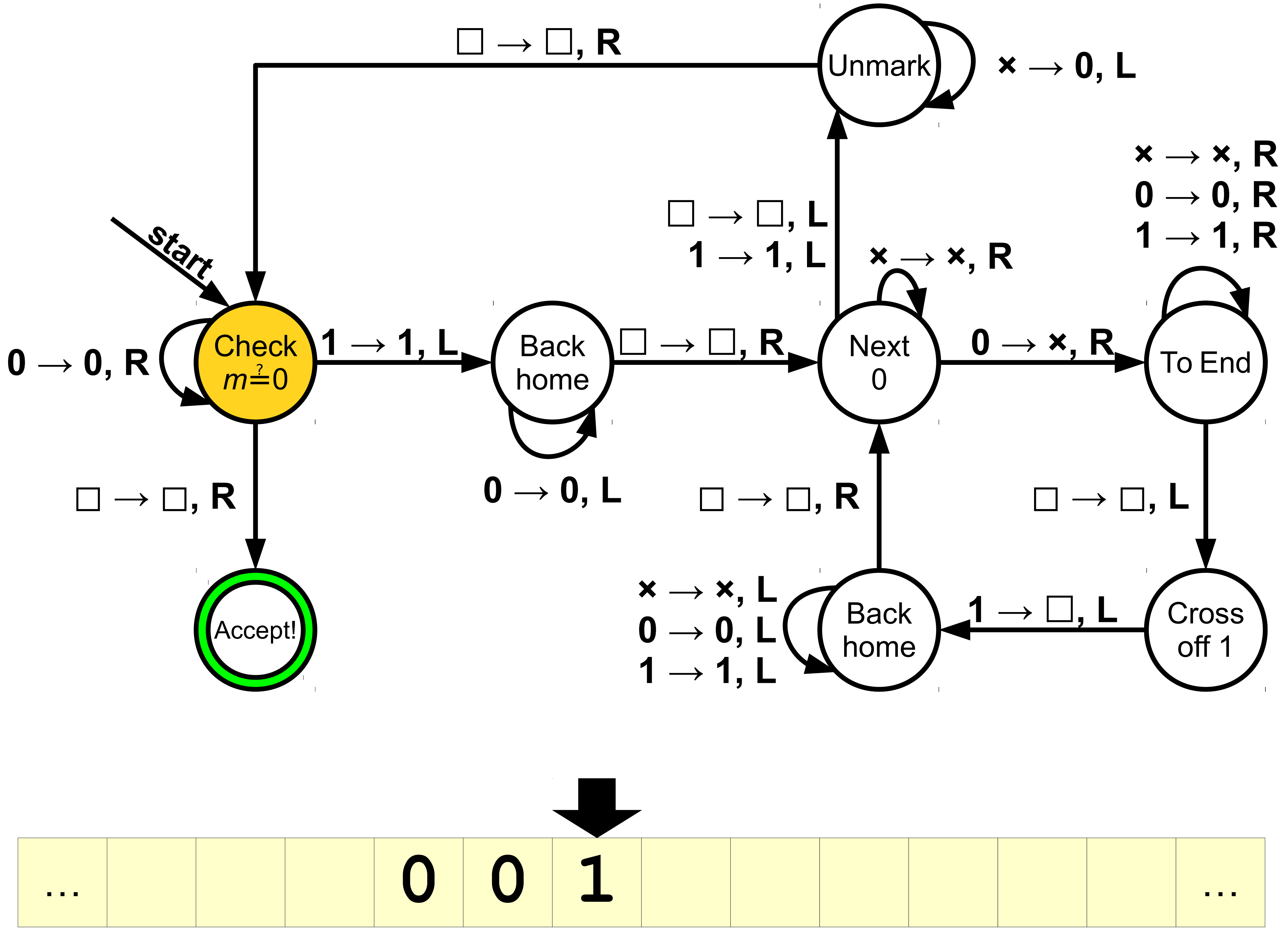
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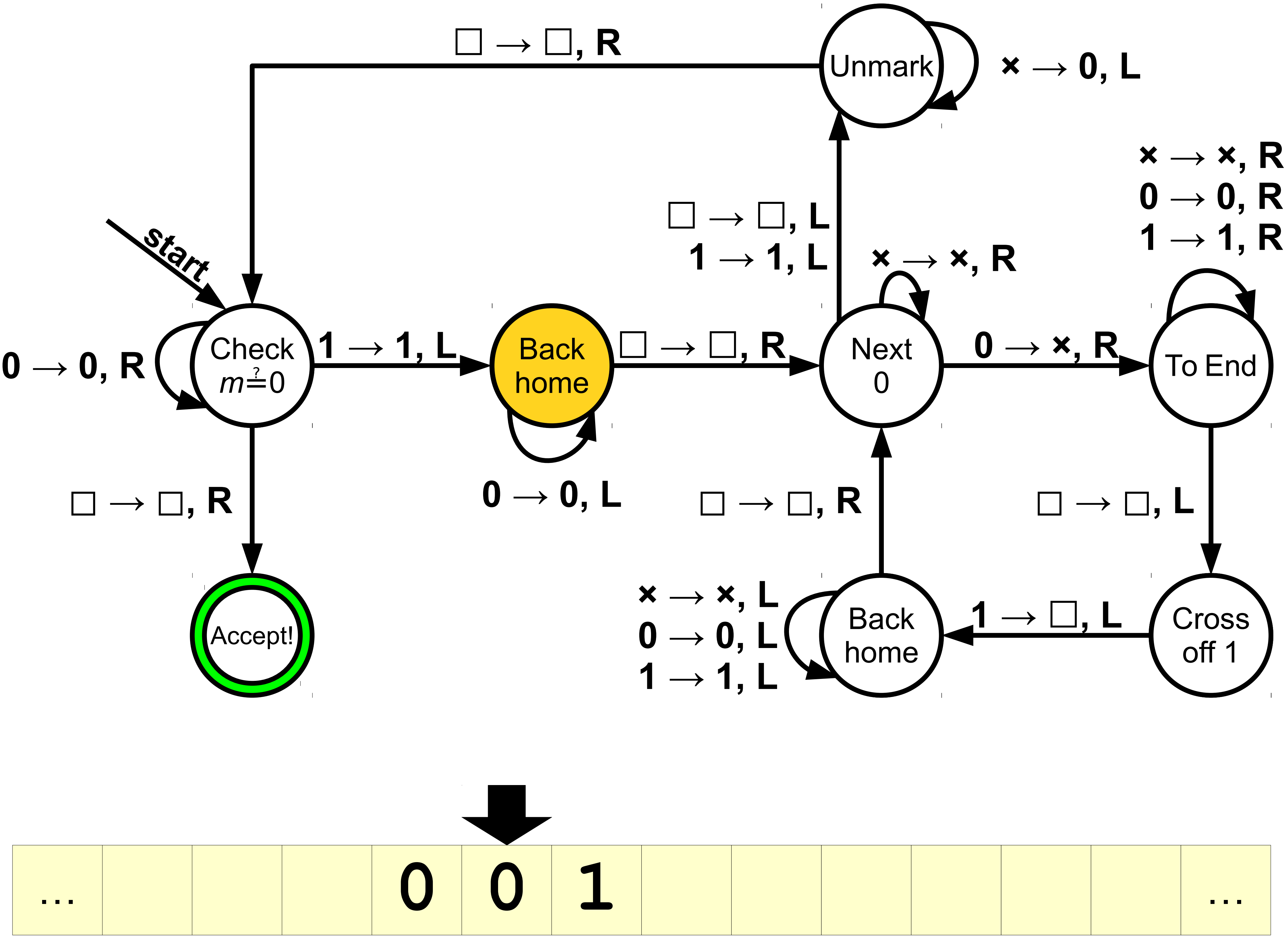
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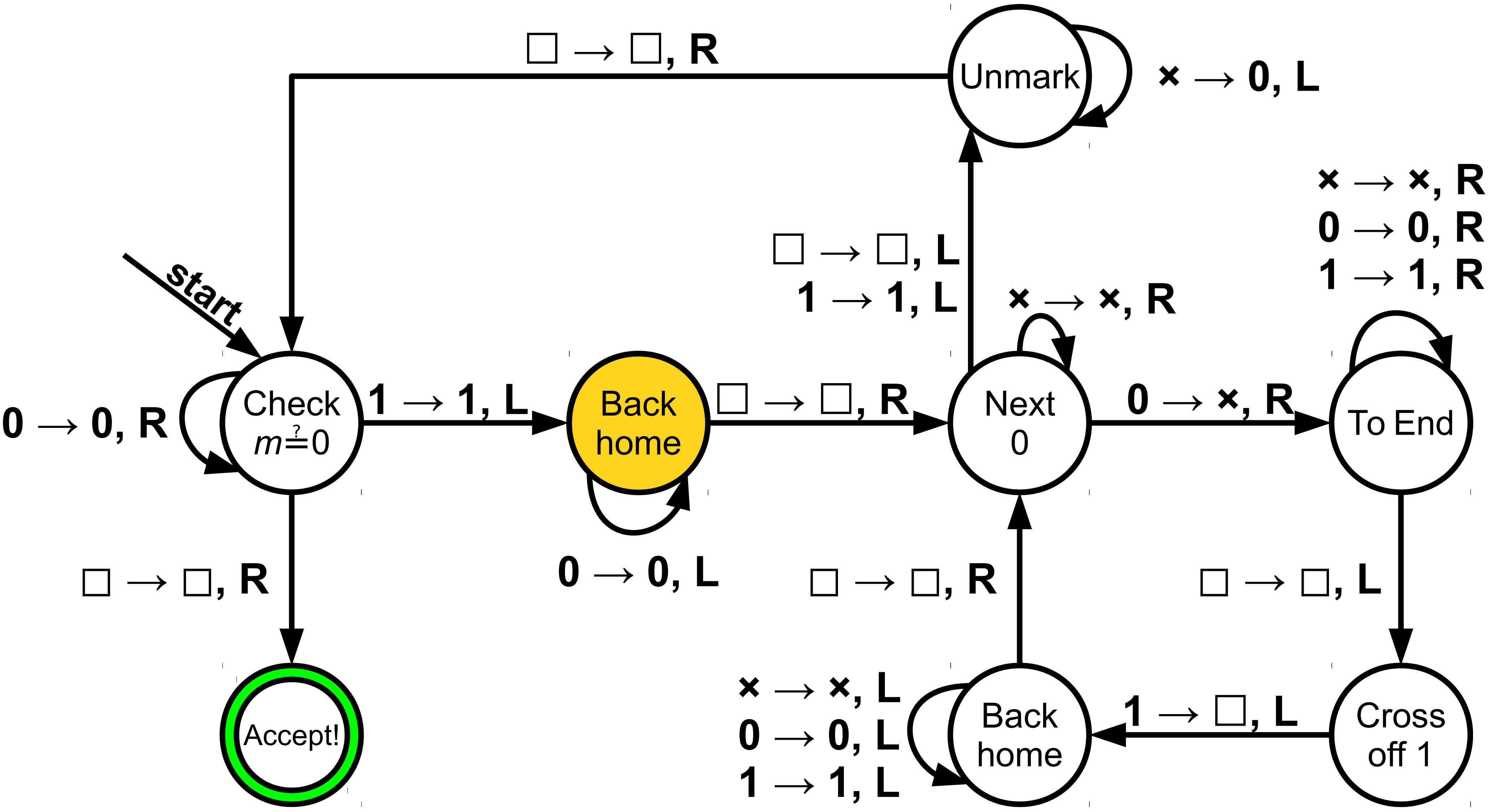
□ → □, R
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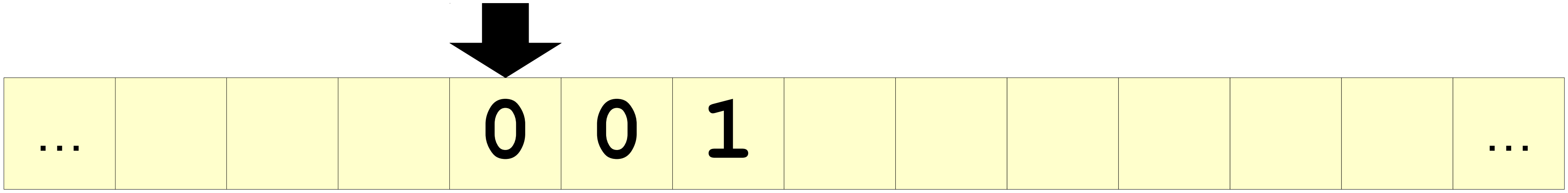
Back
home
1 → □, L
Cross
off 1
Accept!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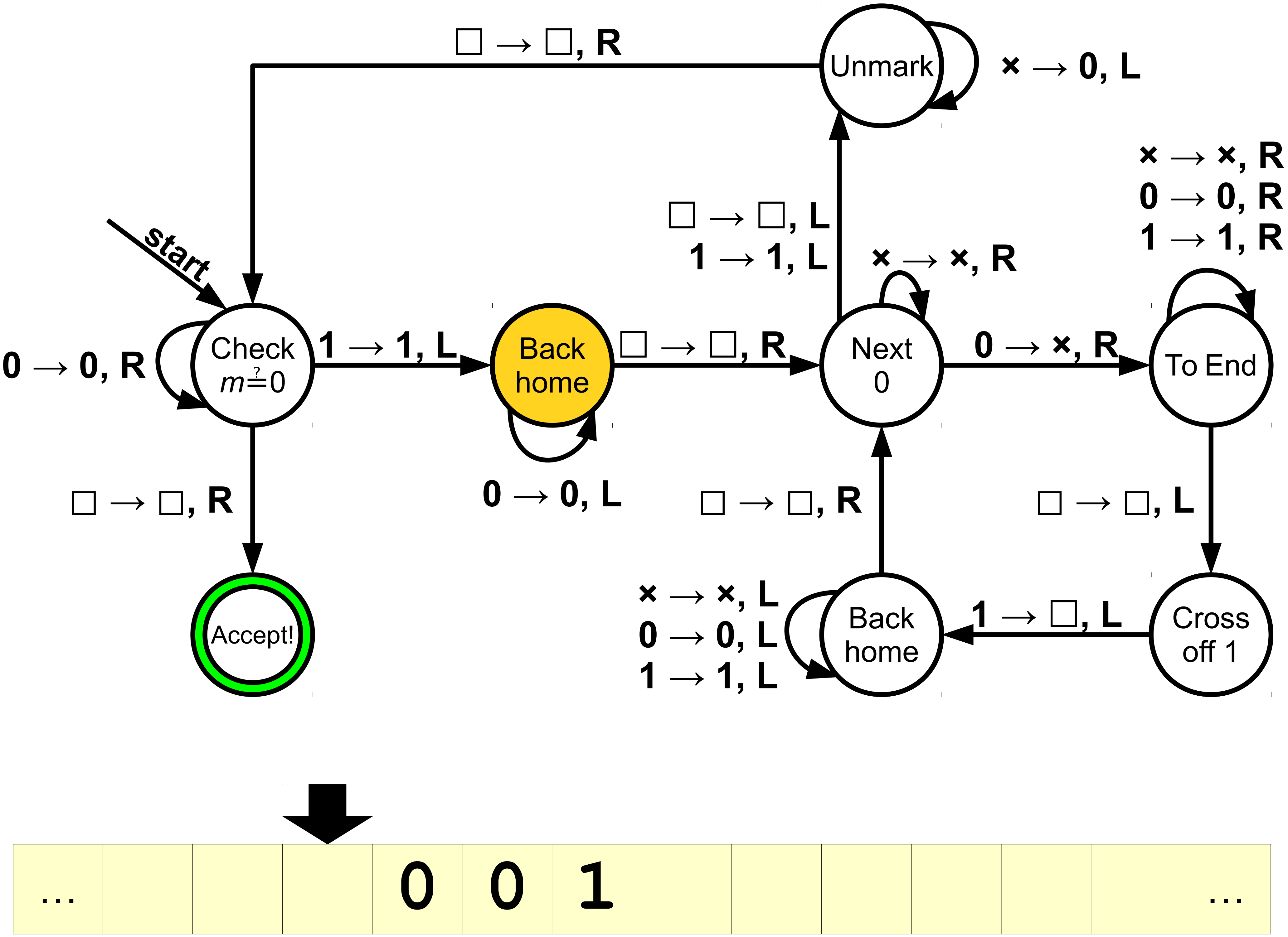
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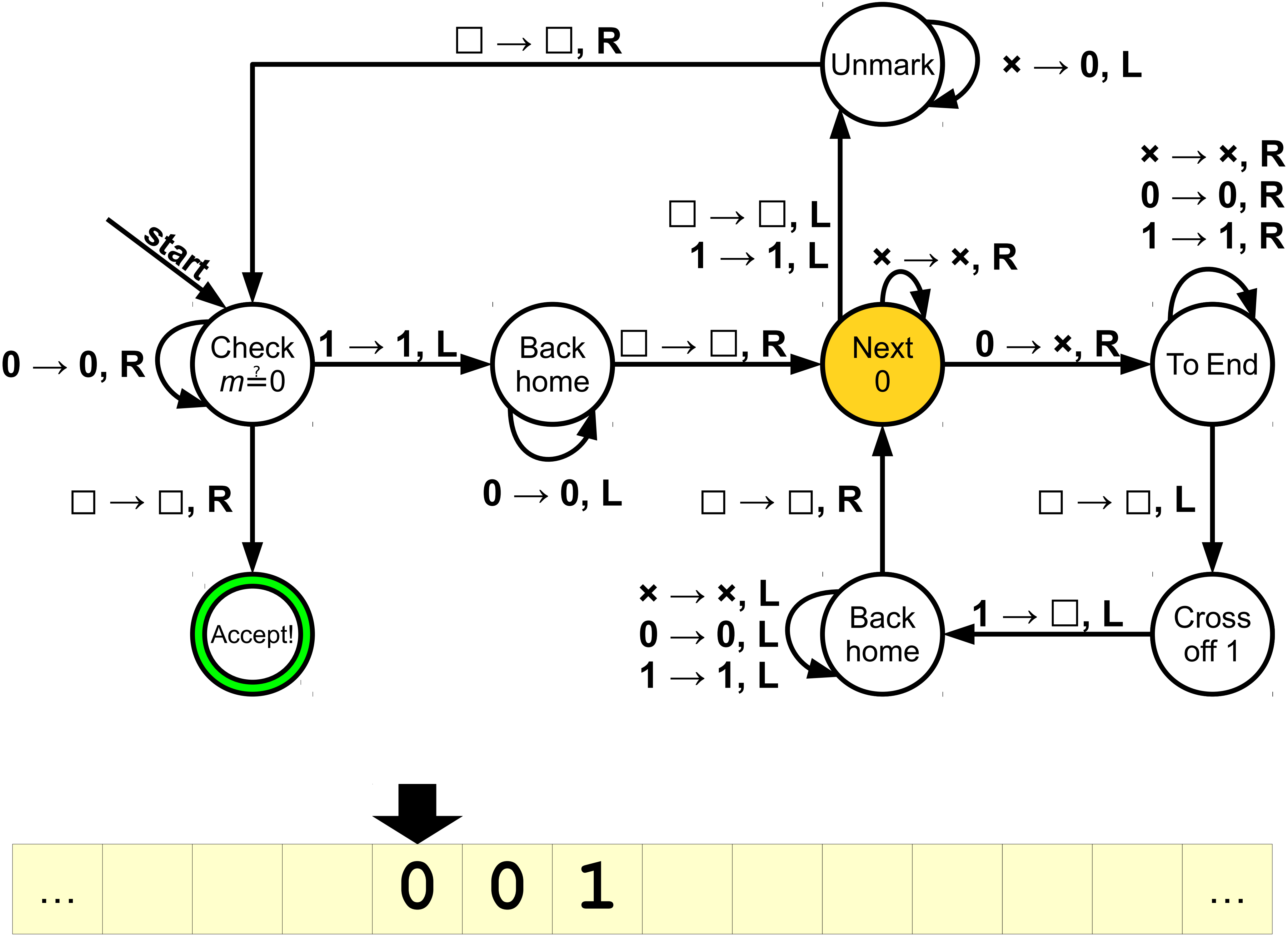
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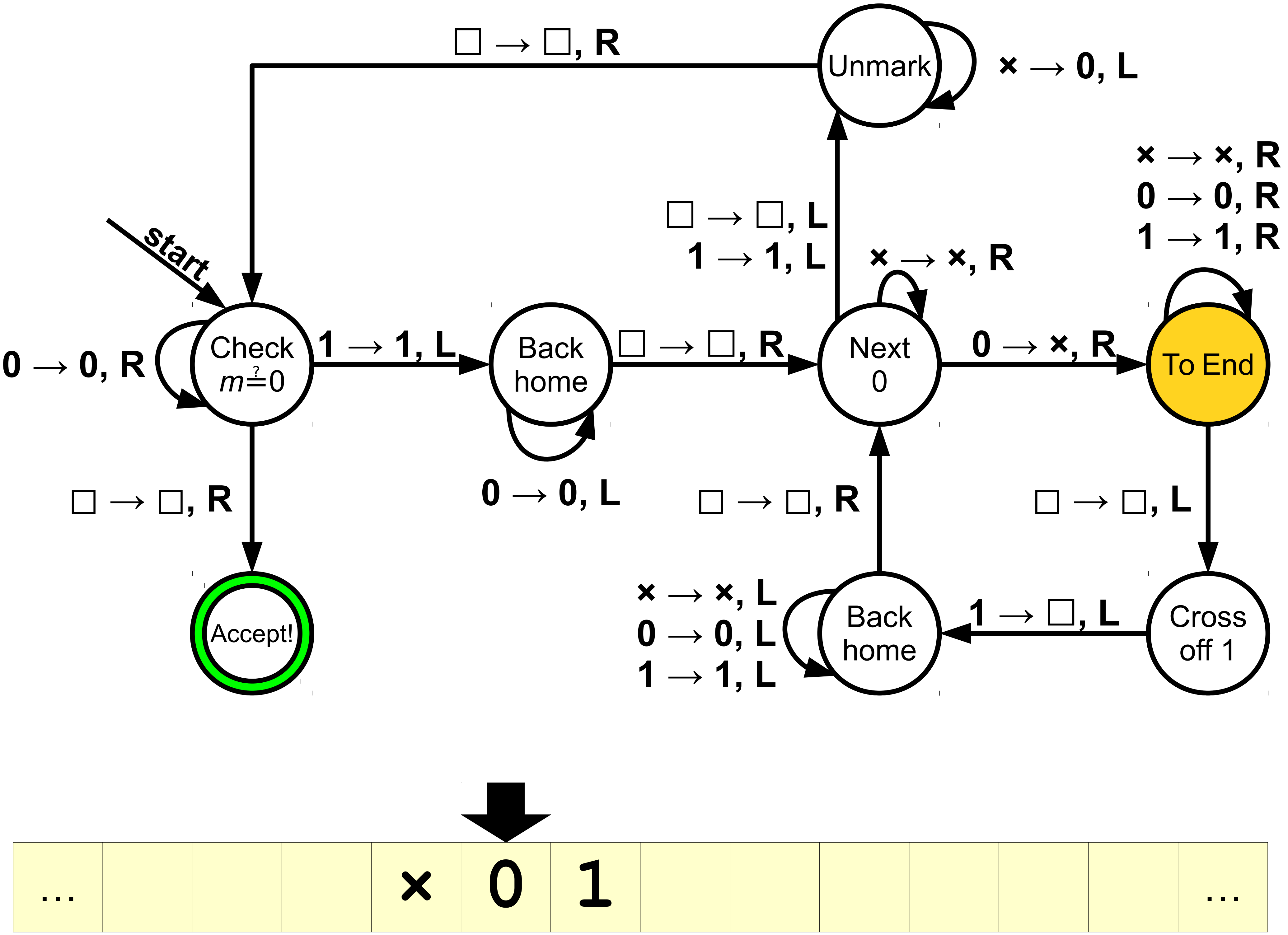
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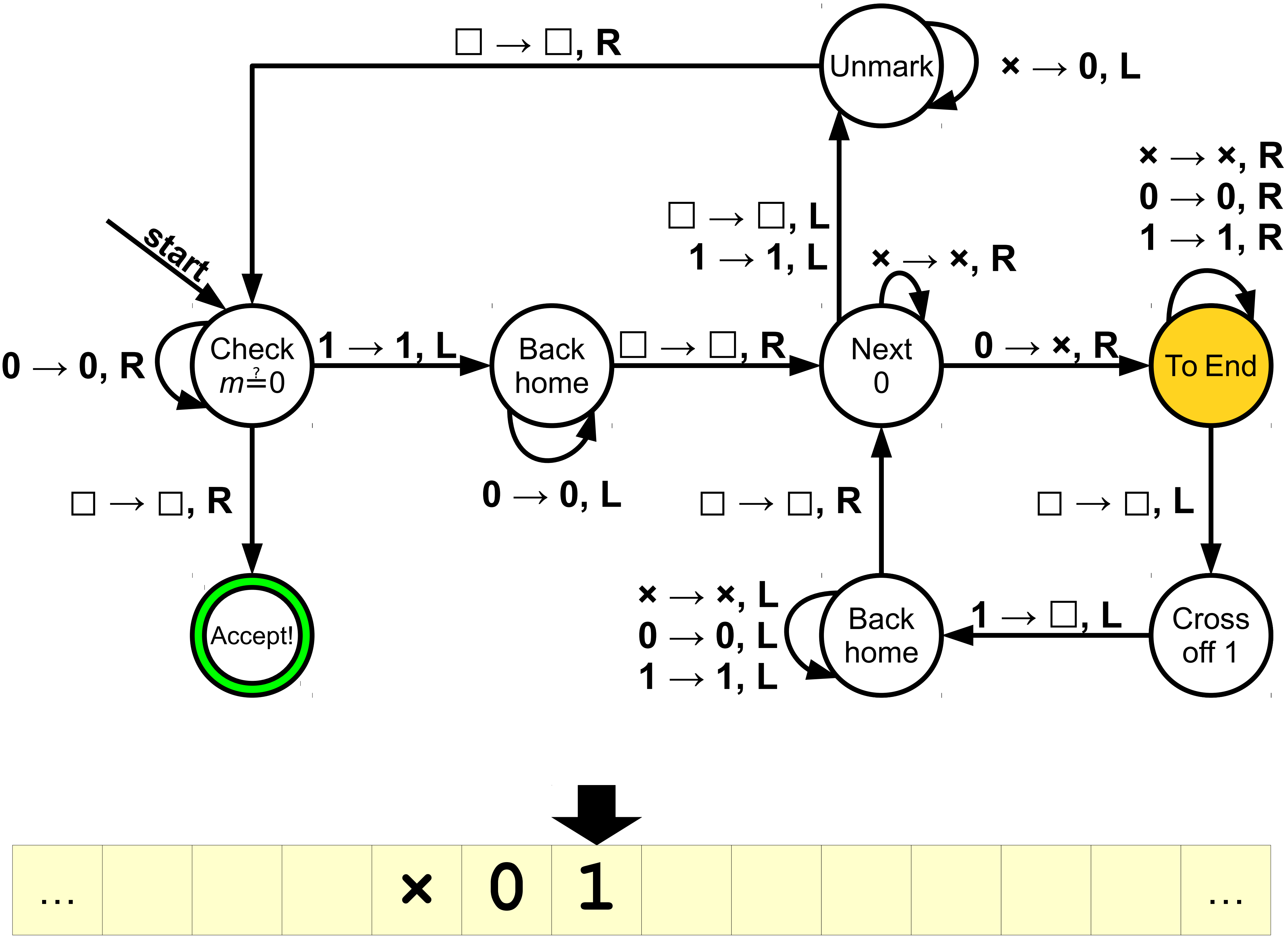
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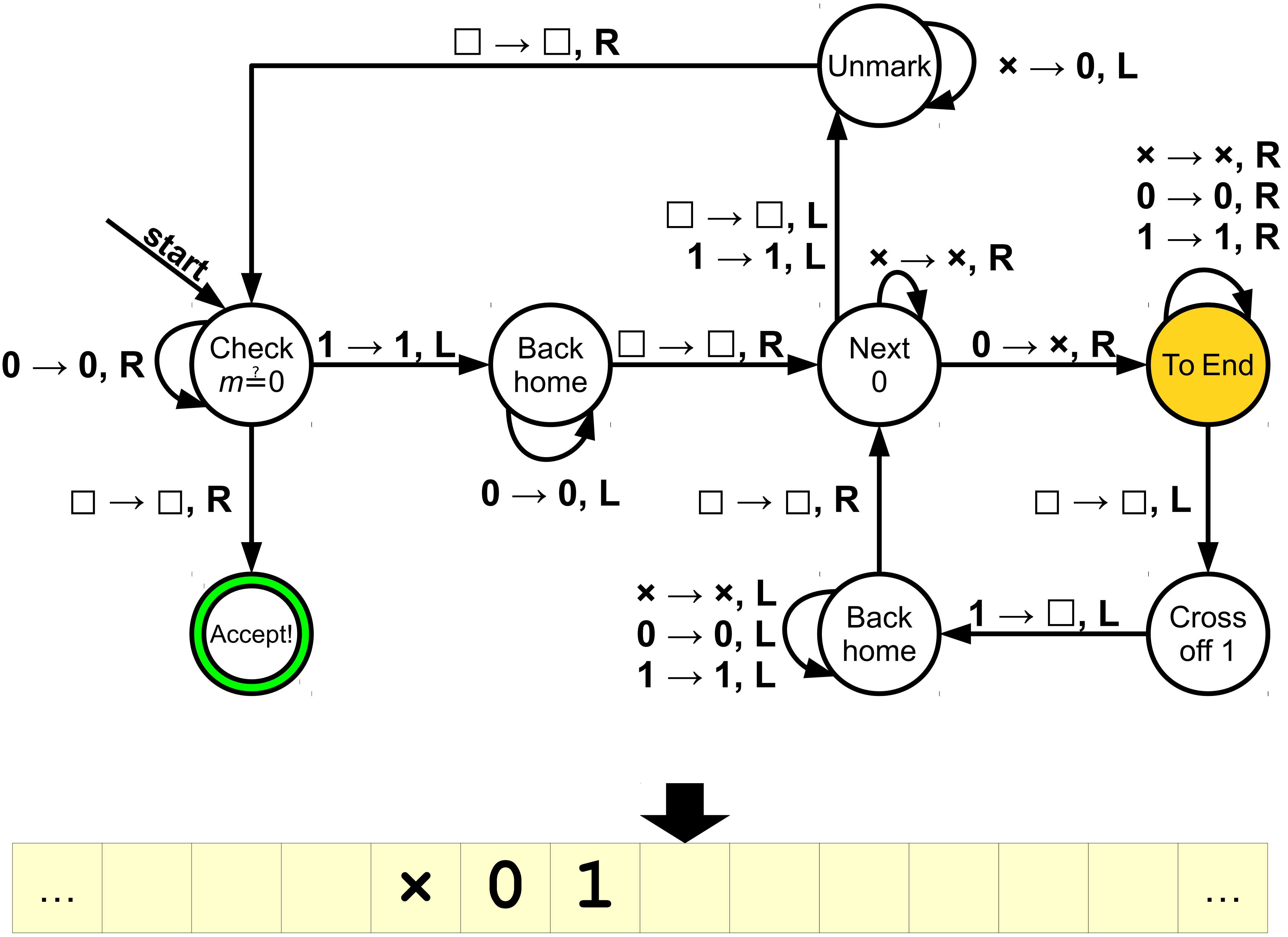
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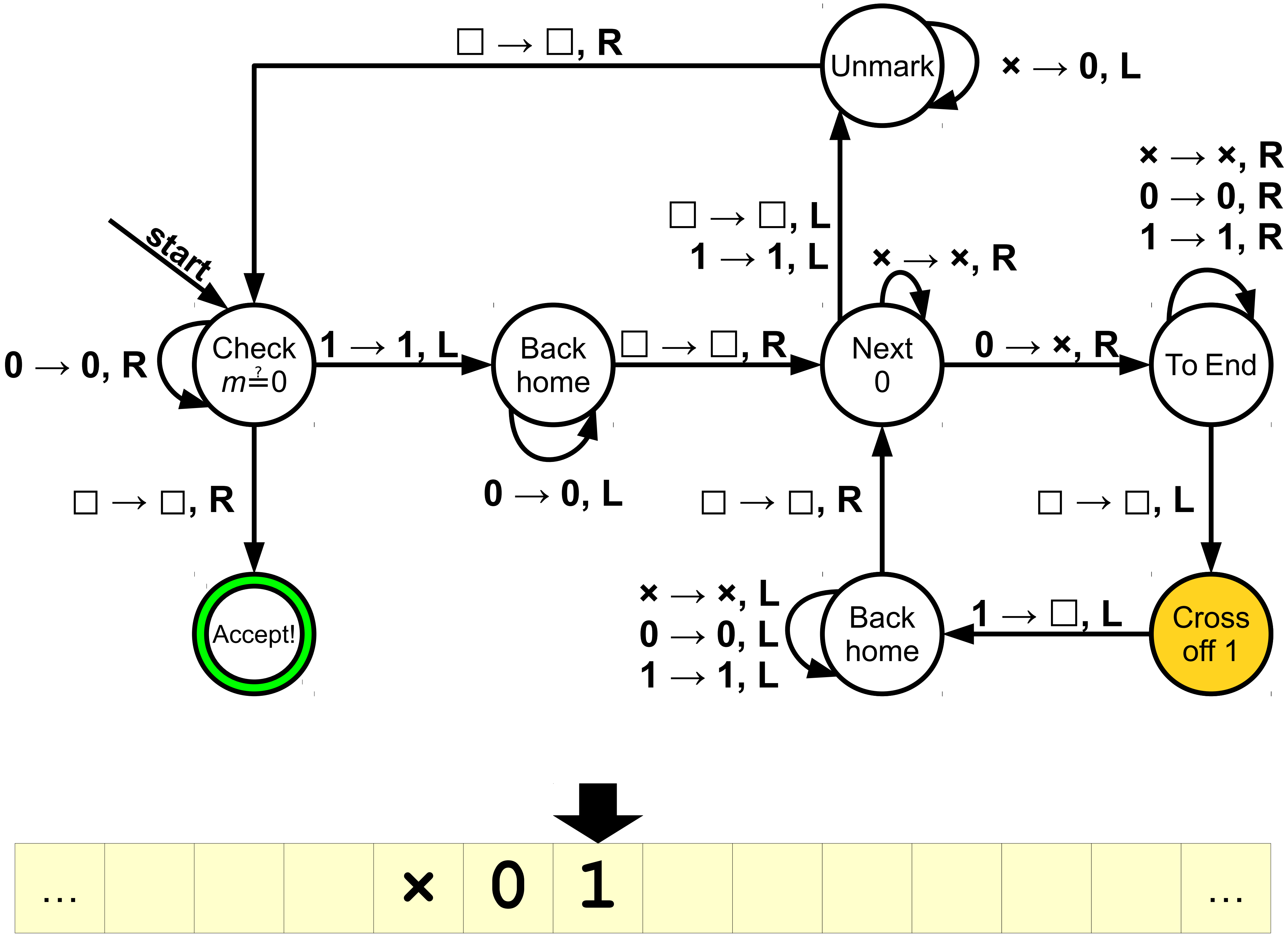
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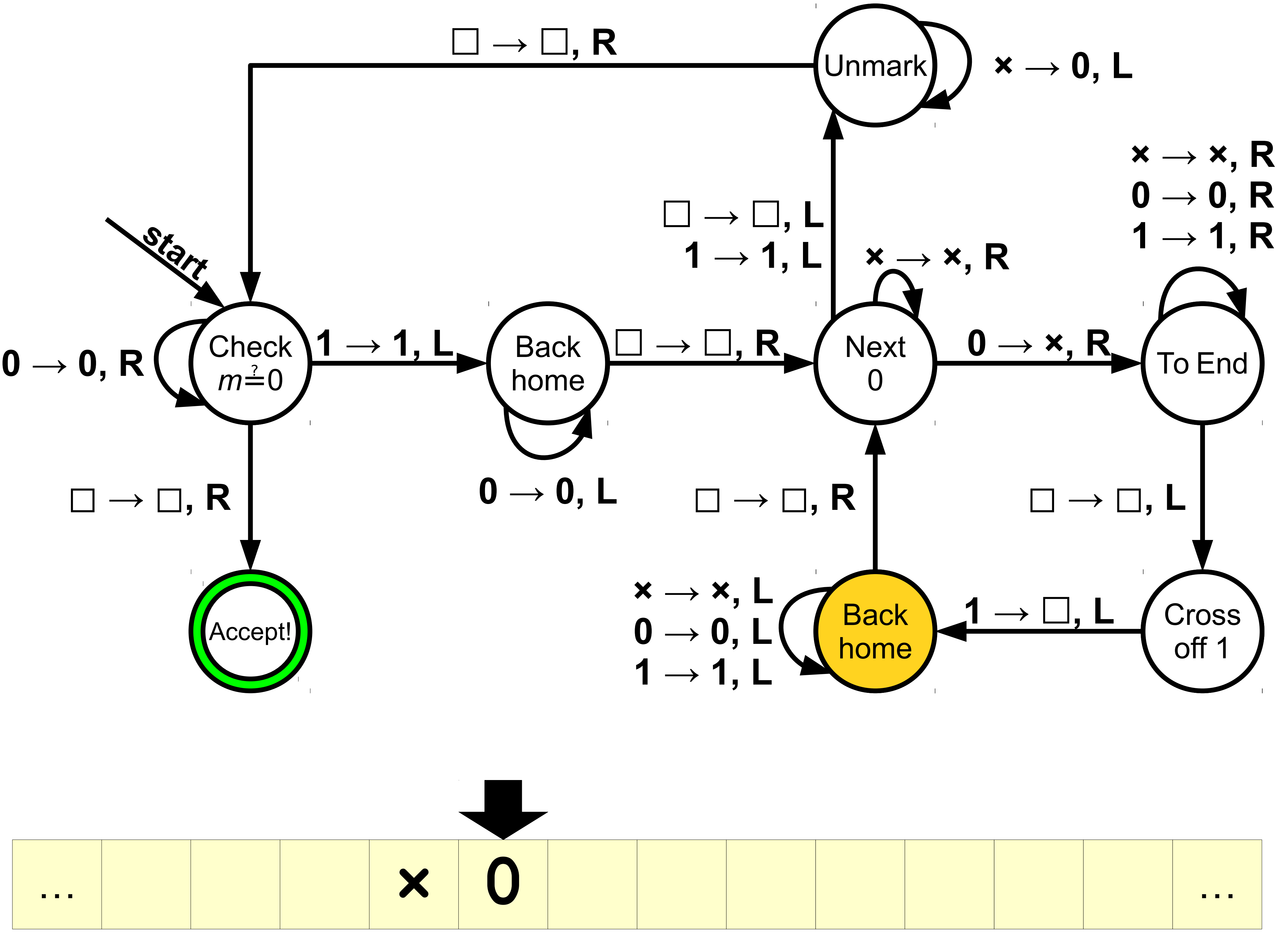
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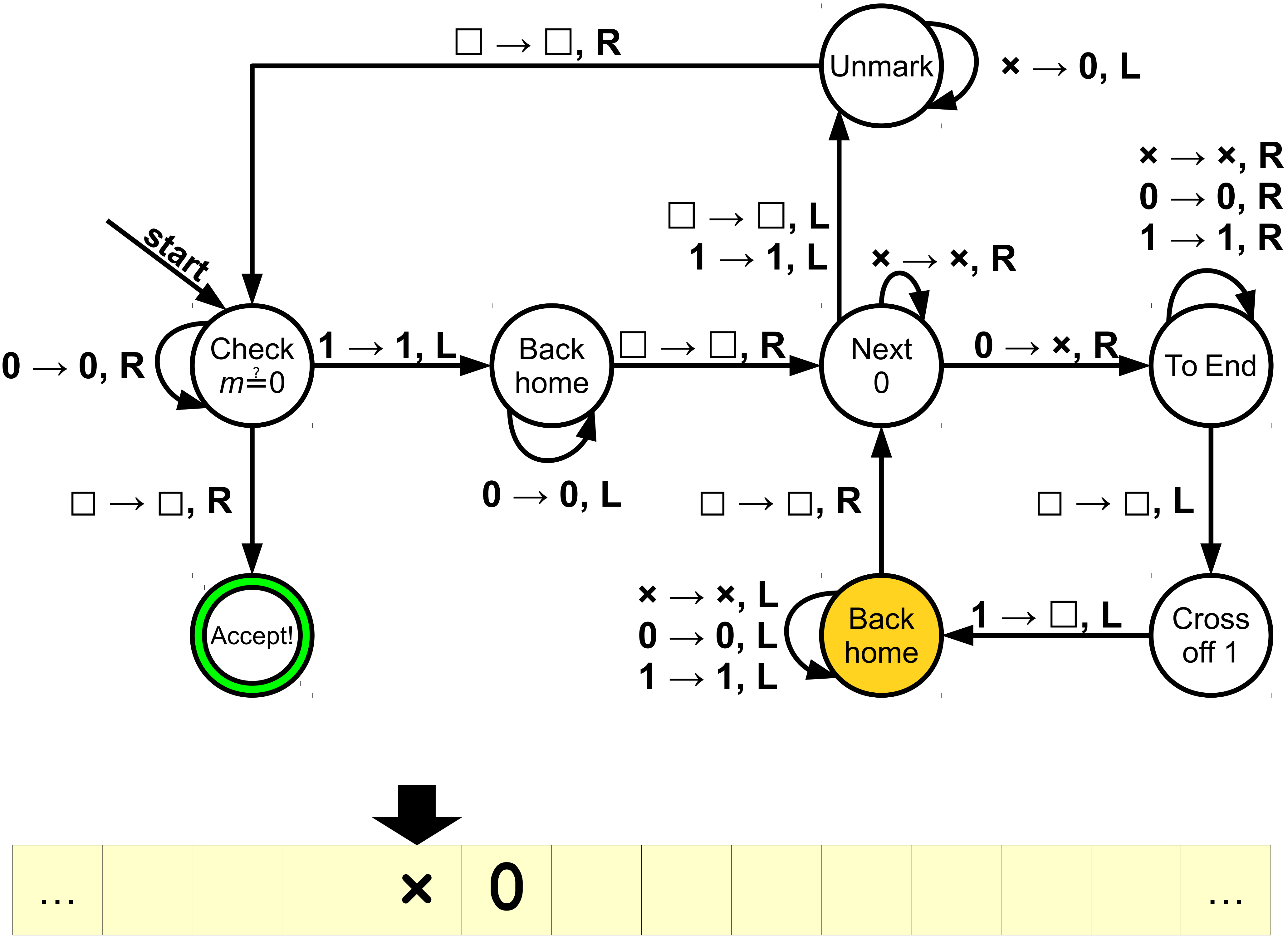
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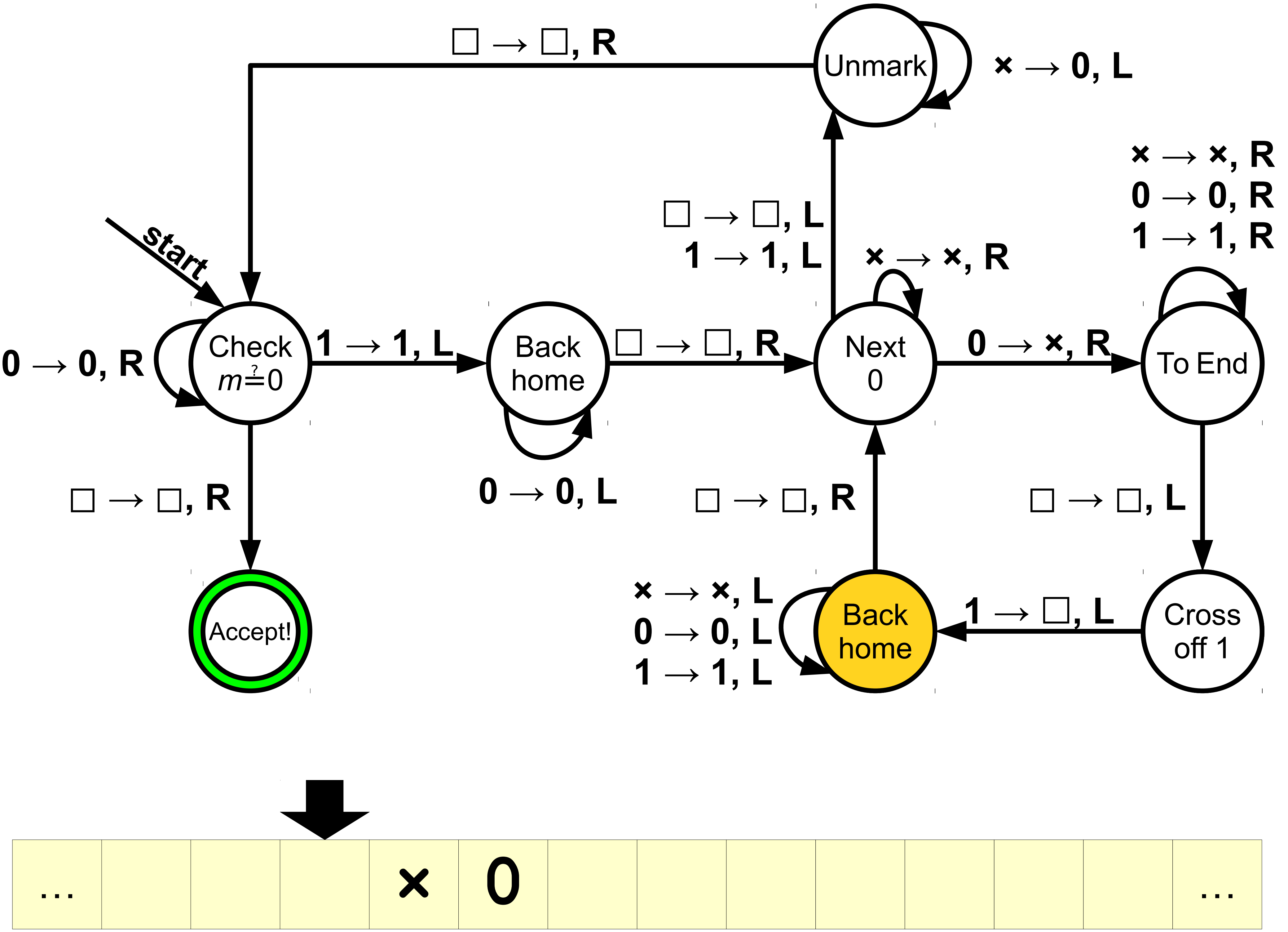

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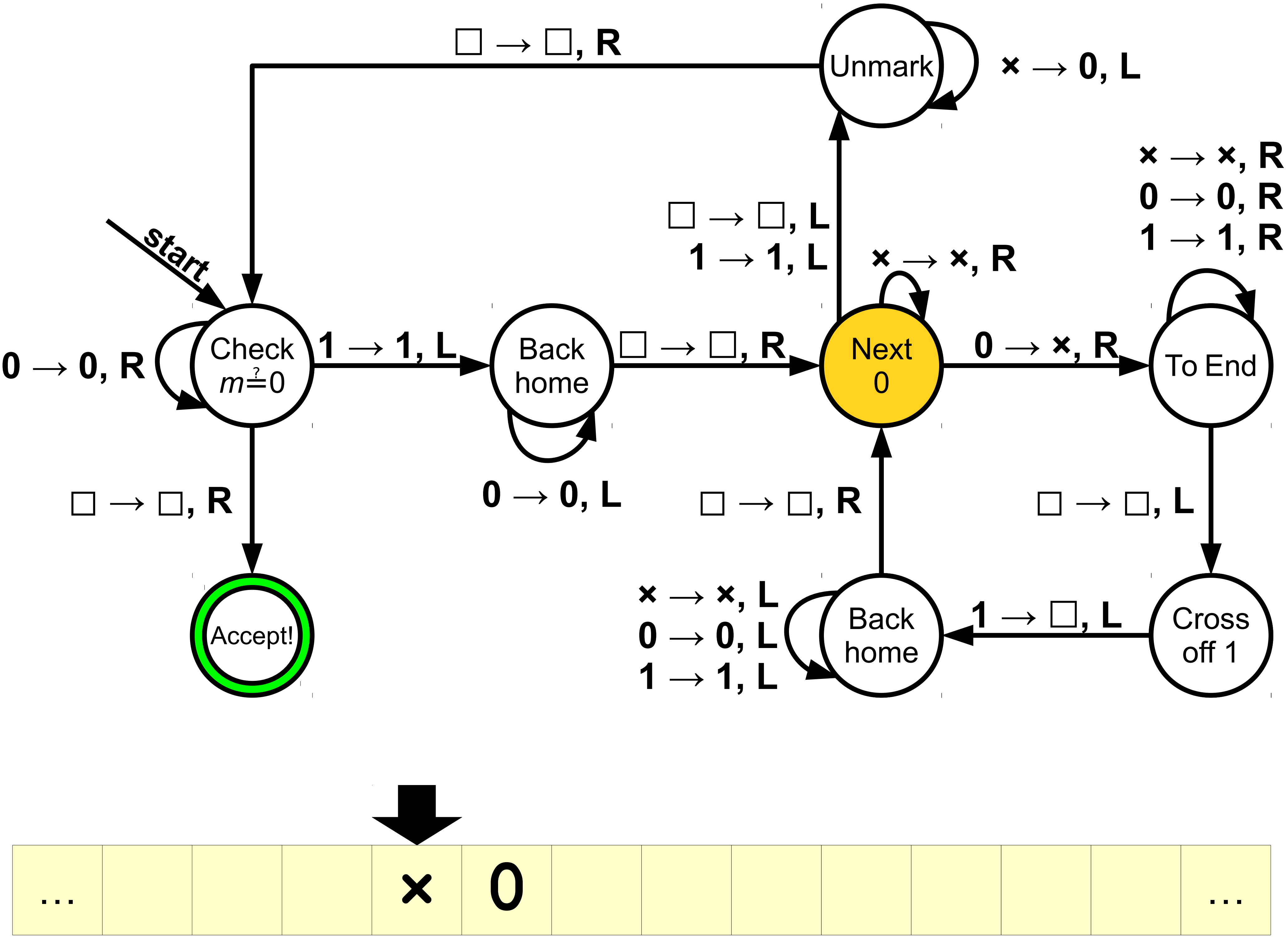
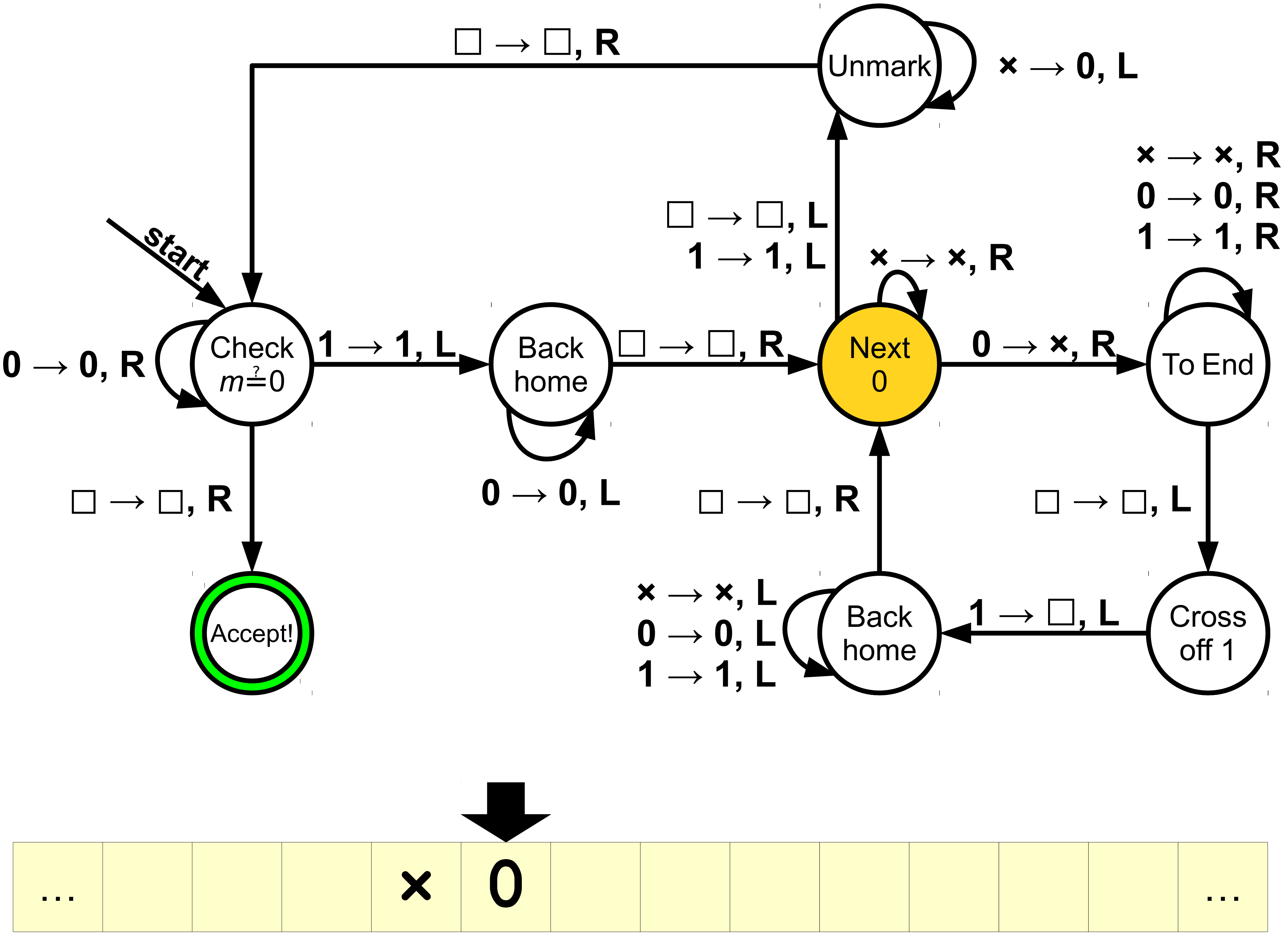
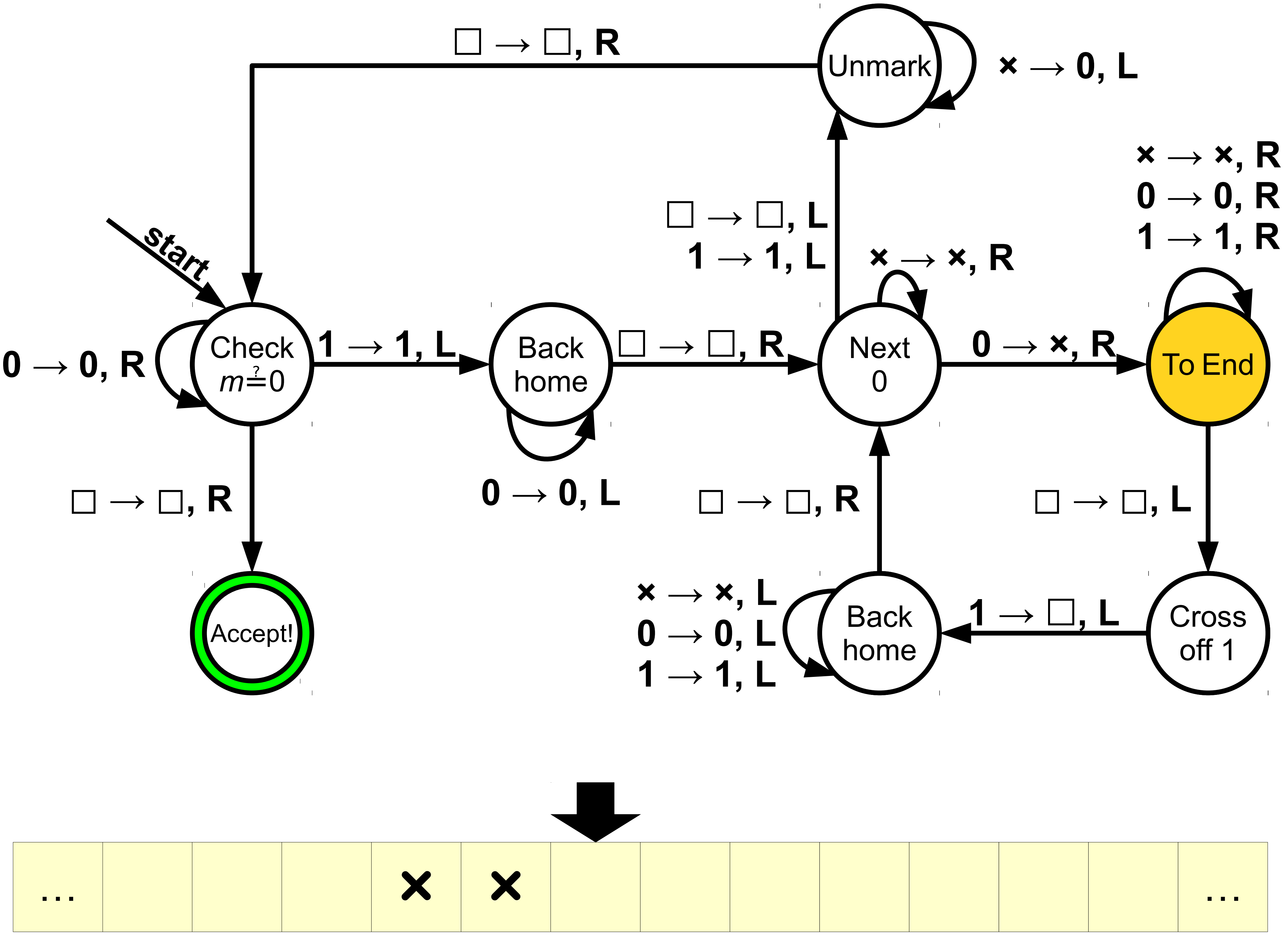
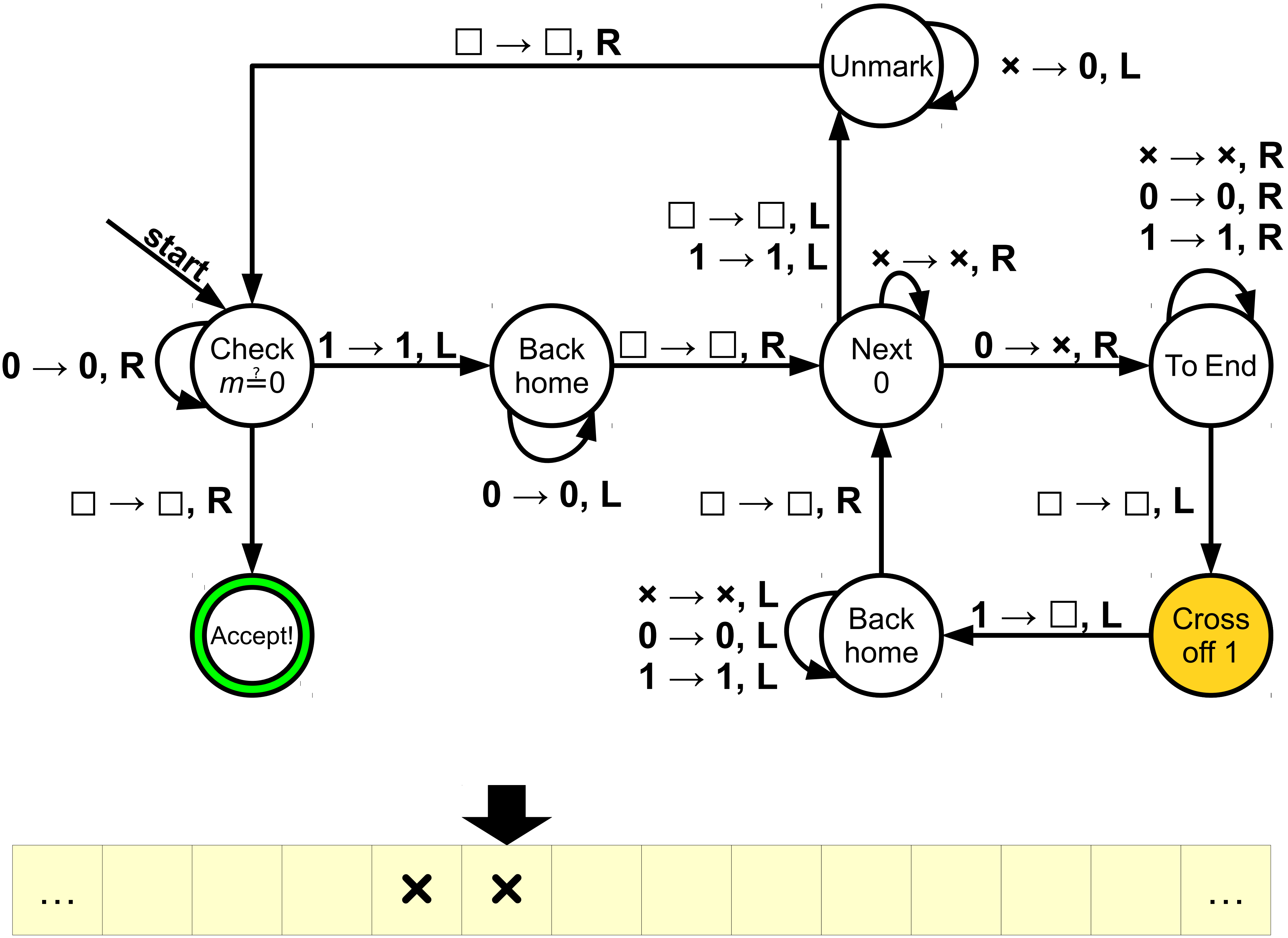
0
…

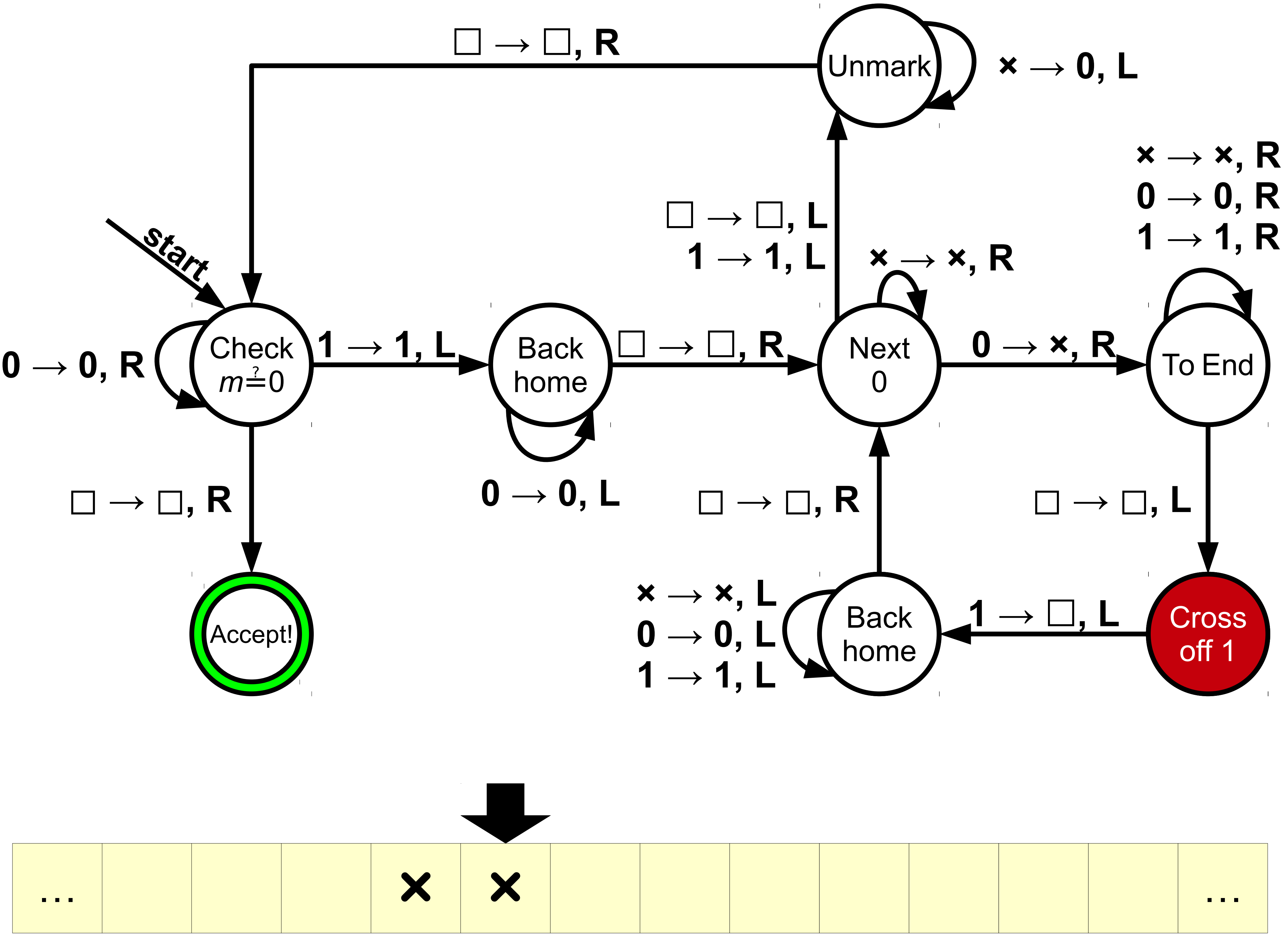

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, L
□ → □, R
Accept!
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
×
0
…

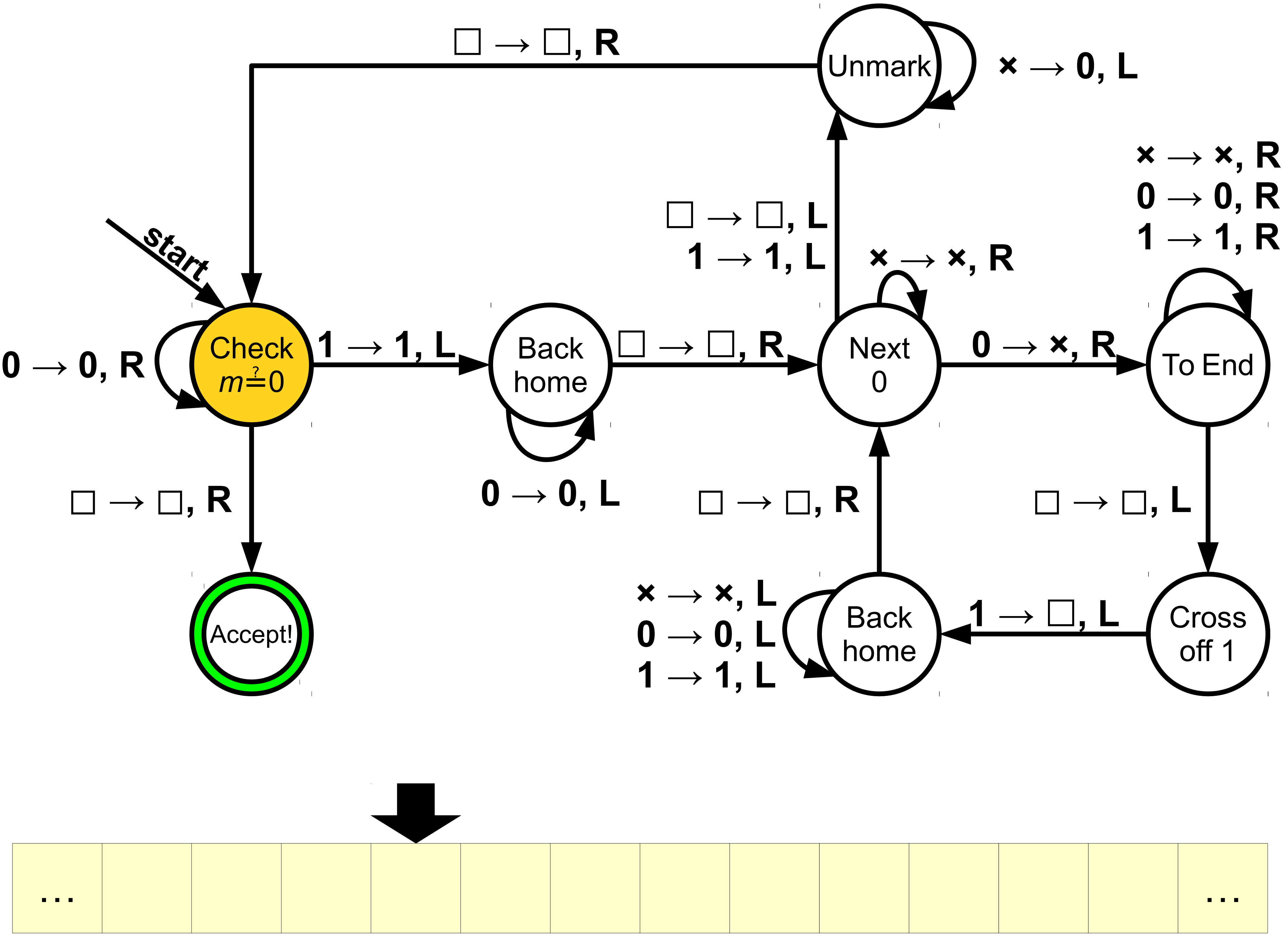

□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, R
□ → □, L
Accept!
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
×
0
…

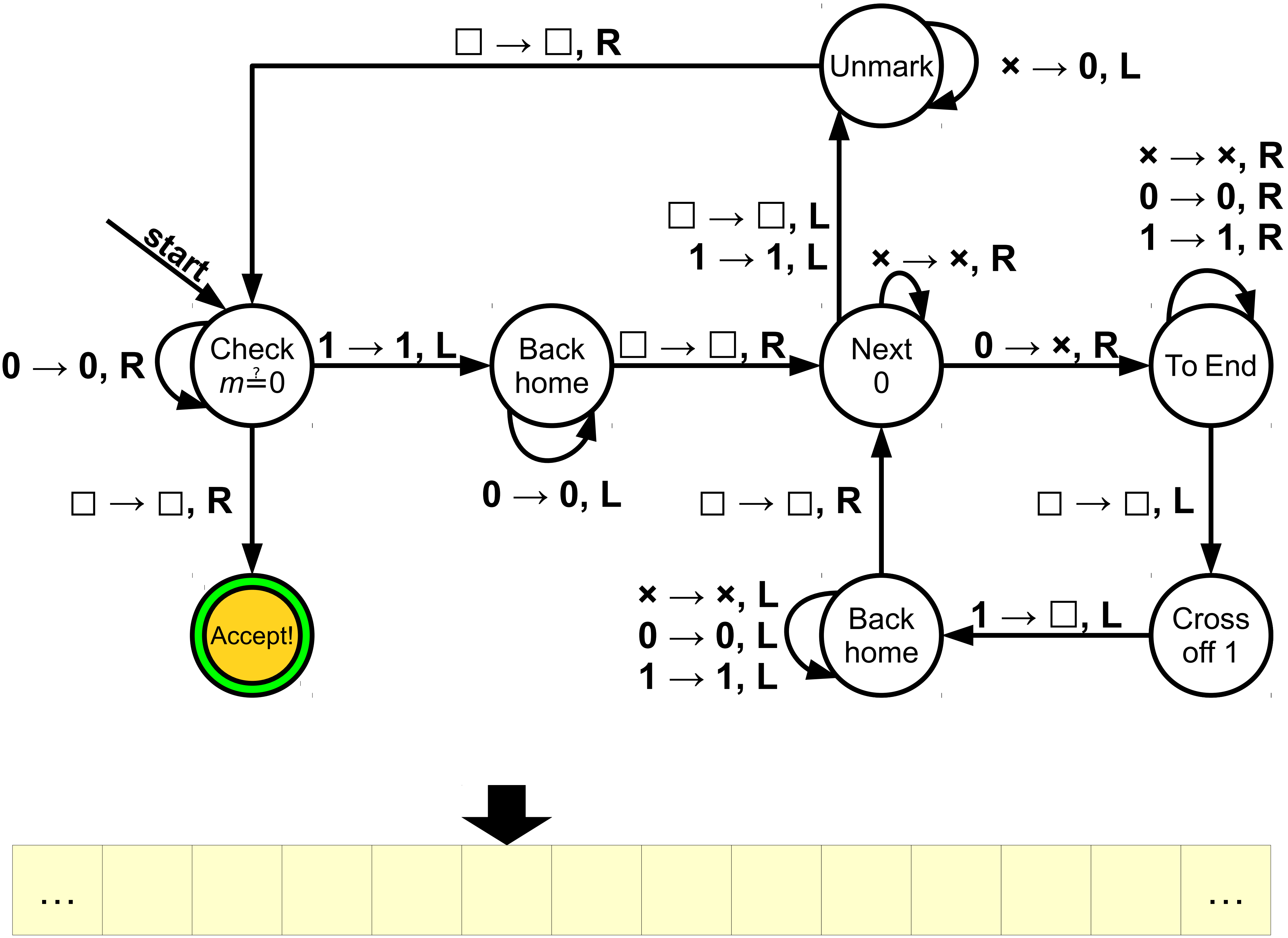

□ → □, R
Unmark
× → 0, L
start
Check
m≟0
0 → 0, R
1 → 1, L
Back
home
0 → 0, L
□ → □, R
□ → □, L
1 → 1, L
Next
0
× → ×, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, R
Accept!
□ → □, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
…
×
×
…

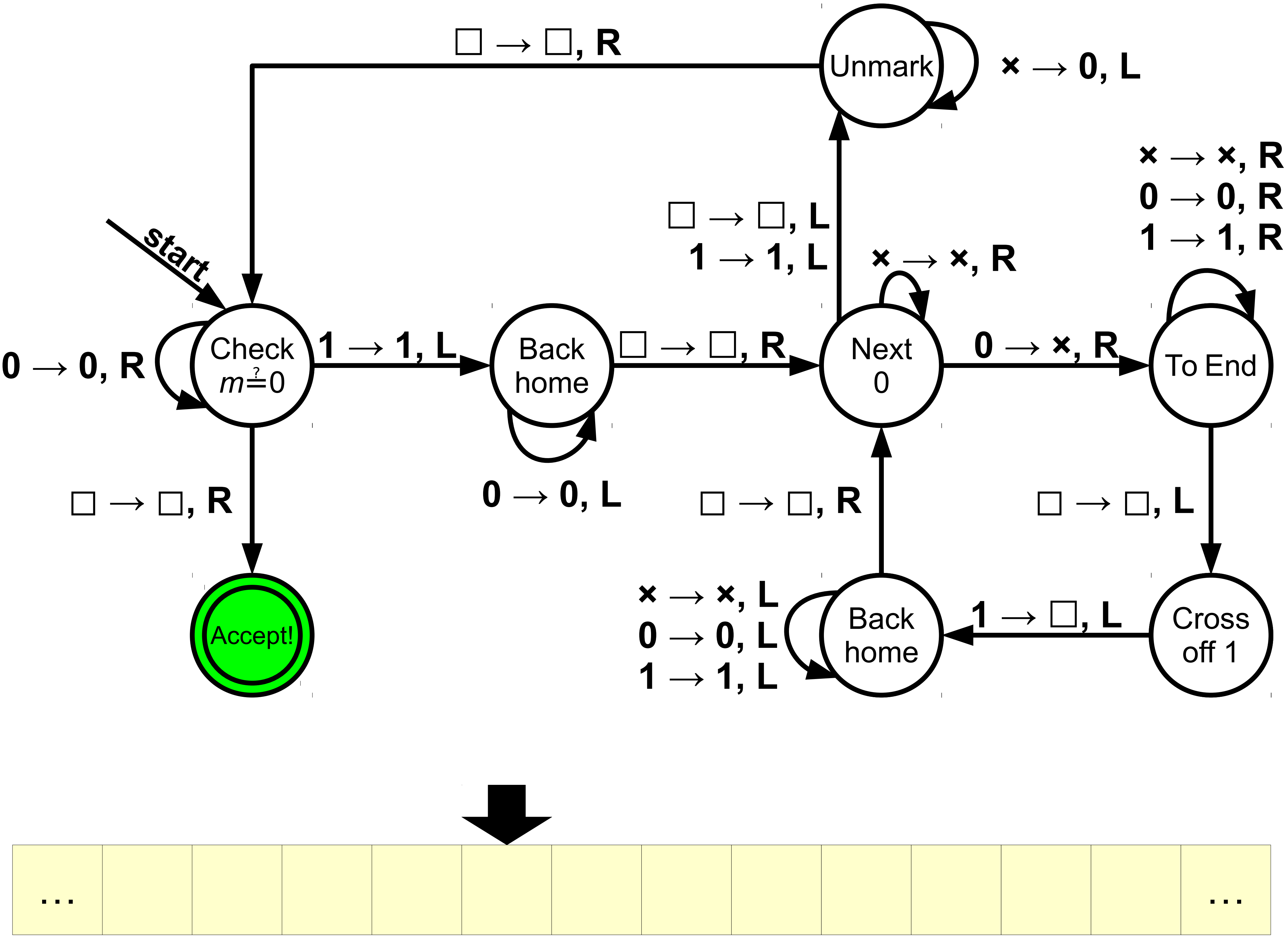


start
Check $m \overset{?}{=} 0$
0 → 0, R
1 → 1, L
□ → □, R
Accept!
Back home
0 → 0, L
□ → □, R
Next 0
× → ×, R
□ → □, L
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross off 1
1 → □, L
Back home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
…
×
×
…


start
Check
$m \overset{?}{=} 0$
0 → 0, R
□ → □, R
Accept!
1 → 1, L
Back
home
0 → 0, L
□ → □, R
Next
0
× → ×, R
□ → □, L
1 → 1, L
Unmark
× → 0, L
□ → □, R
0 → ×, R
To End
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
Cross
off 1
1 → □, L
Back
home
× → ×, L
0 → 0, L
1 → 1, L
□ → □, R
...
×
×
...


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, R
□ → □, L
Accept!
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
1 → 1, L
× → ×, R
start
0 → 0, R
Check
m ≟ 0
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
0 → 0, L
□ → □, R
□ → □, R
□ → □, L
Accept!
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
…


□ → □, R
Unmark
× → 0, L
× → ×, R
0 → 0, R
1 → 1, R
□ → □, L
1 → 1, L
× → ×, R
start
0 → 0, R
Check
$m \overset{?}{=} 0$
1 → 1, L
Back home
□ → □, R
Next 0
0 → ×, R
To End
□ → □, R
0 → 0, L
□ → □, R
□ → □, L
Accept!
× → ×, L
0 → 0, L
1 → 1, L
Back home
1 → □, L
Cross off 1
…
…