Speech and Language Processing

Regular Expresssions and Automata

Chapter 2 of SLP

Regular Expressions and Text Searching

- Everybody does it
  - emacs, vi, grep, sed, Perl, Python, Ruby, Java etc.
- Regular expressions are a compact textual representation of a set of strings representing a language.
- Example web page:
  - http://rubular.com/

Example

- Regular expression search requires a **pattern** that we want to search for and a **corpus** of text to search through.
- Find all the instances of the word "the" in a text.
  - `/the/`
  - `/[tT]he/`
  - `/\b[tT]he\b/`

Errors

- The process we just went through was based on fixing two kinds of errors
  - Matching strings that we should not have matched (there, then, other)
    - False positives (Type I)
  - Not matching things that we should have matched (The)
    - False negatives (Type II)

Errors

- We'll be telling the same story for many tasks, all semester. Reducing the error rate for an application often involves two antagonistic efforts:
  - Increasing accuracy, or precision, (minimizing false positives)
  - Increasing coverage, or recall, (minimizing false negatives).

Range, negation and optionality

- /[A-Z]/ an upper case letter
- /[a-z]/ a lower case letter
- /[0-9]/ a single digit
- /[^A-Z]/ not an upper case letter
- /[^\.]/ not a period
- /colou?r/ color or colour

Kleene * and +

- /s+/ one or more occurrences of s
- /[0-9]+/ a sequence of digits
- /s*/ zero or more occurrences of s
- /[0-9][0-9]*/ a sequence of digits

Anchors

- Special characters that anchor regular expressions to particular places in a string
- /^/ matches the start of a line
- /$/ matches the end of a line
- /^T/ matches what?
- /\.$/ matches what?

Disjunction and Grouping

- Disjunction operator
  - /cat|dog/ matches cat or dog
- Grouping
  - /gupp(y|ies)/
    - Matches guppy or guppies

Advanced operators

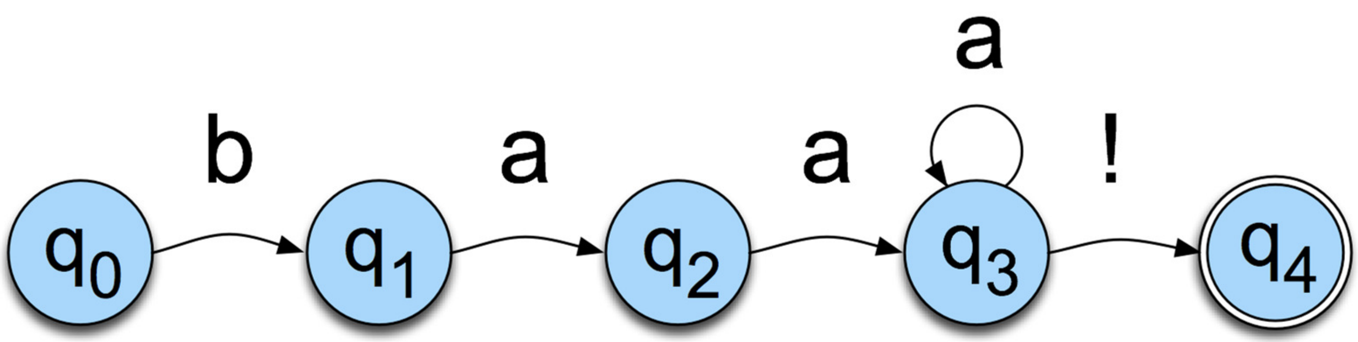
- `/\d/` = `/[0-9]/`
- `/\D/` = `/[^0-9]/`
- `/\w/` = `/[a-zA-Z0-9_]/`
- `/\W/` = `/[^\w]/`
- `/\s/` = `[ \r\t\n\f]` (white space)
- `/\S/` = `/[^\s]/`

Finite State Automata

- Regular expressions can be viewed as a textual way of specifying the structure of finite-state automata (FSA).
- Regular expressions can be implemented with FSAs.
- FSAs and their probabilistic relatives are at the core of much of what we'll be doing all semester.
- They also capture significant aspects of what linguists say we need for morphology and parts of syntax.

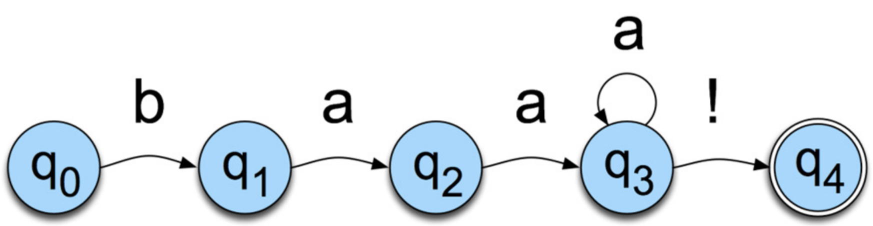
FSAs as Graphs

- Let's start with the sheep language from Chapter 2
  - /baa+!/



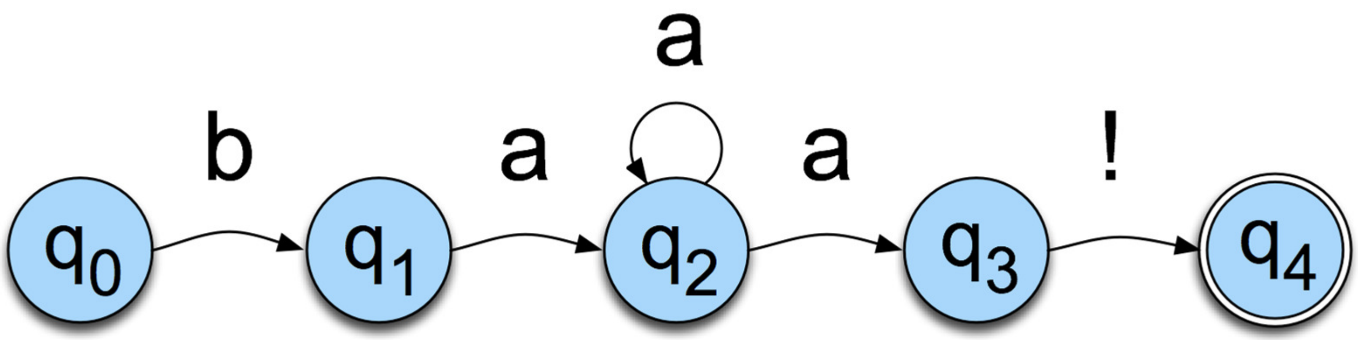
Sheep FSA

- We can say the following things about this machine
  - It has 5 states
  - b, a, and ! are in its alphabet
  - q_0 is the start state
  - q_4 is an accept state
  - It has 5 transitions



But Note

- There are other machines that correspond to this same language



- More on this one later

More Formally

- We can specify an FSA by enumerating the following things.
  - The set of states: Q
  - A finite alphabet: Σ
  - A start state
  - A set F of accept/final states
  - A transition function that maps QxΣ to Q

The sheeptalk automaton

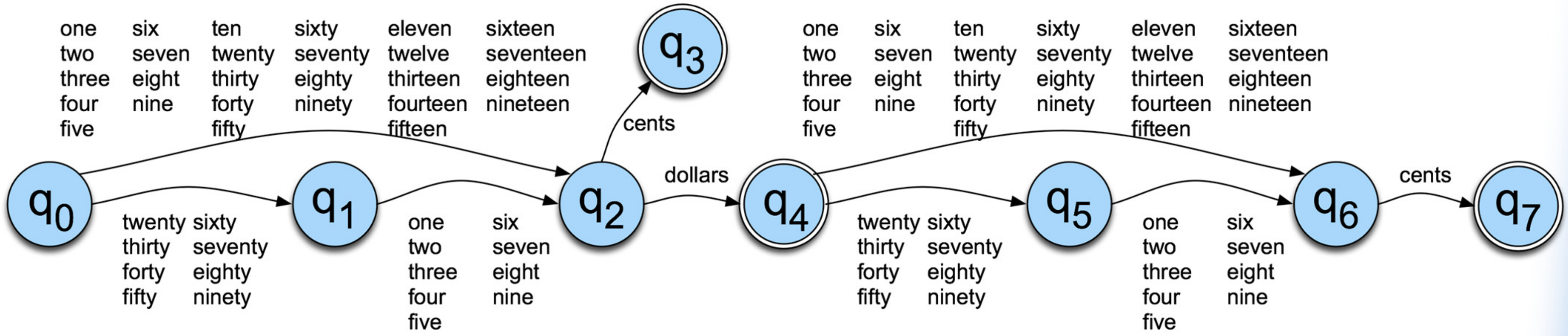
- $Q = \{q_0, q_1, q_2, q_3, q_4\}$
- $\Sigma = \{a, b, !\}$
- $F = \{q_4\}$
- $\delta(q,i) =$

State/ Input	b	a	!
0	1	Ø	Ø
1	Ø	2	Ø
2	Ø	3	Ø
3	Ø	3	4
4:	Ø	Ø	Ø

About Alphabets

- Don't take term *alphabet* word too narrowly; it just means we need a finite set of symbols in the input.
- These symbols can and will stand for bigger objects that can have internal structure.

Dollars and Cents



Recognition

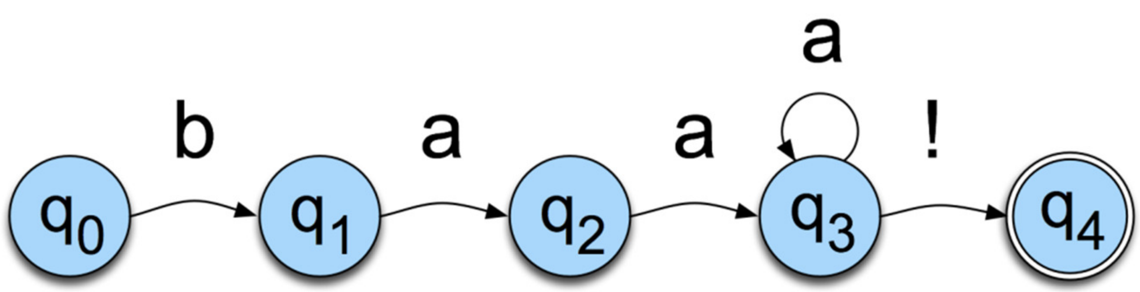
- Recognition is the process of determining if a string should be accepted by a machine
- Or… it's the process of determining if a string is in the language we're defining with the machine
- Or… it's the process of determining if a regular expression matches a string
- Those all amount the same thing in the end

Recognition

- Simply a process of starting in the start state
- Examining the current input
- Consulting the table
- Going to a new state and updating the input pointer.
- Until you run out of input.

Deterministic (Finite-state) Automaton (DFA)

- The behavior during recognition is fully **determined** by the state it is in and the symbol it is looking at.



Deterministic recognition

- Input: a string x ending with EOF. DFA, D, with start state q_0 and a set, F, of final states.
- Output: true if D recognizes x, otherwise false.

```
q = q0
c = nextchar();
while (c <> EOF) {
   q = move(q, c); // returns the state to which the
                  // automaton moves
                  // from state q on input c
   c = nextchar();
}
if q ∈ F then return true
else return false;
```

Key Points

- Deterministic means that at each point in processing there is always one unique thing to do (no choices).
- D(eterministic)-recognize is a simple table-driven interpreter
- The algorithm is universal for all unambiguous regular languages.
  - To change the machine, you simply change the table.

Key Points

- Crudely therefore… matching strings with regular expressions (ala Perl, grep, vi, etc.) is a matter of
  - translating the regular expression into a machine (a table) and
  - passing the table and the string to an interpreter

Generative Formalisms

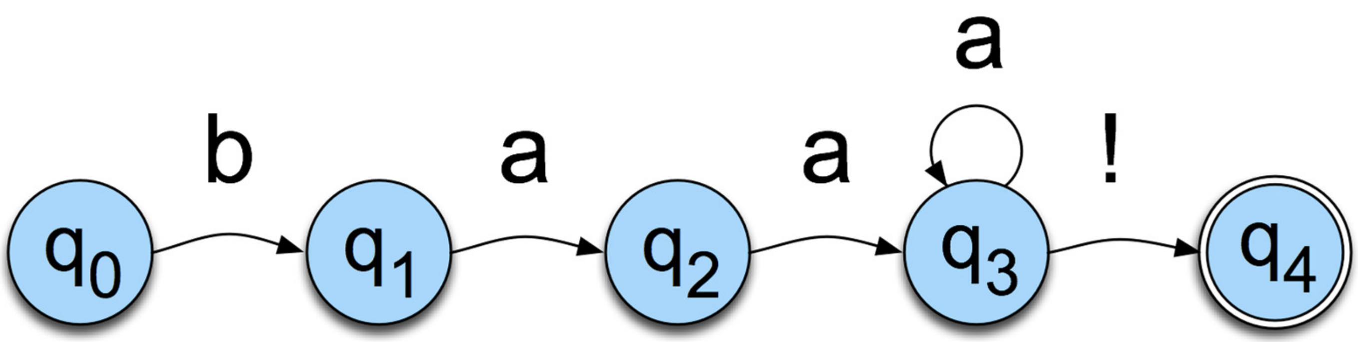
- *Formal Languages* are sets of strings composed of symbols from a finite set of symbols.
- Finite-state automata define formal languages (without having to enumerate all the strings in the language)
- The term *Generative* is based on the view that you can run the machine as a generator to get strings from the language.

Generative Formalisms

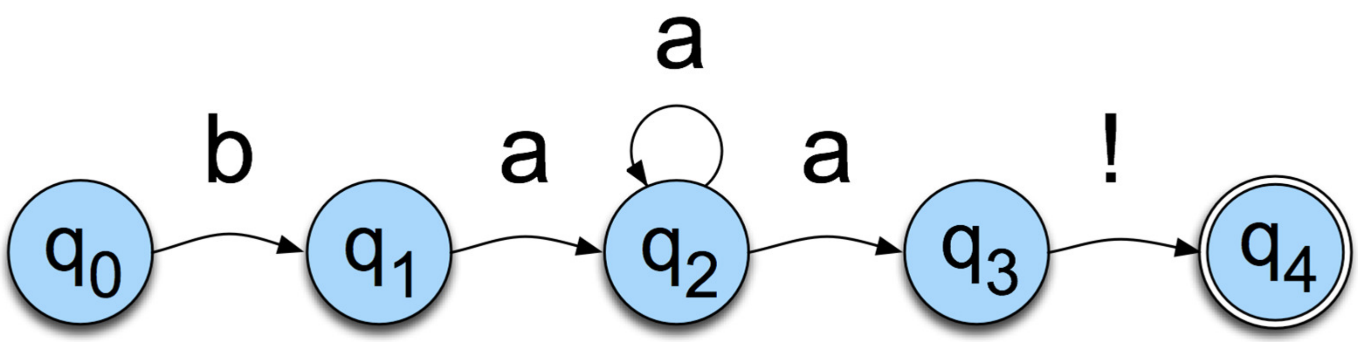
- FSAs can be viewed from two perspectives:
  - Acceptors that can tell you if a string is in the language
  - Generators to produce *all and only* the strings in the language

Non-Deterministic FSA (NFA)

DFA

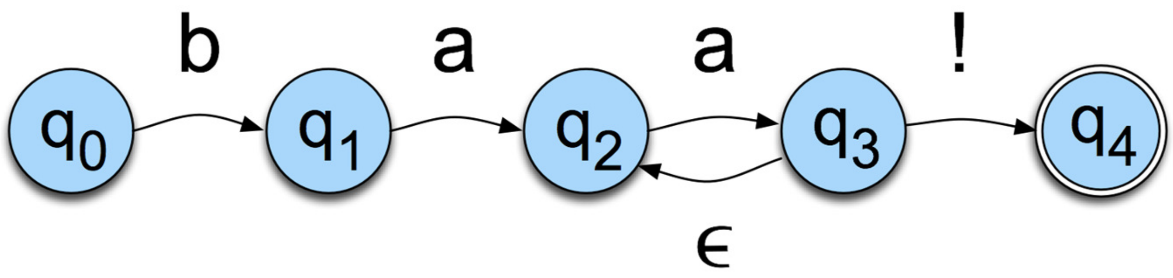


NFA



Non-Determinism cont.

- Yet another technique
  - Epsilon transitions (ϵ-transitions)
  - Key point: these transitions do not examine or advance the input during recognition



Equivalence

- Non-deterministic machines can be converted to deterministic ones with a fairly simple construction
- That means that they have the same power; non-deterministic machines are not more powerful than deterministic ones in terms of the languages they can accept

NFA Recognition

- Two basic approaches (used in all major implementations of regular expressions, see Friedl 2006)
  1. Either take a NFA machine and convert it to a DFA machine and then do recognition with that.
  2. Or explicitly manage the process of recognition as a state-space search (leaving the machine as is).

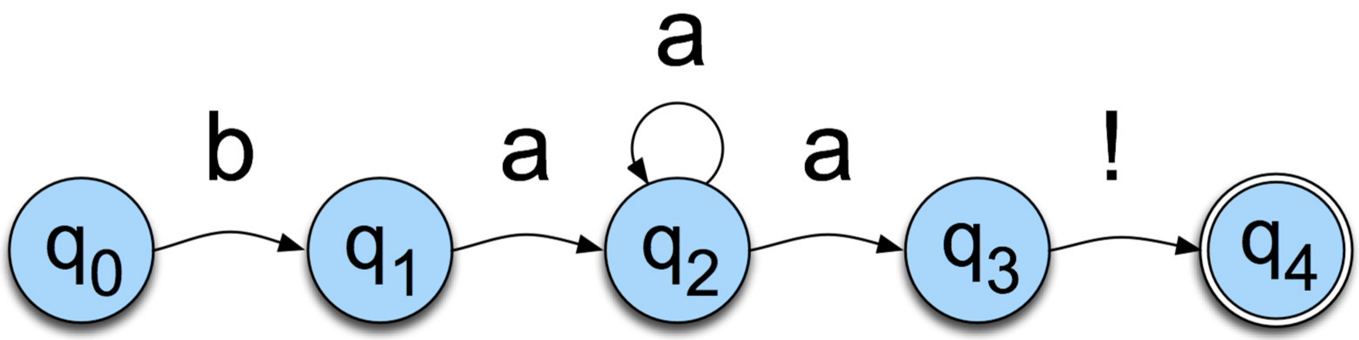
Non-Deterministic Recognition: Search

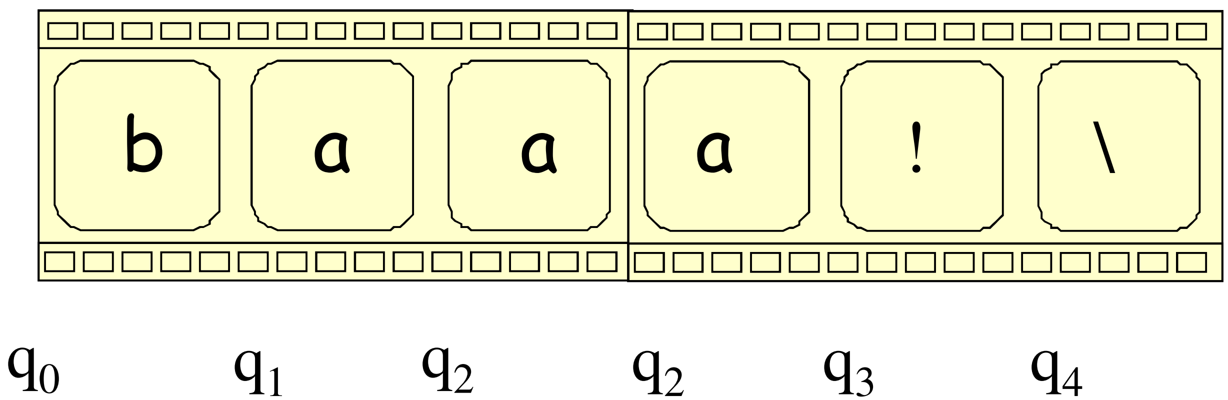
- In an NFA there exists at least one path through the machine for a string that is in the language defined by the machine.
- But not all paths directed through the machine for an accept string lead to an accept state.
- No paths through the machine lead to an accept state for a string not in the language.

Non-Deterministic Recognition

- So success in non-deterministic recognition occurs when a path is found through the machine that ends in an accept.
- Failure occurs when all of the possible paths for a given string lead to failure.

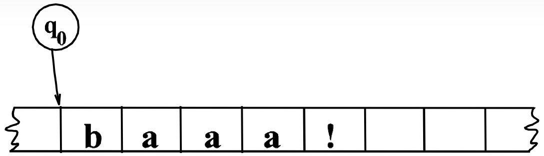
Example

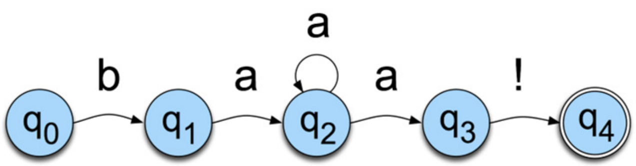




Example

1

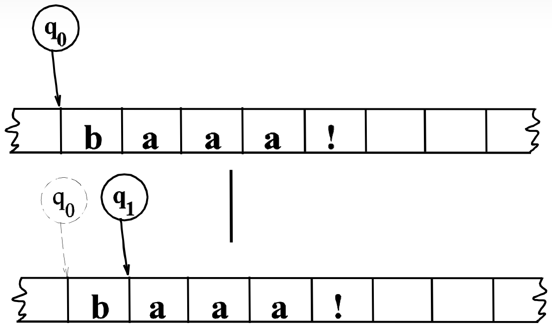


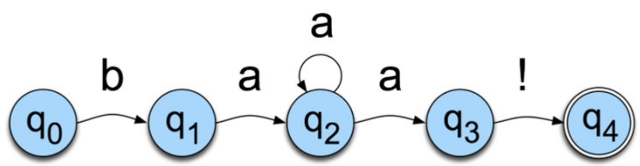


Example

1

2





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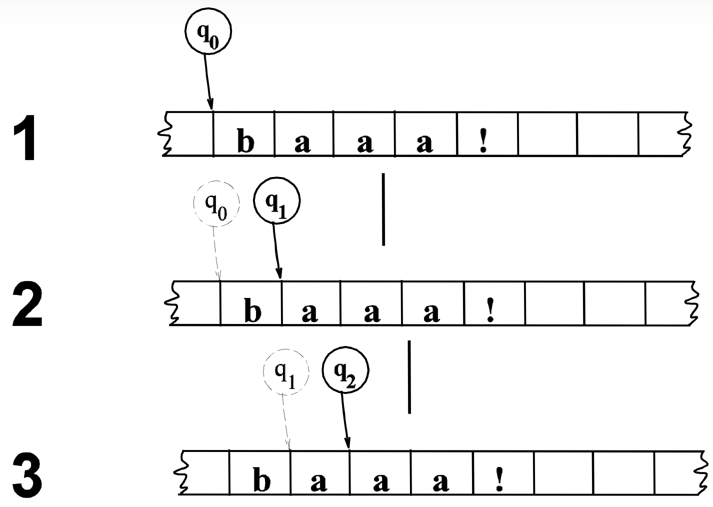

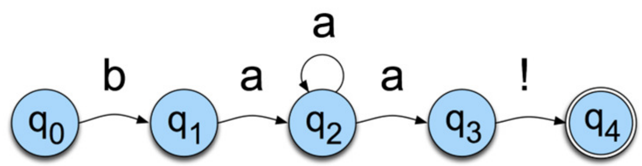

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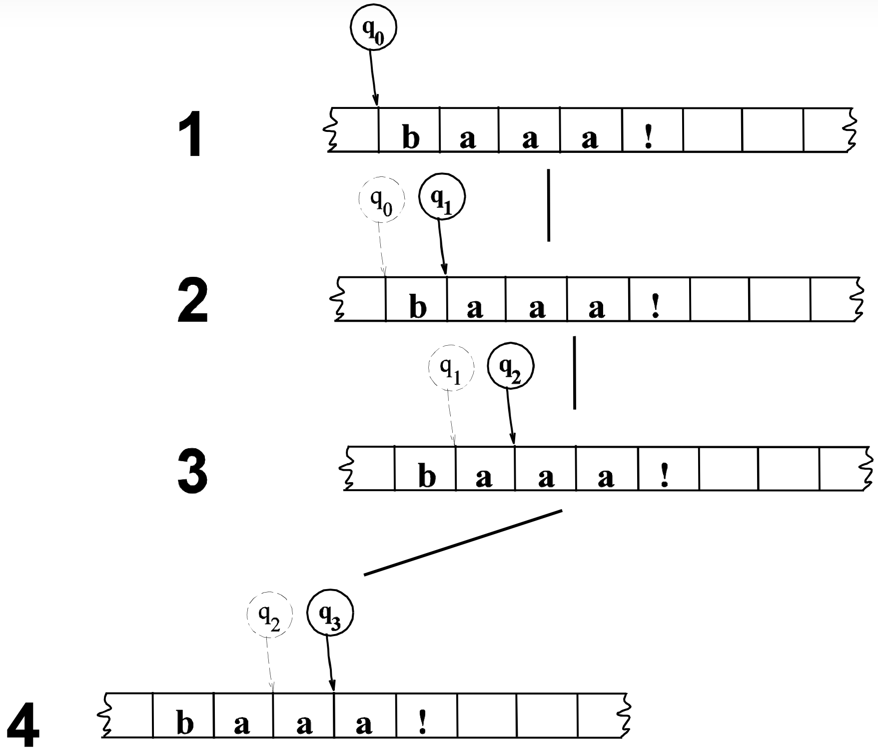

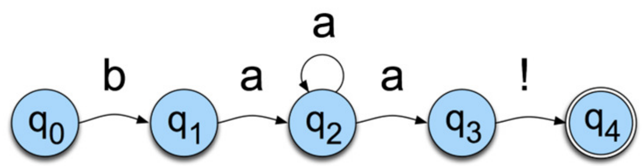

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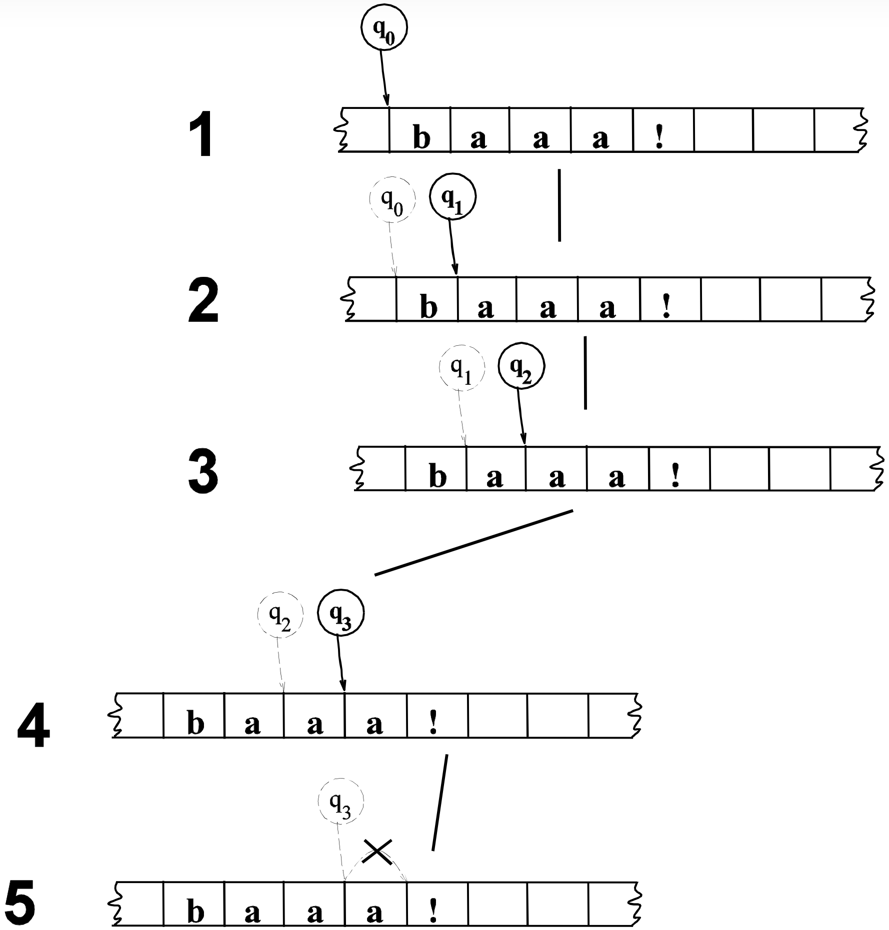

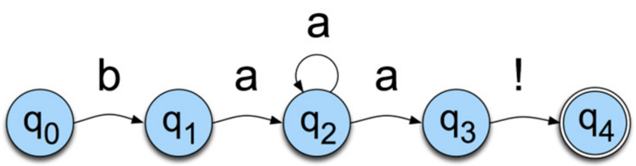

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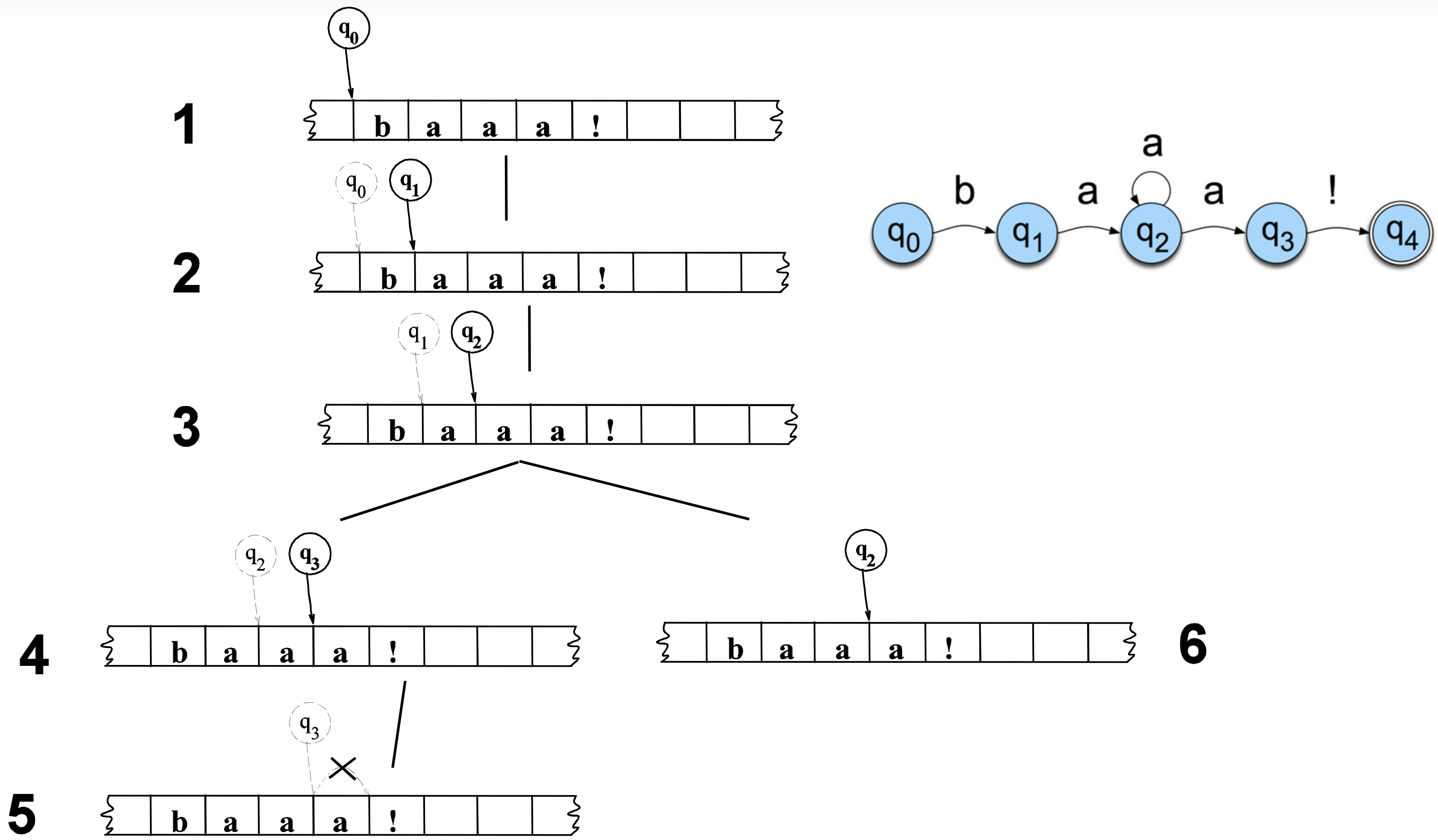

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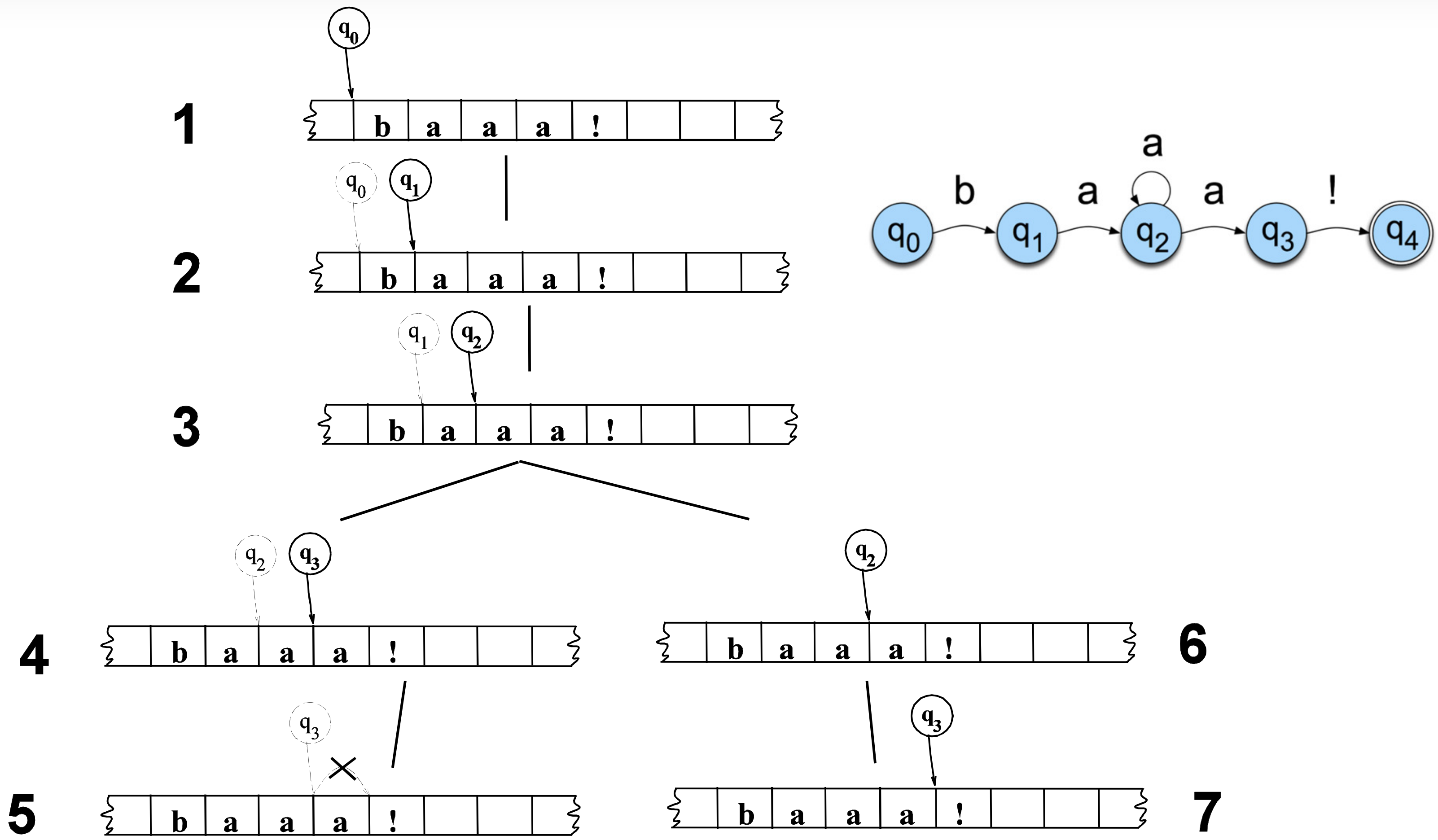

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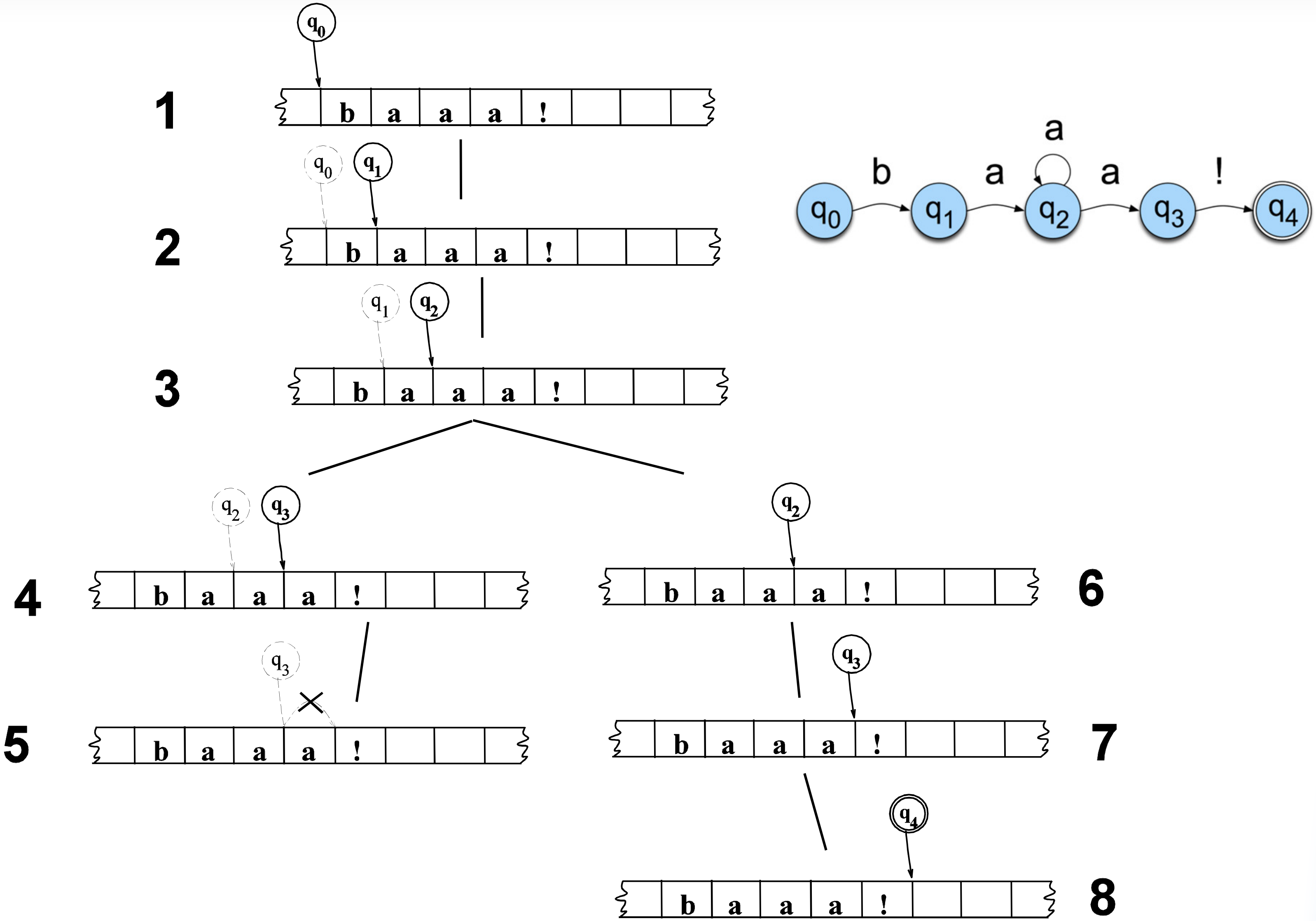


Key Points

- States in the search space are pairings of input positions and states in the machine.
- By keeping track of as yet unexplored states, a recognizer can systematically explore all the paths through the machine given an input.

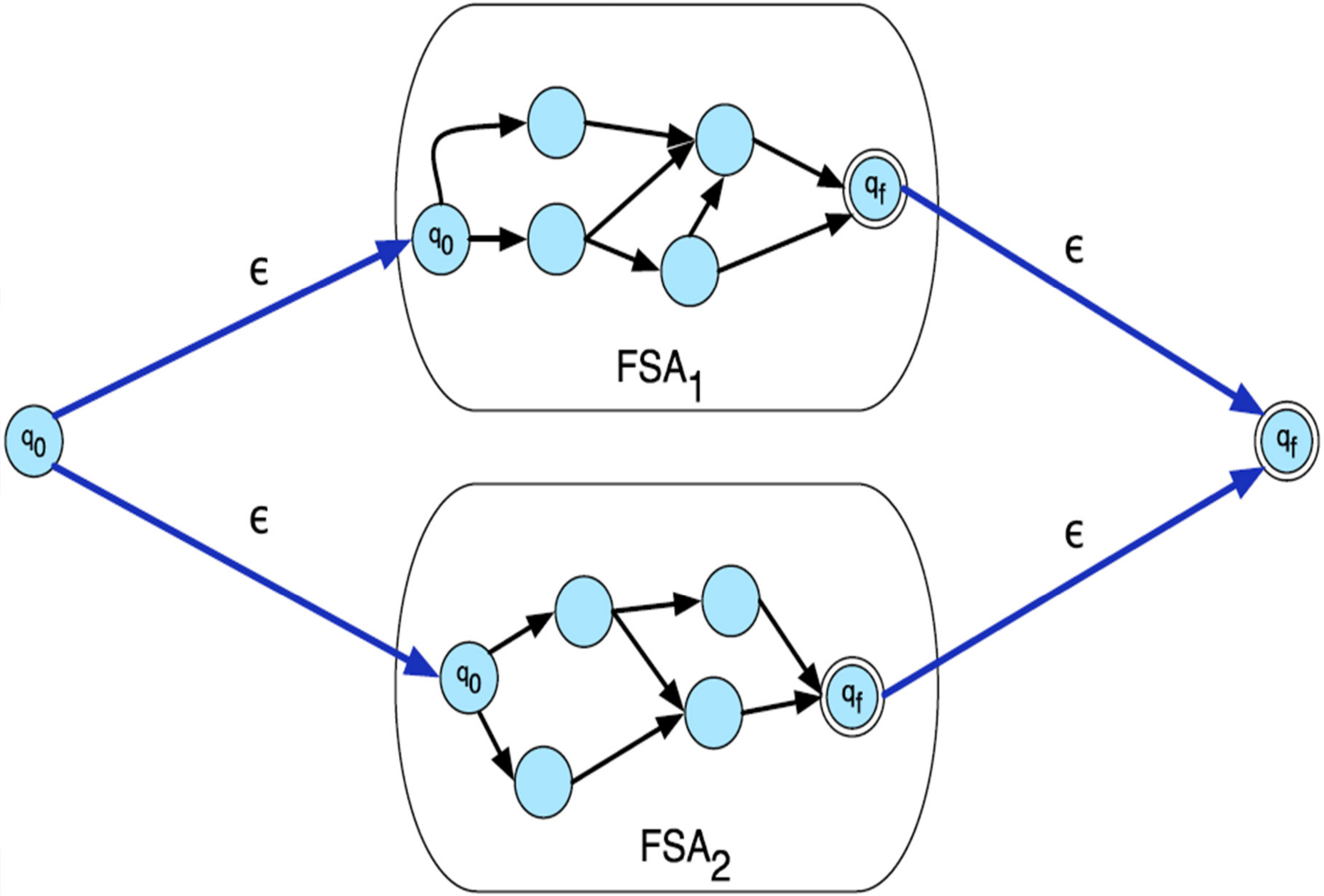
Why Bother?

- Non-determinism doesn’t get us more formal power and it causes headaches so why bother?
  - More natural (understandable) solutions
  - Regular expressions can (easily) be converted automatically to an NFA

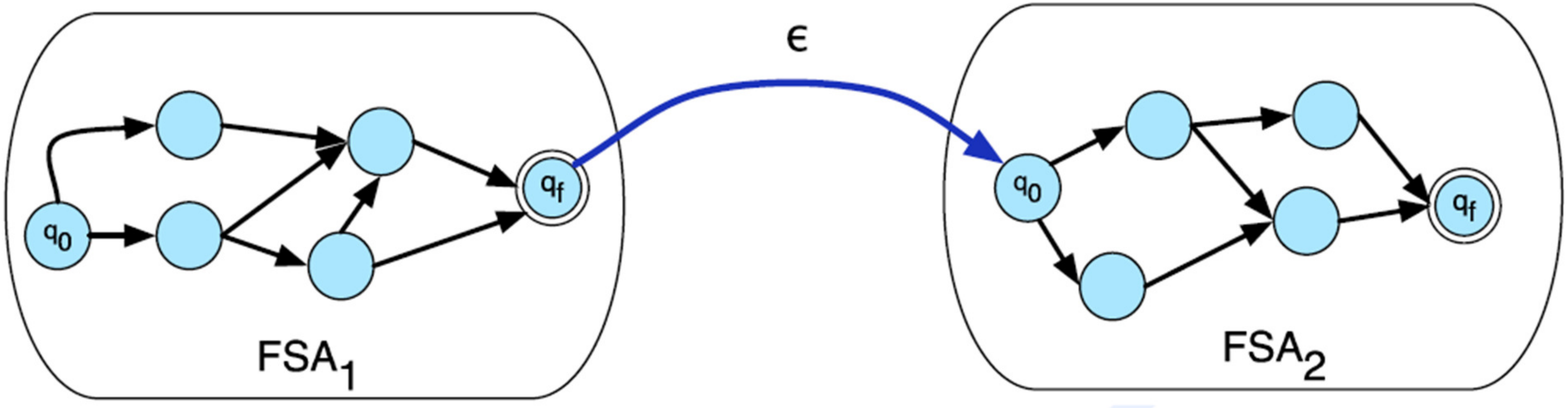
Compositional Machines

- Formal languages are just sets of strings
- Therefore, we can talk about various set operations (intersection, union, concatenation)
- This turns out to be a useful exercise

Union



Concatenation



Negation

- Construct a machine M2 to accept all strings not accepted by machine M1 and reject all the strings accepted by M1
  - Invert all the accept and not accept states in M1
- Does that work for non-deterministic machines?