Speech and Language Processing

Lecture 2

Chapter 2 of SLP

Today

- Finite-state methods

Regular Expressions and Text Searching

- Everybody does it
  - Emacs, vi, perl, grep, etc..
- Regular expressions are a compact textual representation of a set of strings representing a language.

Example

- 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 two fixing 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

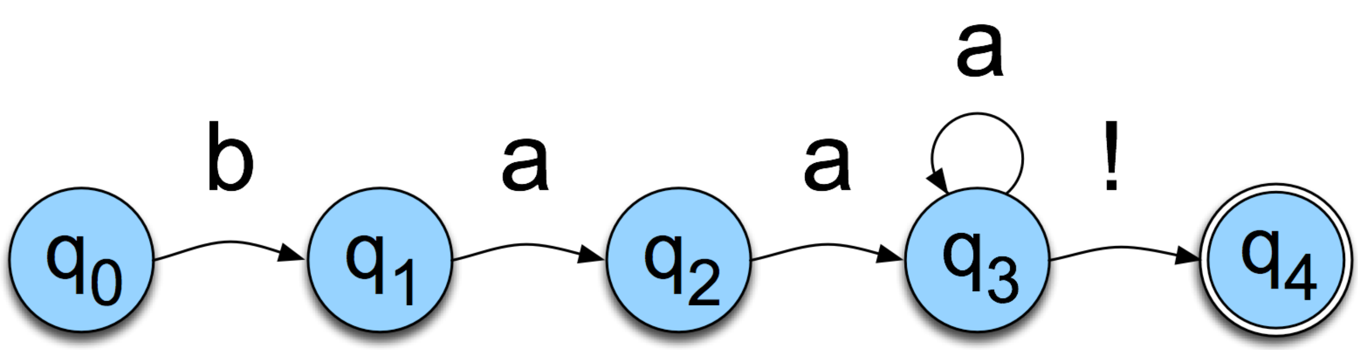
- We'll be telling the same story for many tasks, all semester. Reducing the error rate for an application often involves two antagonistic efforts:
  - Increasing accuracy, or precision, (minimizing false positives)
  - Increasing coverage, or recall, (minimizing false negatives).

Finite State Automata

- Regular expressions can be viewed as a textual way of specifying the structure of finite-state automata.
- 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.

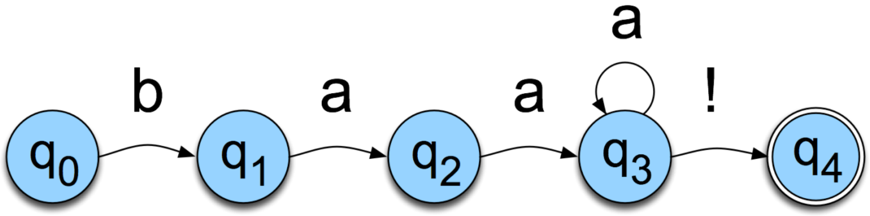
FSAs as Graphs

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



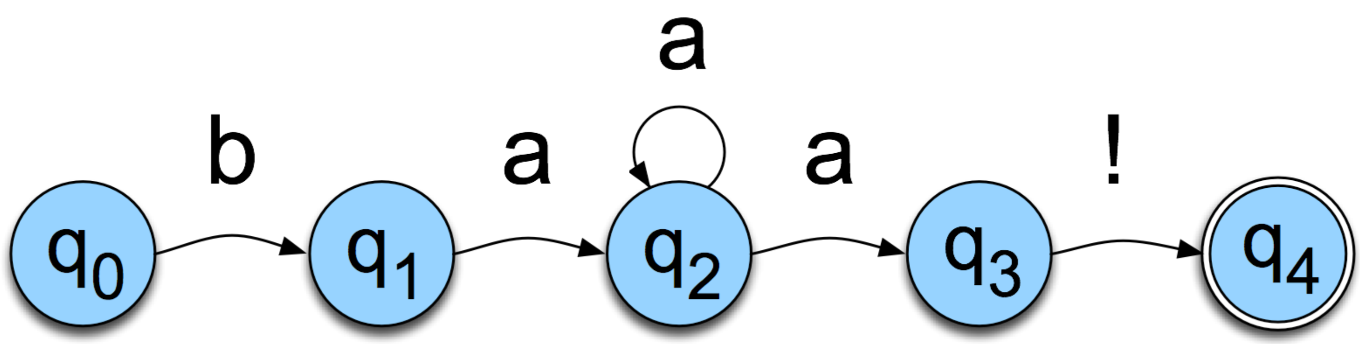
Sheep FSA

- 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

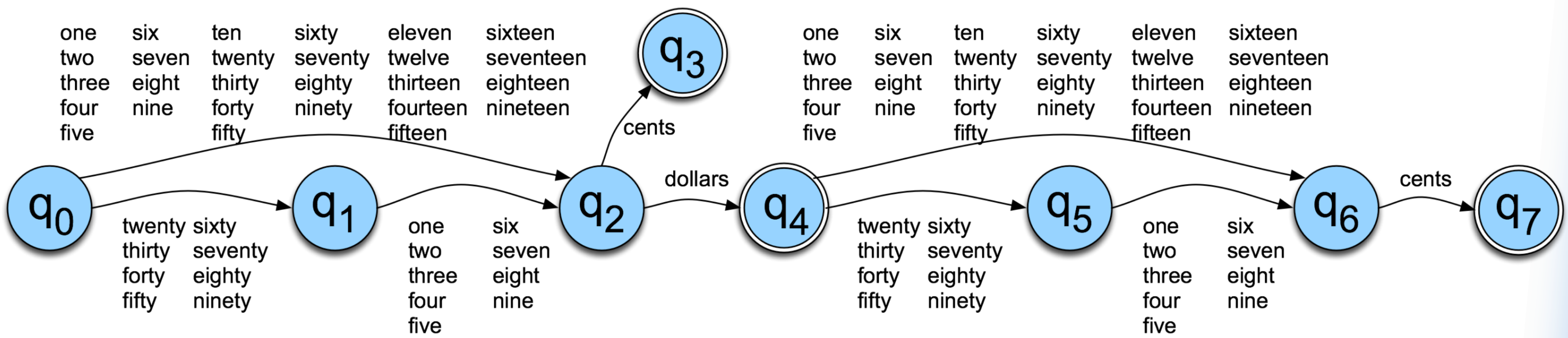
More Formally

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

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

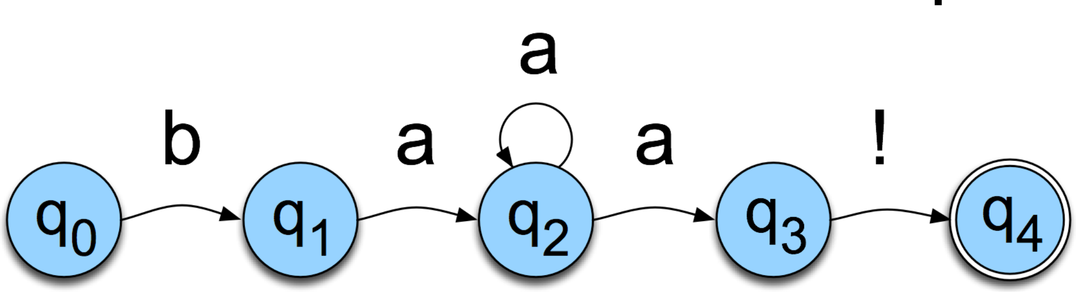


Yet Another View

- The guts of FSAs can ultimately be represented as tables

	b	a	!	e
0	1			
1		2		
2		2,3		
3			4	
4				

If you're in state 1 and you're looking at an a, go to state 2

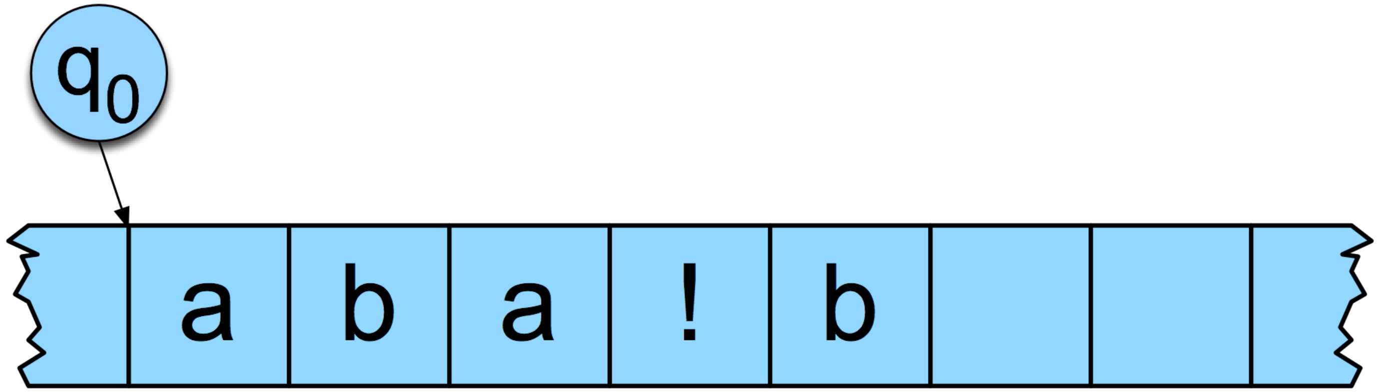


Recognition

- 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

- Traditionally, (Turing's notion) this process is depicted with a tape.



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 tape pointer.
- Until you run out of tape.

D-Recognize

```
function D-RECOGNIZE(tape, machine) returns accept or reject

  index ← Beginning of tape
  current-state ← Initial state of machine
  loop
   if End of input has been reached then
     if current-state is an accept state then
       return accept
     else
       return reject
   elsif transition-table[current-state,tape[index]] is empty then
     return reject
   else
     current-state ← transition-table[current-state,tape[index]]
     index ← index + 1
  end
```

Key Points

- Deterministic means that at each point in processing there is always one unique thing to do (no choices).
- D-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, etc.) is a matter of
  - translating the regular expression into a machine (a table) and
  - passing the table and the string to an interpreter

Recognition as Search

- You can view this algorithm as a trivial kind of *state-space search*.
- States are pairings of tape positions and state numbers.
- Operators are compiled into the table
- Goal state is a pairing with the end of tape position and a final accept state
- It is trivial because?

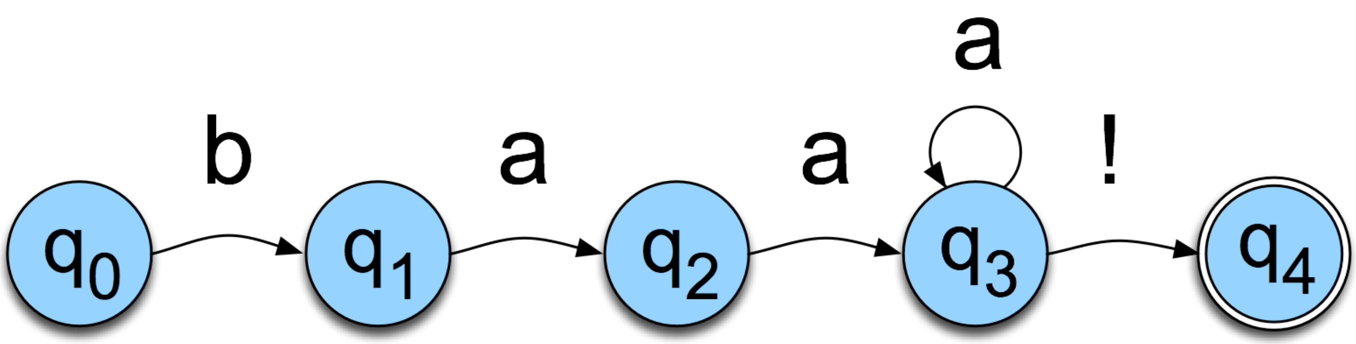
Generative Formalisms

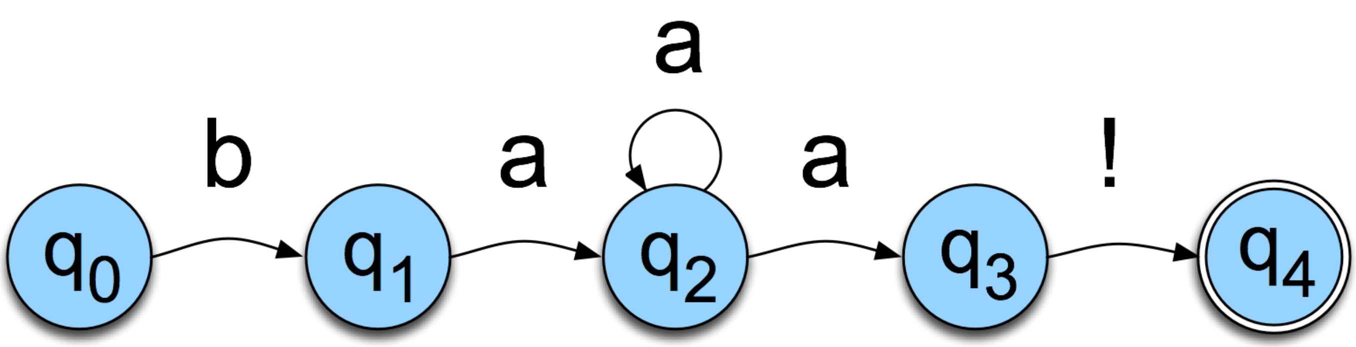
- *Formal Languages* are sets of strings composed of symbols from a finite set of symbols.
- Finite-state automata define formal languages (without having to enumerate all the strings in the language)
- The term *Generative* is based on the view that you can run the machine as a generator to get strings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

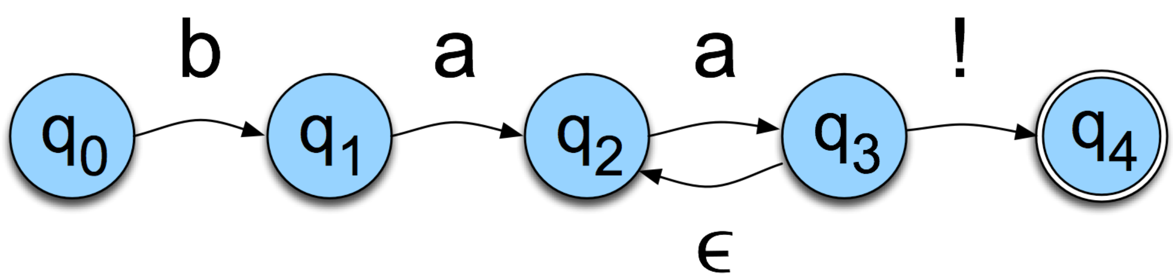
Non-Determinism





Non-Determinism cont.

- Yet another technique
  - Epsilon transitions
  - Key point: these transitions do not examine or advance the tape 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

ND Recognition

- Two basic approaches (used in all major implementations of regular expressions, see Friedl 2006)
  1. Either take a ND machine and convert it to a D 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).

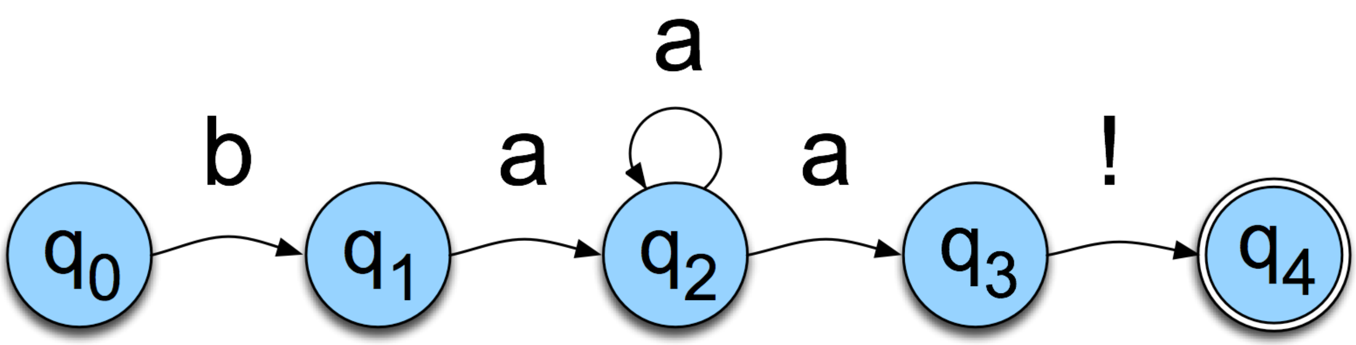
Non-Deterministic Recognition: Search

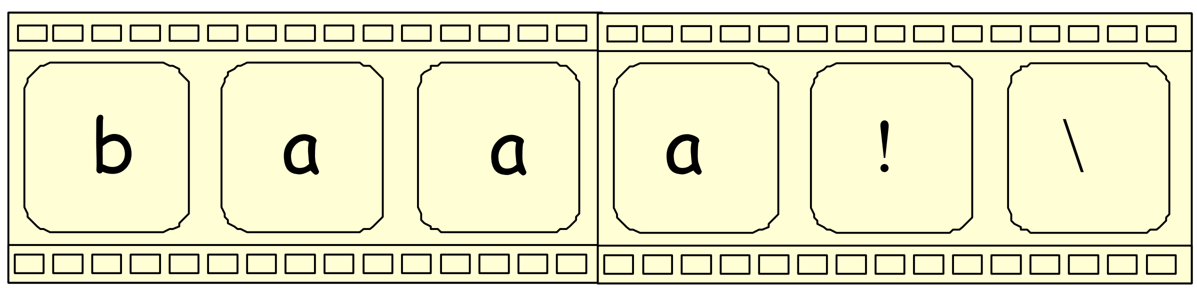
- In a ND FSA there exists at least one path through the machine for a string that is in the language defined by the machine.
- But not all paths directed through the machine for an accept string lead to an accept state.
- No paths through the machine lead to an accept state for a string not in the language.

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

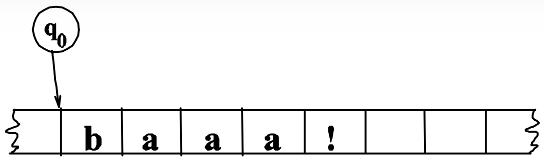


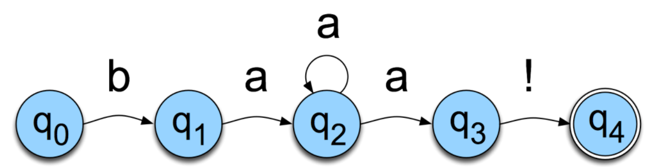


q_0 q_1 q_2 q_2 q_3 q_4

Example

1

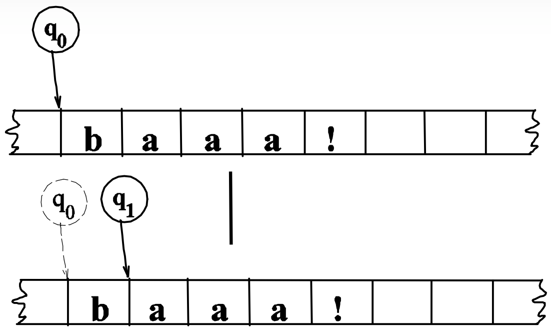


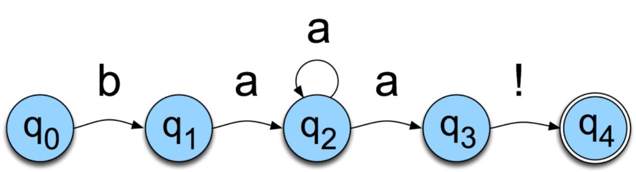


Example

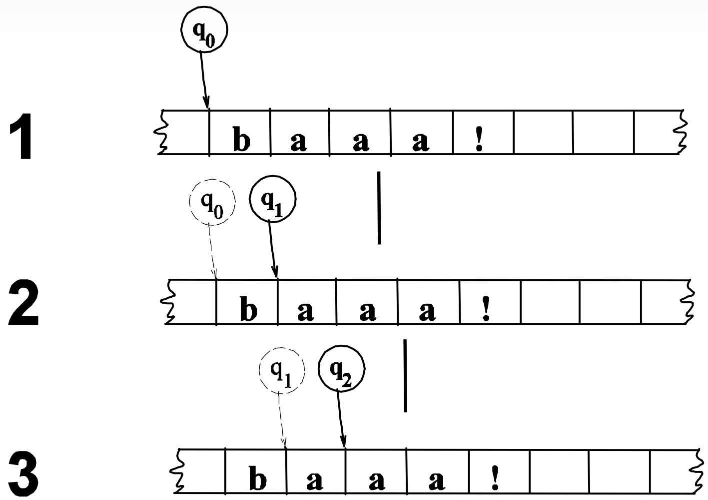
1

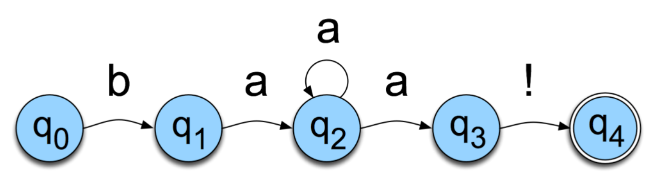
2





Example





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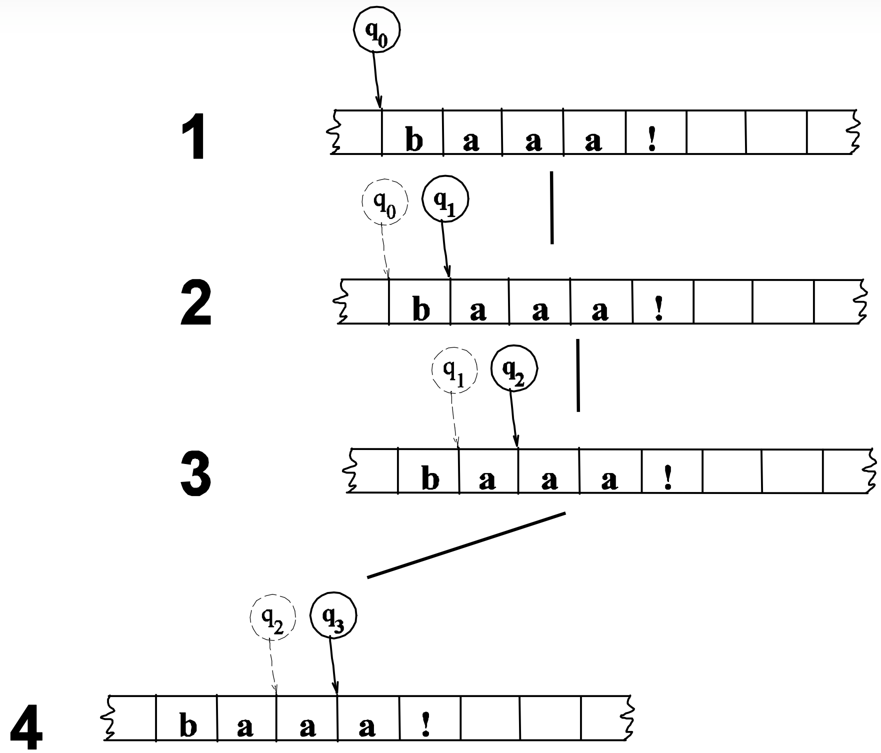

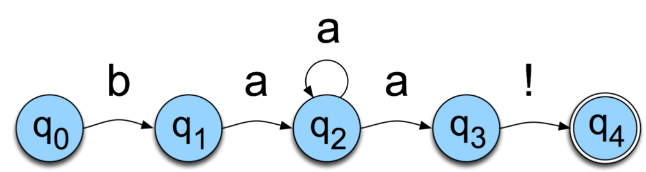

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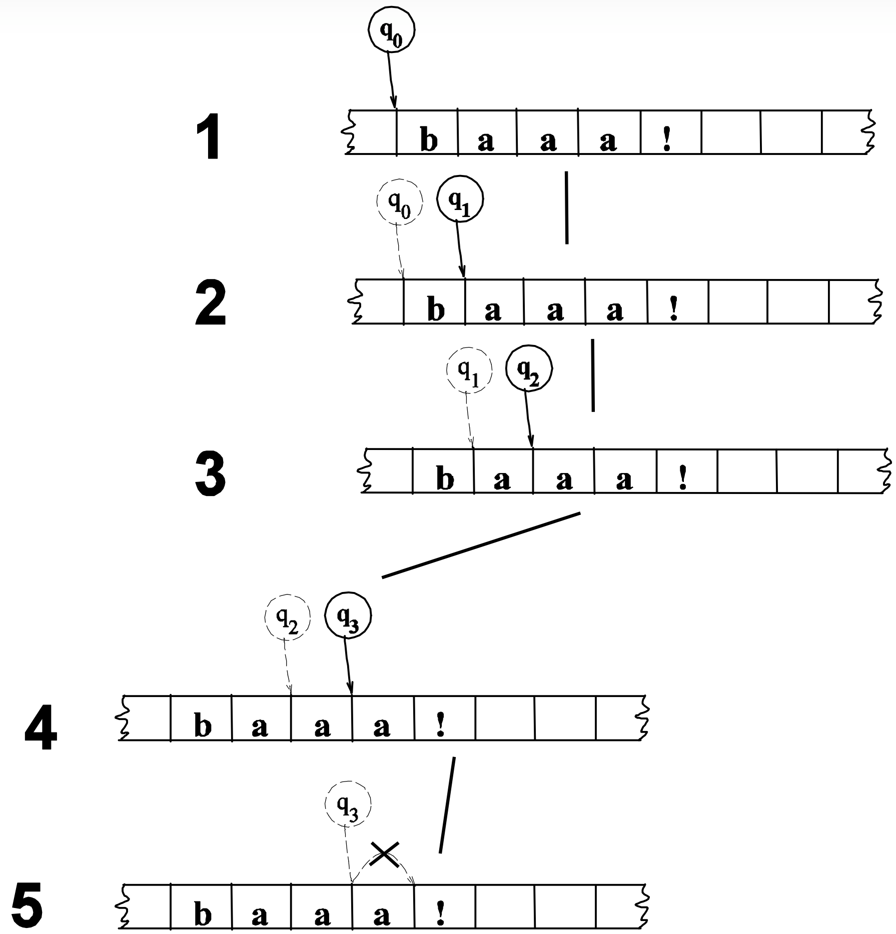

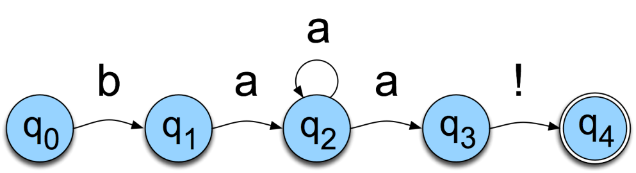

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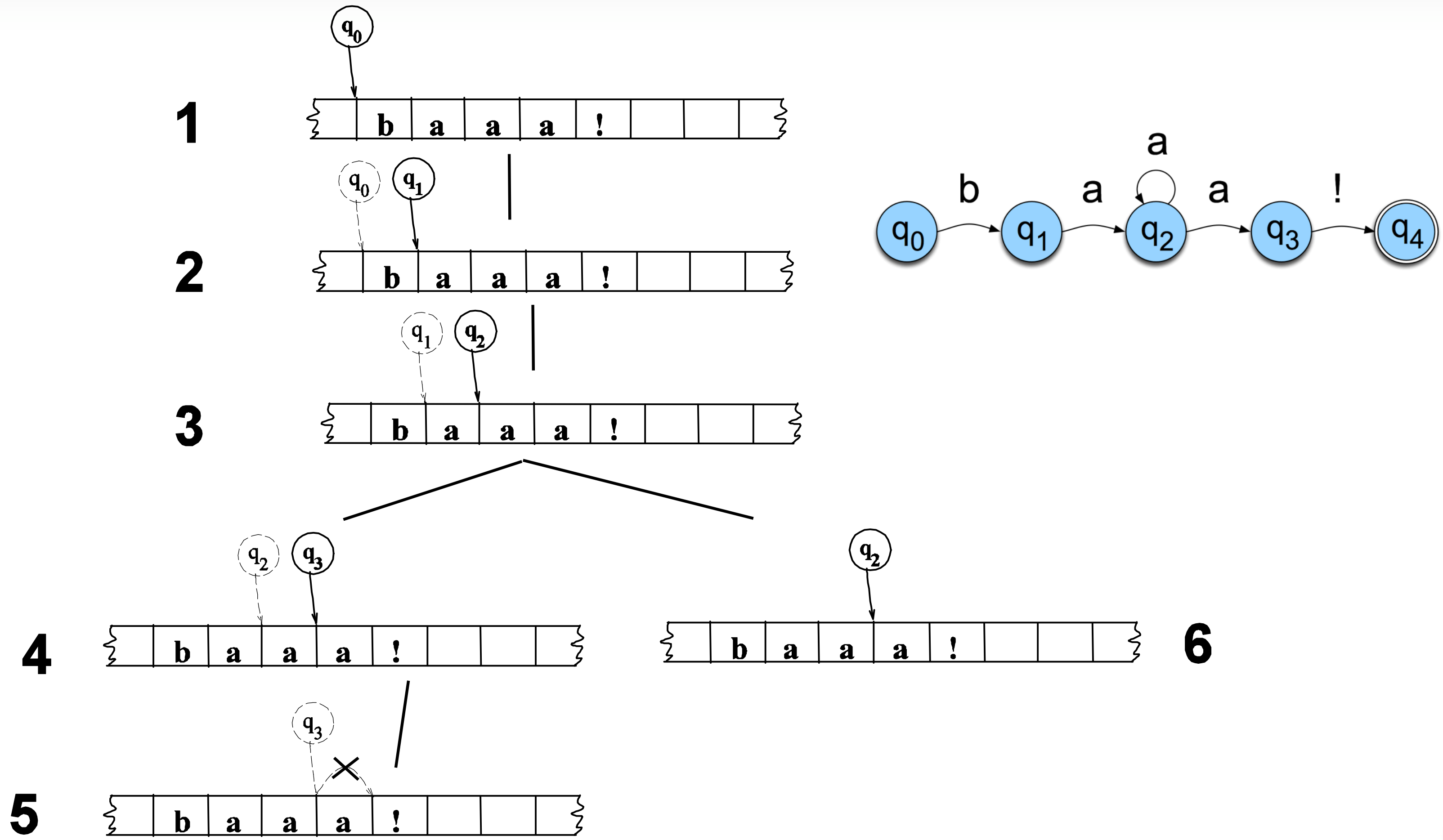

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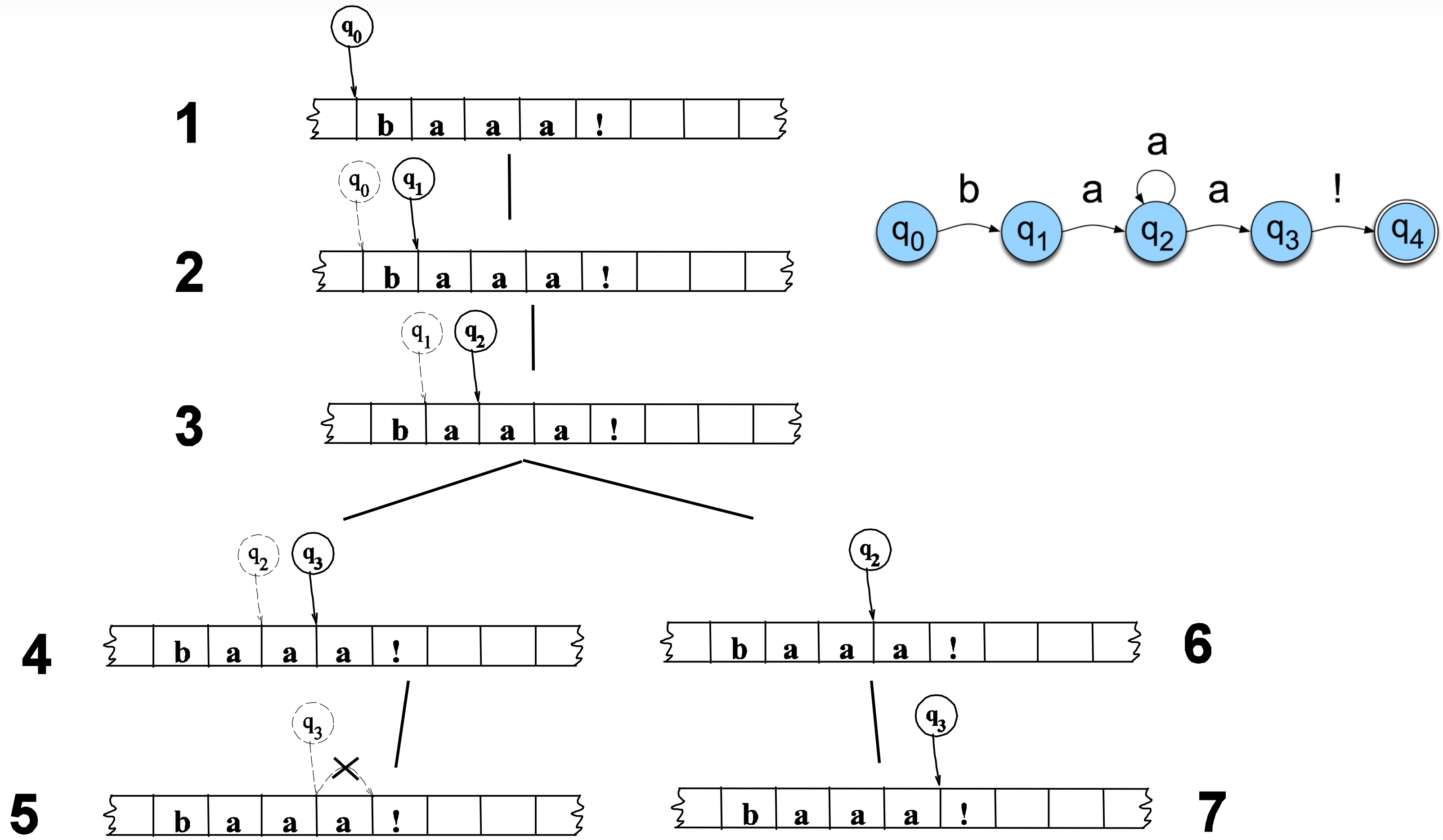

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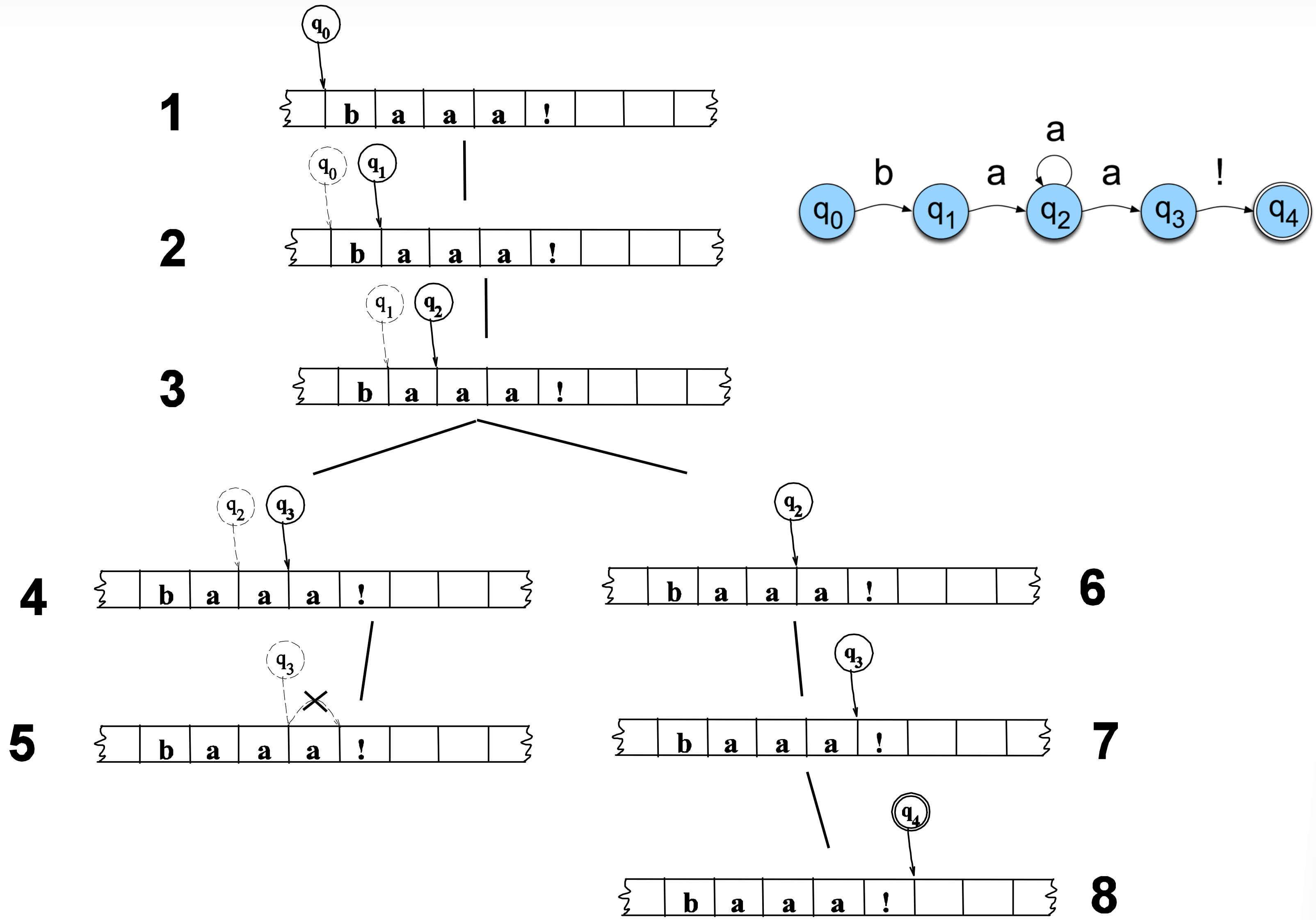


Key Points

- States in the search space are pairings of tape 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.

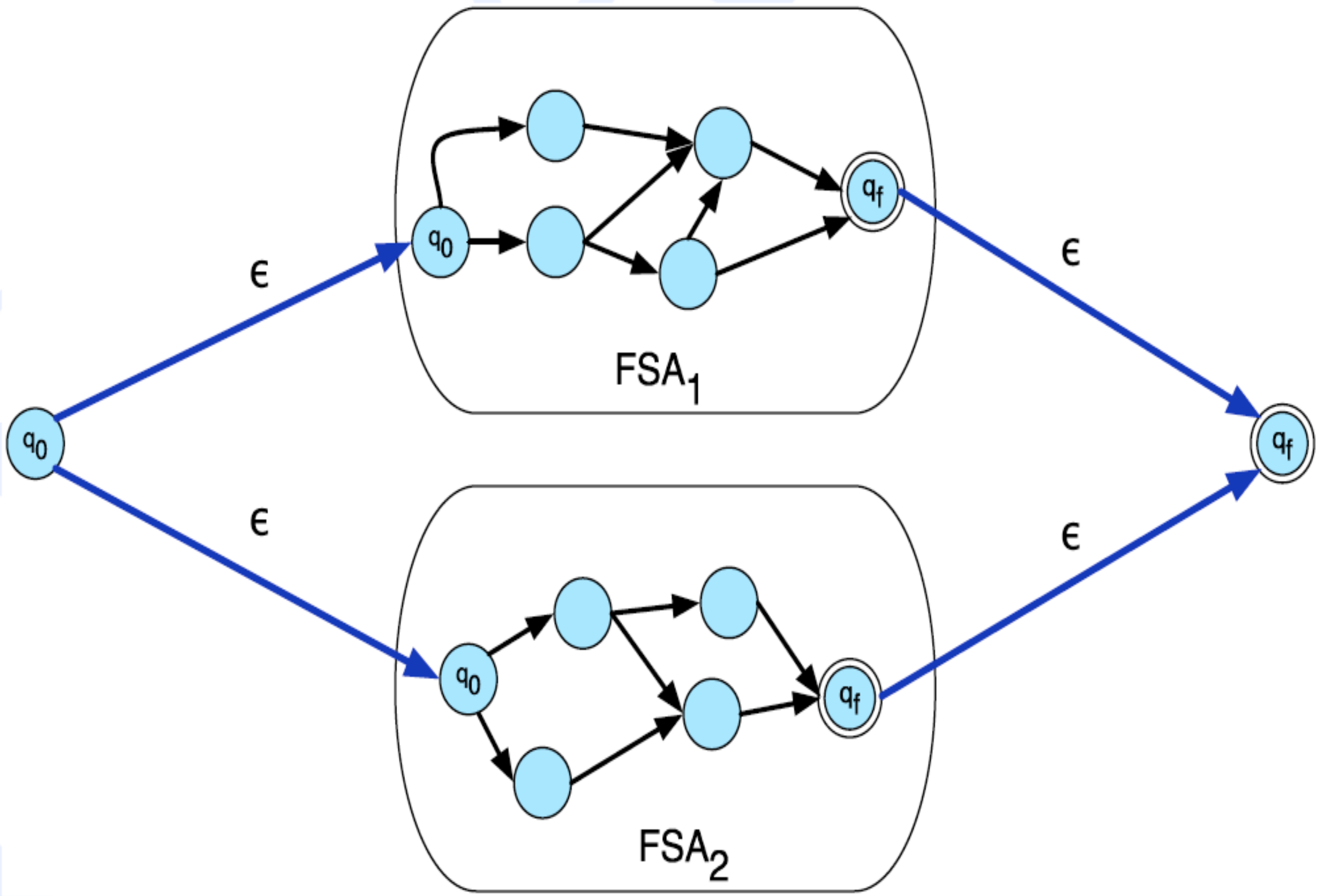
Why Bother?

- Non-determinism doesn't get us more formal power and it causes headaches so why bother?
  - More natural (understandable) solutions

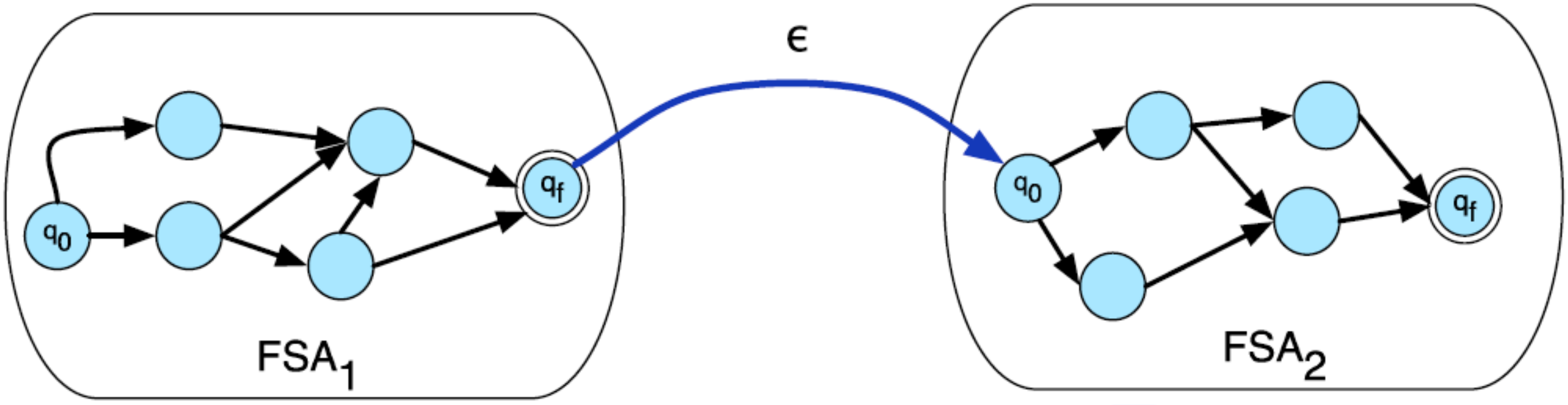
Compositional Machines

- 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?

Intersection

- Accept a string that is in both of two specified languages
- An indirect construction…
  - A^B = ~(~A or ~B)