Basic Text Processing

Regular Expressions

Regular expressions

- A formal language for specifying text strings
- How can we search for any of these?
  - woodchuck
  - woodchucks
  - Woodchuck
  - Woodchucks

Regular Expressions: Disjunctions

- Letters inside square brackets []

Pattern	Matches
[wW]oodchuck	*Woodchuck, woodchuck*
[1234567890]	*Any digit*

- Ranges [A-Z]

Pattern	Matches	
[A-Z]	*An upper case letter*	*Drenched Blossoms*
[a-z]	*A lower case letter*	*my beans were impatient*
[0-9]	*A single digit*	*Chapter 1: Down the Rabbit Hole*

Regular Expressions: Negation in Disjunction

- Negations `[^Ss]`
  - Carat means negation only when first in []

Pattern	Matches	
`[^A-Z]`	*Not an upper case letter*	`Oyfn pripetchik`
`[^Ss]`	*Neither 'S' nor 's'*	`I have no exquisite reason"`
`[^e^]`	*Neither e nor ^*	`Look here`
`a^b`	*The pattern a carat b*	`Look up a^b now`

Regular Expressions: More Disjunction

- Woodchucks is another name for groundhog!
- The pipe | for disjunction

Pattern	Matches
groundhog|woodchuck	
yours|mine	yours
a|b|c	= [abc]
[gG]roundhog|[Ww]oodchuck	

Regular Expressions: ?   *   +   .

Pattern	Matches	
colou?r	Optional previous char	color colour
oo*h!	0 or more of previous char	oh! ooh! oooh! ooooh!
o+h!	1 or more of previous char	oh! ooh! oooh! ooooh!
baa+		baa baaa baaaa baaaaa
beg.n		begin begun begun beg3n

Stephen C Kleene

Kleene *, Kleene +

Regular Expressions: Anchors ^ $

Pattern	Matches
`^[A-Z]`	Palo Alto
`^[^A-Za-z]`	1 "Hello"
`\.$`	The end.
`.$`	The end? The end!

'the' example [in terminal]

The Example

- Find me all instances of the word "the" in a text.

  `the`

  Misses capitalized examples

  `[tT]he`

  Incorrectly returns `other` or `theology`

  `[^a-zA-Z][tT]he[^a-zA-Z]`

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 cont.

- In text processing, we are always dealing with these kinds of errors.
- 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).

Summary

- Regular expressions play a surprisingly large role
  - Sophisticated sequences of regular expressions are often the first model for any text processing text
- For many hard tasks, we use machine learning classifiers
  - But regular expressions are used as features in the classifiers
  - Can be very useful in capturing generalizations

Basic Text Processing

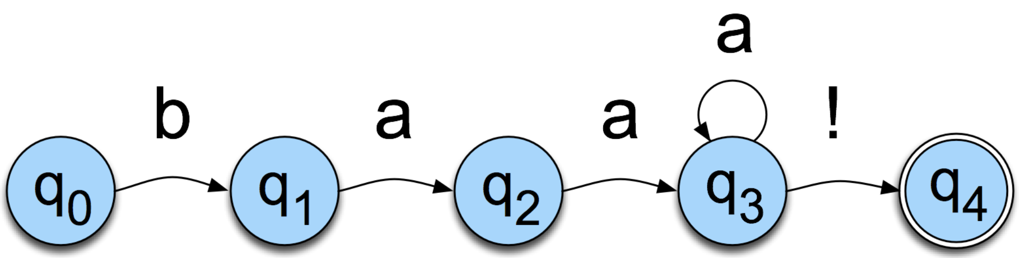
Regular Expressions

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 quarter.
- They also capture significant aspects of what linguists say we need for morphology and parts of syntax.

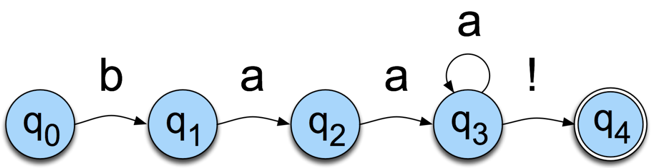
FSAs as Graphs

- Let’s start with the sheep language
  - /baa+!/



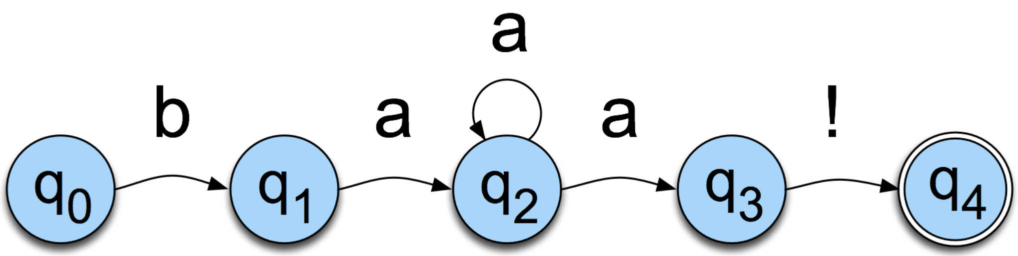
Sheep FSA

- 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

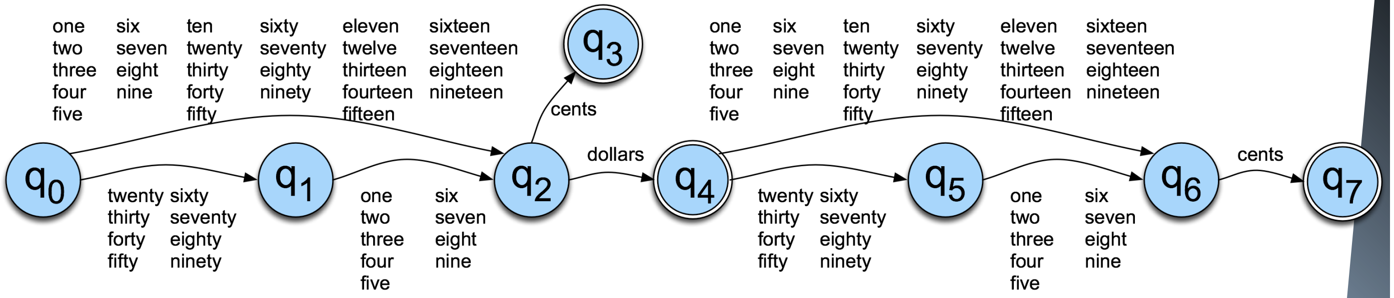
More Formally

- 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

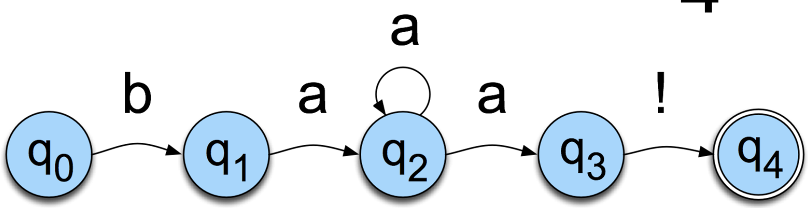


Yet Another View

- 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

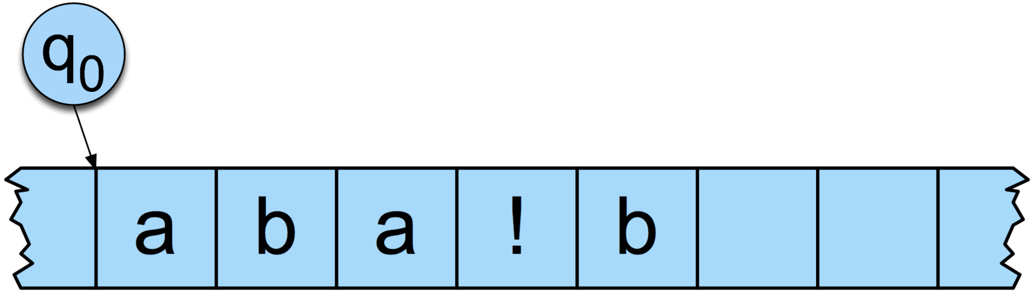


Recognition

- 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?

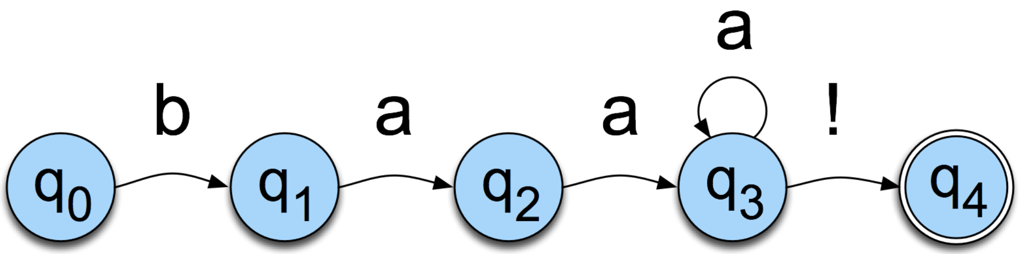
Generative Formalisms

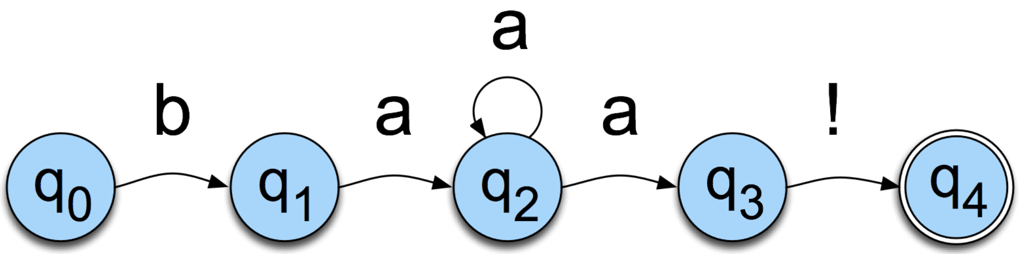
- Formal Languages are sets of strings composed of symbols from a finite set of symbols.
- Finite-state automata define formal languages (without having to enumerate all the strings in the language)
- The term Generative is based on the view that you can run the machine as a generator to get strings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

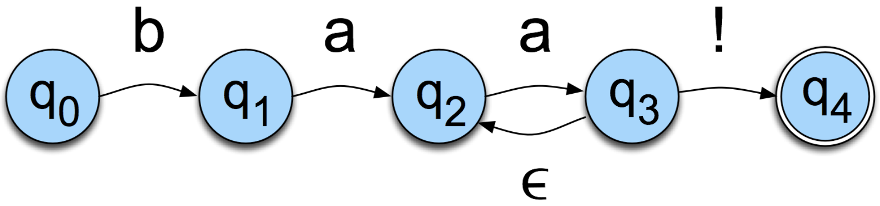
Non-Determinism





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).

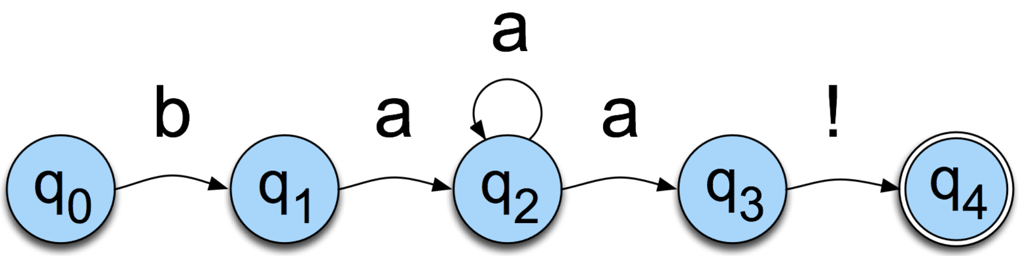
Non-Deterministic Recognition: Search

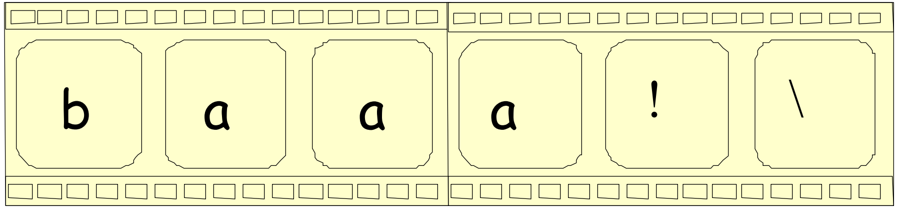
- In a ND FSA there exists at least one path through the machine for a string that is in the language defined by the machine.
- But not all paths directed through the machine for an accept string lead to an accept state.
- No paths through the machine lead to an accept state for a string not in the language.

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

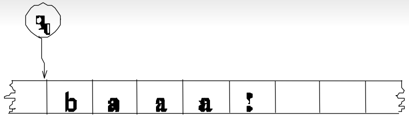


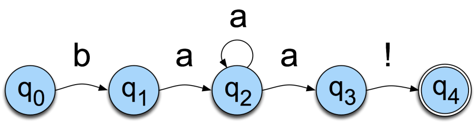


q_0 q_1 q_2 q_2 q_3 q_4

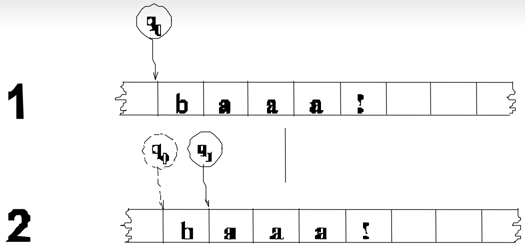
Example

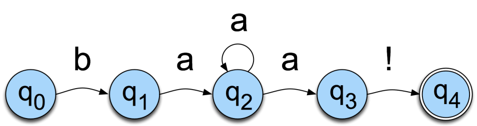
1



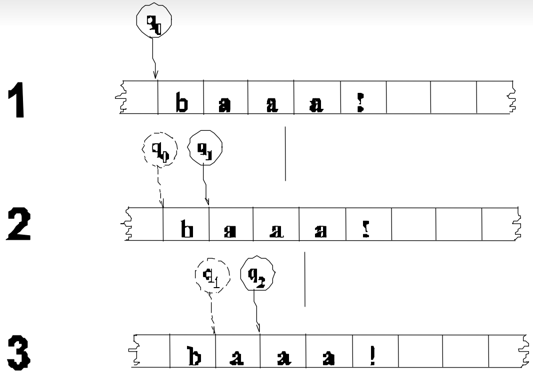


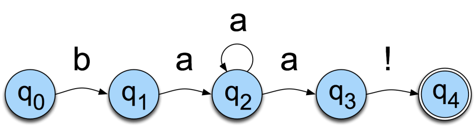
Example



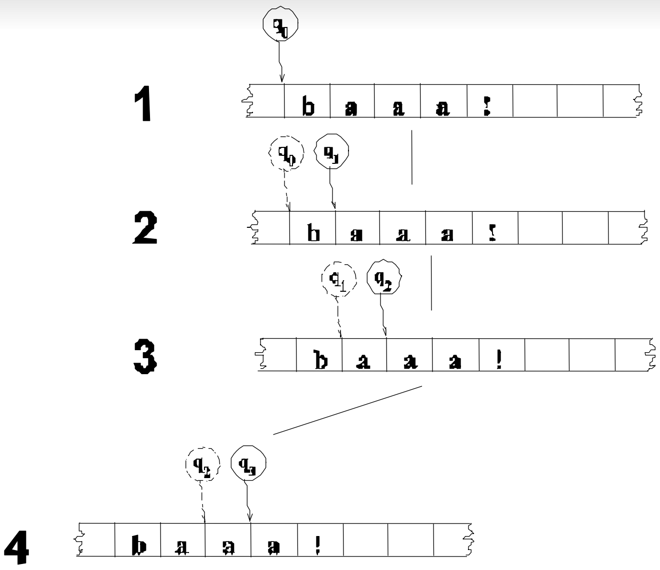


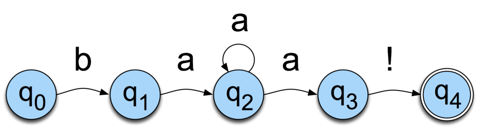
Example



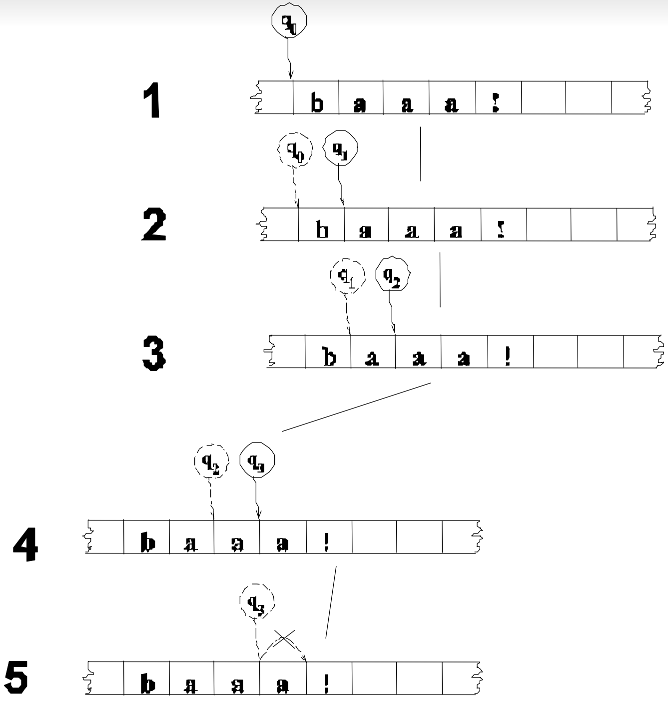


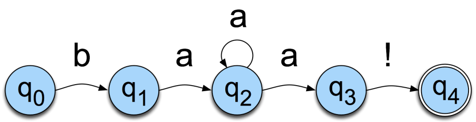
Example



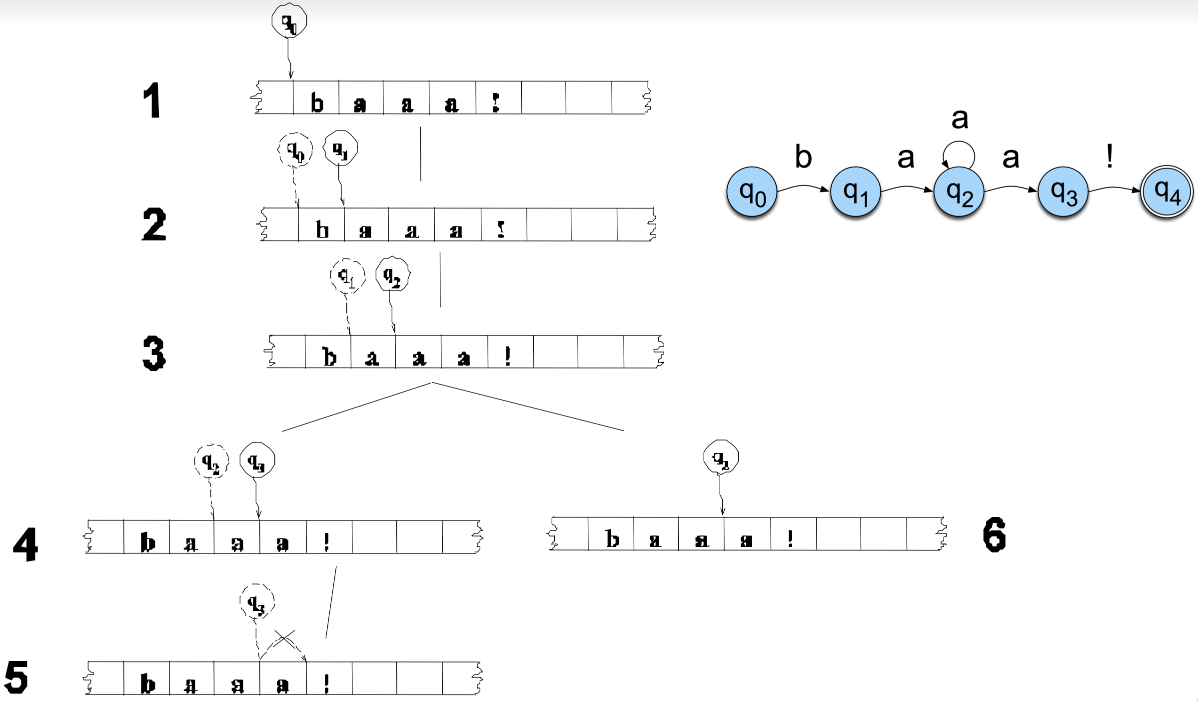


Example

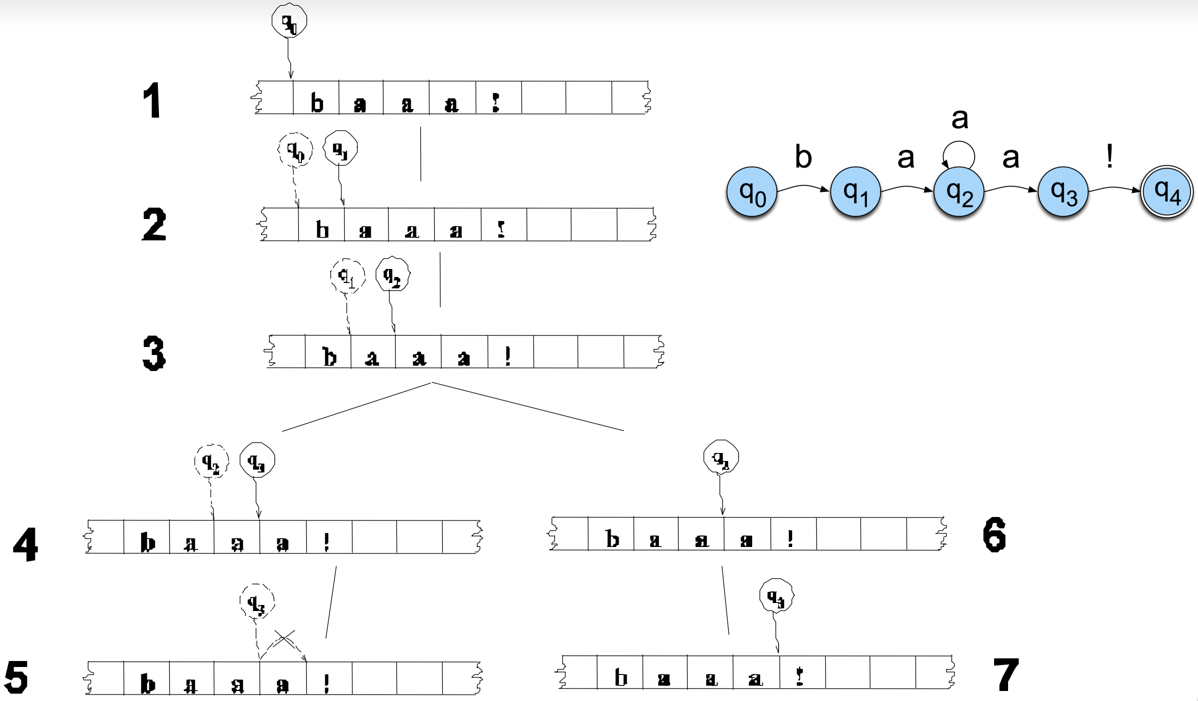

1
b a a a !
q_0
2
b a a a !
q_0 q_1
3
b a a a !
q_1 q_2
4
b a a a !
q_2 q_3
5
b a a a !
q_3


q_0
b
q_1
a
q_2
a
a
q_3
!
q_4

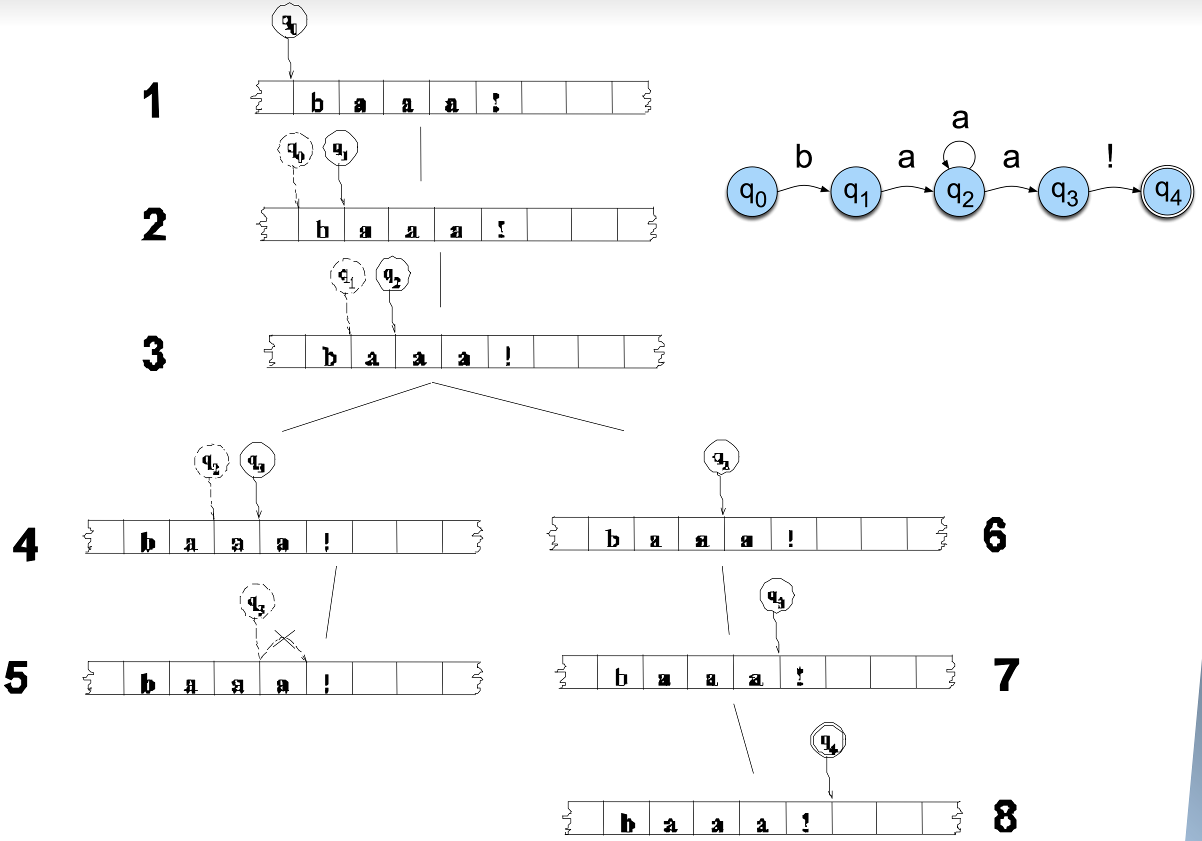
Example



Example



Example



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.

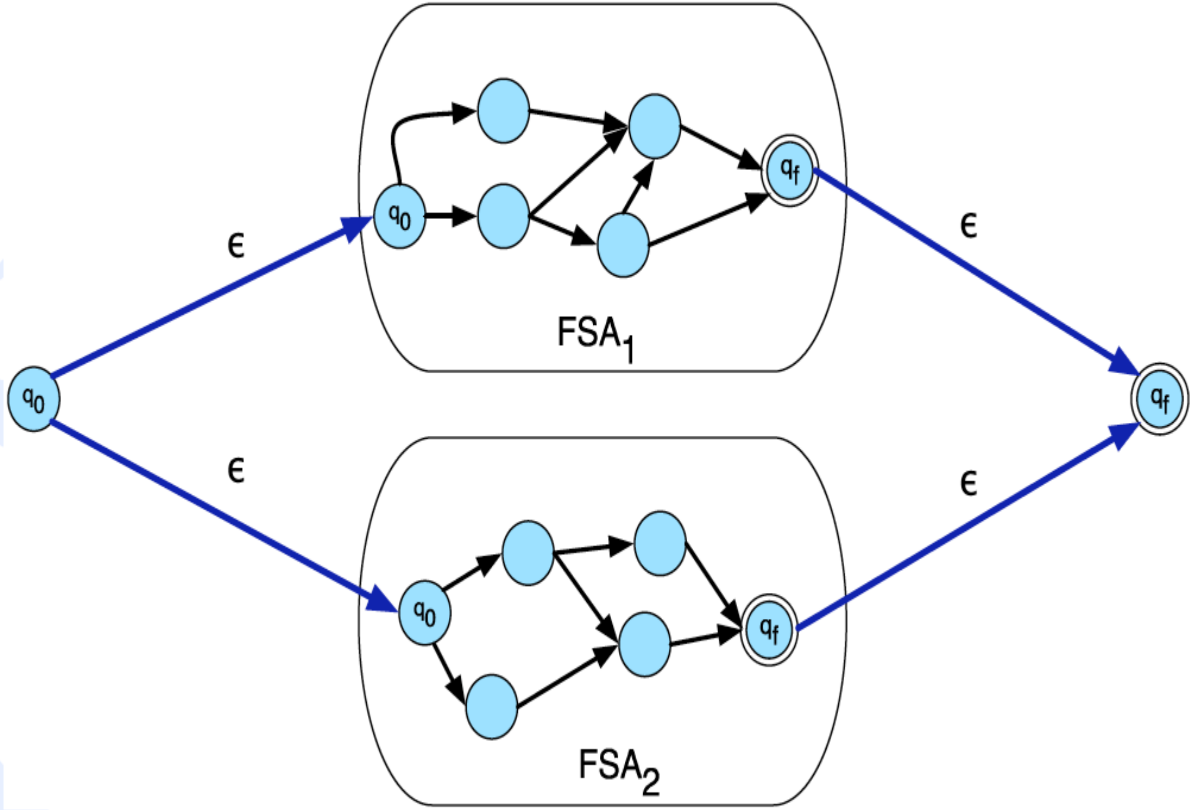
Why Bother?

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

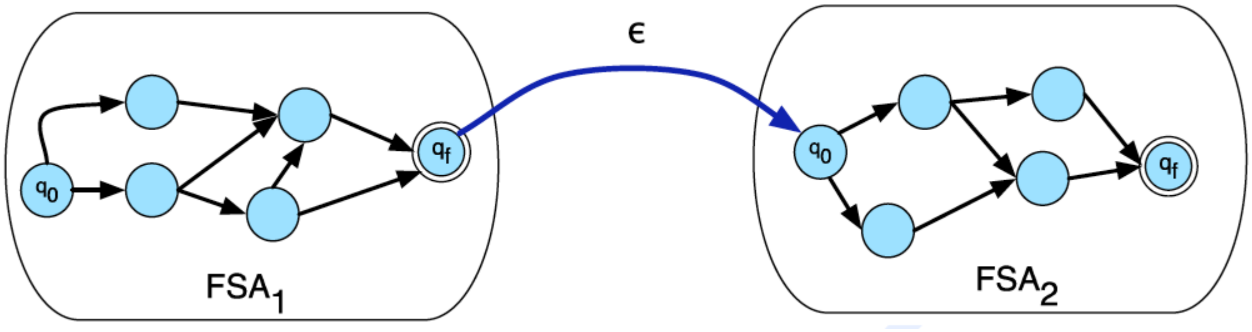
Compositional Machines

- 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



Basic Text Processing

Word tokenization

Text Normalization

- Every NLP task needs to do text normalization:
  1. Segmenting/tokenizing words in running text
  2. Normalizing word formats
  3. Segmenting sentences in running text

How many words?

- I do uh main- mainly business data processing
  - Fragments, filled pauses
- Seuss's cat in the hat is different from other cats!
  - **Lemma**: same stem, part of speech, rough word sense
    - cat and cats = same lemma
  - **Wordform**: the full inflected surface form
    - cat and cats = different wordforms

How many words?

they lay back on the San Francisco grass and looked at the stars and their

- **Type**: an element of the vocabulary.
- **Token**: an instance of that type in running text.
- How many?
  - 15 tokens (or 14)
  - 13 types (or 12) (or 11?)

How many words?

N = number of tokens

V = vocabulary = set of types

$|V|$ is the size of the vocabulary

Church and Gale (1990): $|V| > O(N^{\frac{1}{2}})$

	Tokens = N	**Types = |V|**
Switchboard phone	***2.4 million***	***20 thousand***
Shakespeare	***884,000***	***31 thousand***
Google N-grams	***1 trillion***	***13 million***

Issues in Tokenization

- Finland's capital → Finland Finlands Finland's ?
- what're, I'm, isn't → What are, I am, is not
- Hewlett-Packard → Hewlett Packard ?
- state-of-the-art → state of the art ?
- Lowercase → lower-case lowercase lower case ?
- San Francisco → one token or two?
- m.p.h., PhD. → ??

Tokenization: language issues

- French
  - ***L'ensemble*** → one token or two?
    - ***L*** ? ***L’*** ? ***Le*** ?
    - Want ***l’ensemble*** to match with ***un ensemble***
- German noun compounds are not segmented
  - ***Lebensversicherungsgesellschaftsangestellter***
  - ‘life insurance company employee’
  - German information retrieval needs **compound splitter**

Tokenization: language issues

- Chinese and Japanese no spaces between words:
  - 莎拉波娃现在居住在美国东南部的佛罗里达。
  - 莎拉波娃 现在 居住 在 美国 东南部 的 佛罗里达
  - Sharapova now lives in US southeastern Florida
- Further complicated in Japanese, with multiple alphabets intermingled
  - Dates/amounts in multiple formats

フォーチュン500社は情報不足のため時間あた$500K(約6,000万円)

Katakana Hiragana Kanji Romaji

End-user can express query entirely in hiragana!

Word Tokenization in Chinese

- Also called **Word Segmentation**
- Chinese words are composed of characters
  - Characters are generally 1 syllable and 1 morpheme.
  - Average word is 2.4 characters long.
- Standard baseline segmentation algorithm:
  - Maximum Matching (also called Greedy)

Maximum Matching
Word Segmentation Algorithm

- Given a wordlist of Chinese, and a string.

1) Start a pointer at the beginning of the string
2) Find the longest word in dictionary that matches the string starting at pointer
3) Move the pointer over the word in string
4) Go to 2

Max-match segmentation illustration

- Thecatinthehat
- Thetabledownthere

the cat in the hat

the table down there

theta bled own there

- Doesn't generally work in English!

- But works astonishingly well in Chinese
  - 莎拉波娃现在居住在美国东南部的佛罗里达。
  - 莎拉波娃 现在 居住 在 美国 东南部 的 佛罗里达
- Modern probabilistic segmentation algorithms even better

Basic Text Processing

Word tokenization