Finite-State Morphology

CMSC 723 / LING 723 / INST 725

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Recall: Morphological Analysis

- Morpheme = smallest linguistic unit that has meaning

- Morphemes are combined into words
  - duck + s = [$_N$ duck] + [$_{plural}$ s]
  - duck + s = [$_V$ duck] + [$_{3rd\ person\ singular}$ s]
  - happiness = [$_{Adj}$ happy] + [ness]

Recall: Complex Morphology

In Turkish, from the root "uyu-" (sleep), the following can be derived…

uyuyorum	I am sleeping
uyuyorsun	you are sleeping
uyuyor	he/she/it is sleeping
uyuyoruz	we are sleeping
uyuyorsunuz	you are sleeping
uyuyorlar	they are sleeping
uyuduk	we slept
uyudukça	as long as (somebody) sleeps
uyumalıyız	we must sleep
uyumadan	without sleeping
uyuman	your sleeping
uyurken	while (somebody) is sleeping
uyuyunca	when (somebody) sleeps
uyutmak	to cause somebody to sleep
uyutturmak	to cause (somebody) to cause (another) to sleep

uyutturtturmak to cause (somebody) to cause (some other) to cause (yet another) to sleep

. .

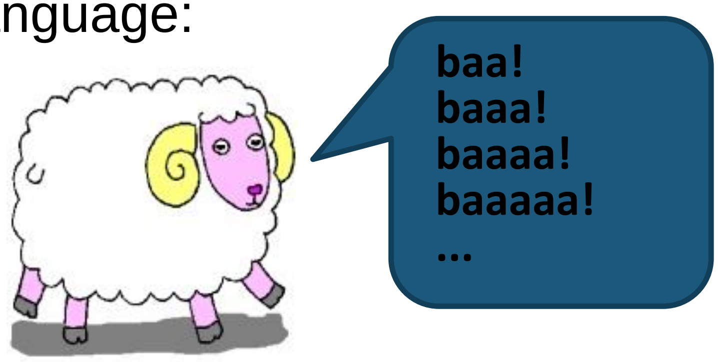
Today

- Computational tools
  - Finite-state automata
  - Finite-state transducers

- Morphology
  - Introduction to morphological processes
  - Computational morphology with finite-state methods

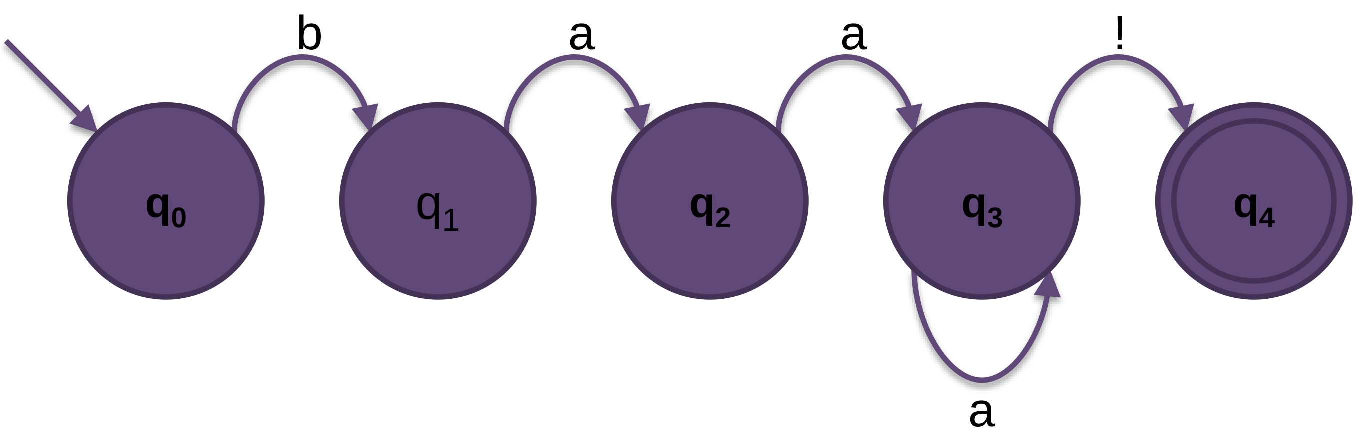
Sheeptalk!

Language:



Regular Expression:
/baa+!/

Finite-State Automaton:

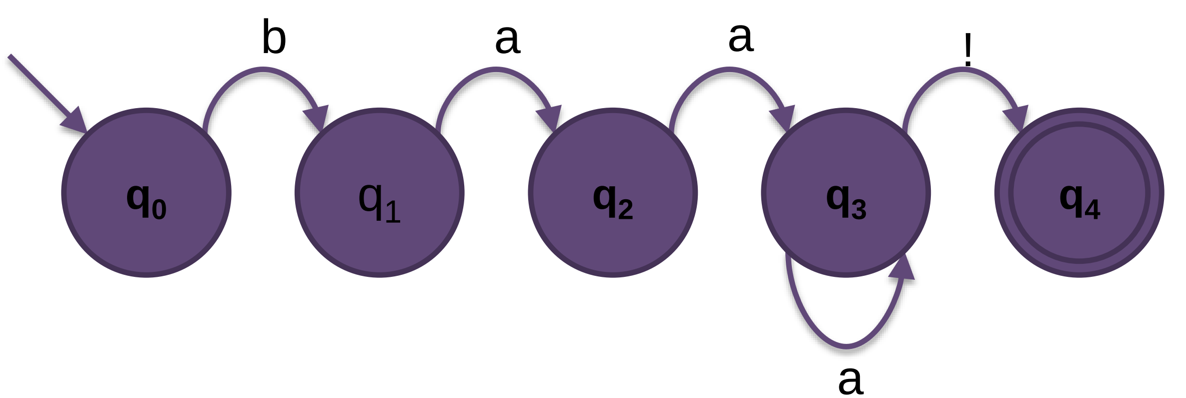


Finite-State Automata

- What are they?
- What do they do?
- How do they work?

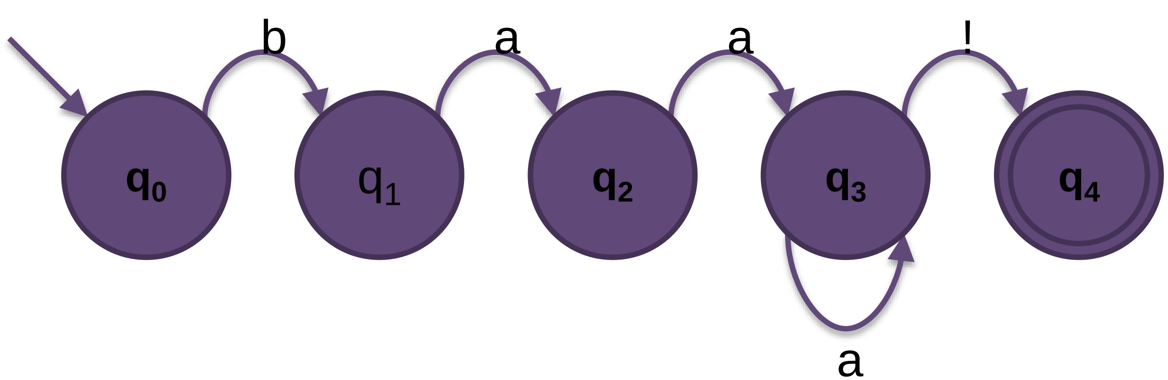
FSA: What are they?

- Q: a finite set of N states
  - Q = $\{q_0, q_1, q_2, q_3, q_4\}$
  - The start state: q_0
  - The set of final states: F = $\{q_4\}$
- Σ: a finite input alphabet of symbols
  - Σ = $\{a, b, !\}$
- $\delta(q,i)$: transition function
  - Given state q and input symbol i, return new state q'
  - $\delta(q_3,!) \rightarrow q_4$



FSA: State Transition Table

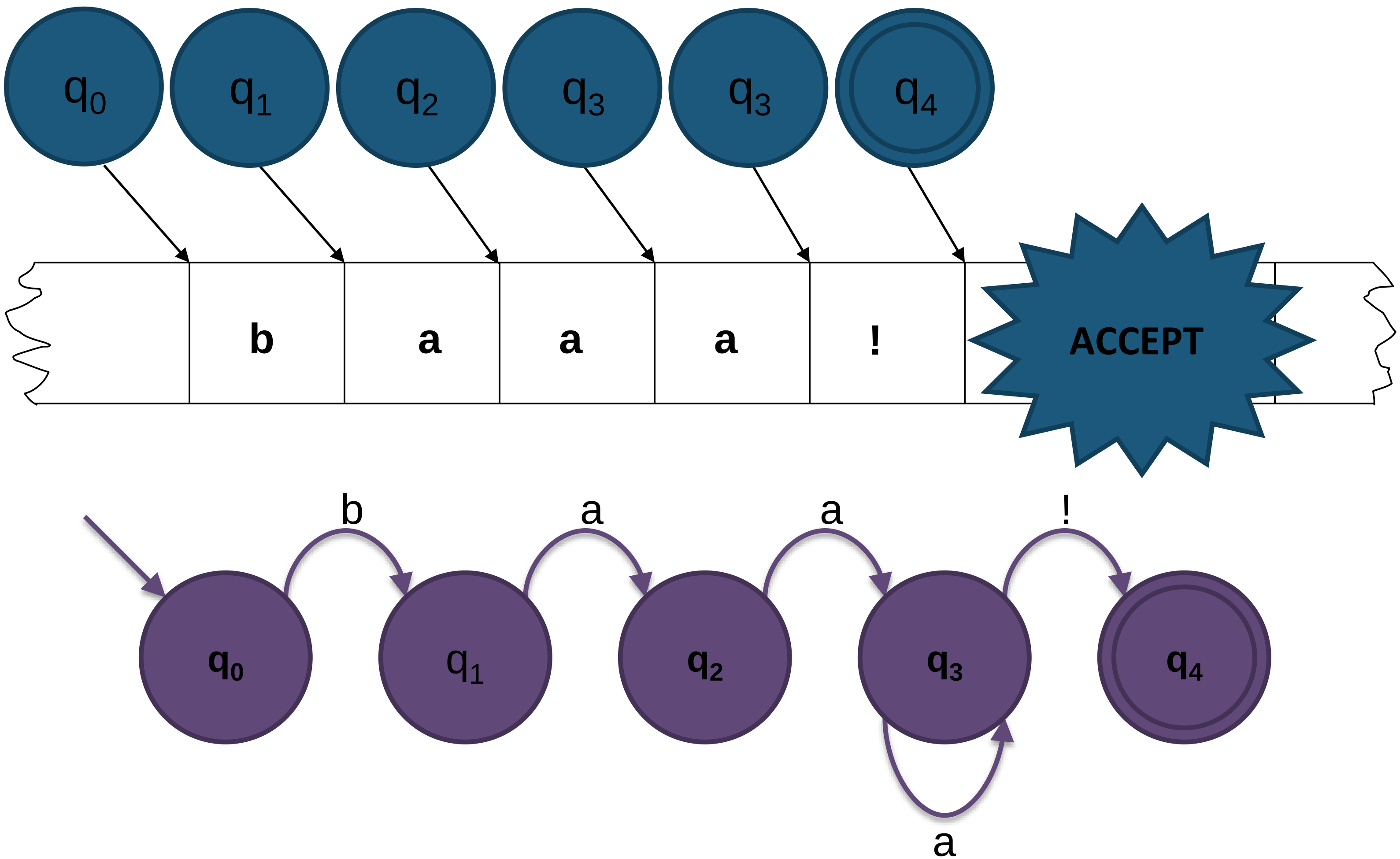
	Input		
State	**b**	**a**	**!**
0	1	∅	∅
1	∅	2	∅
2	∅	3	∅
3	∅	3	4
4	∅	∅	∅



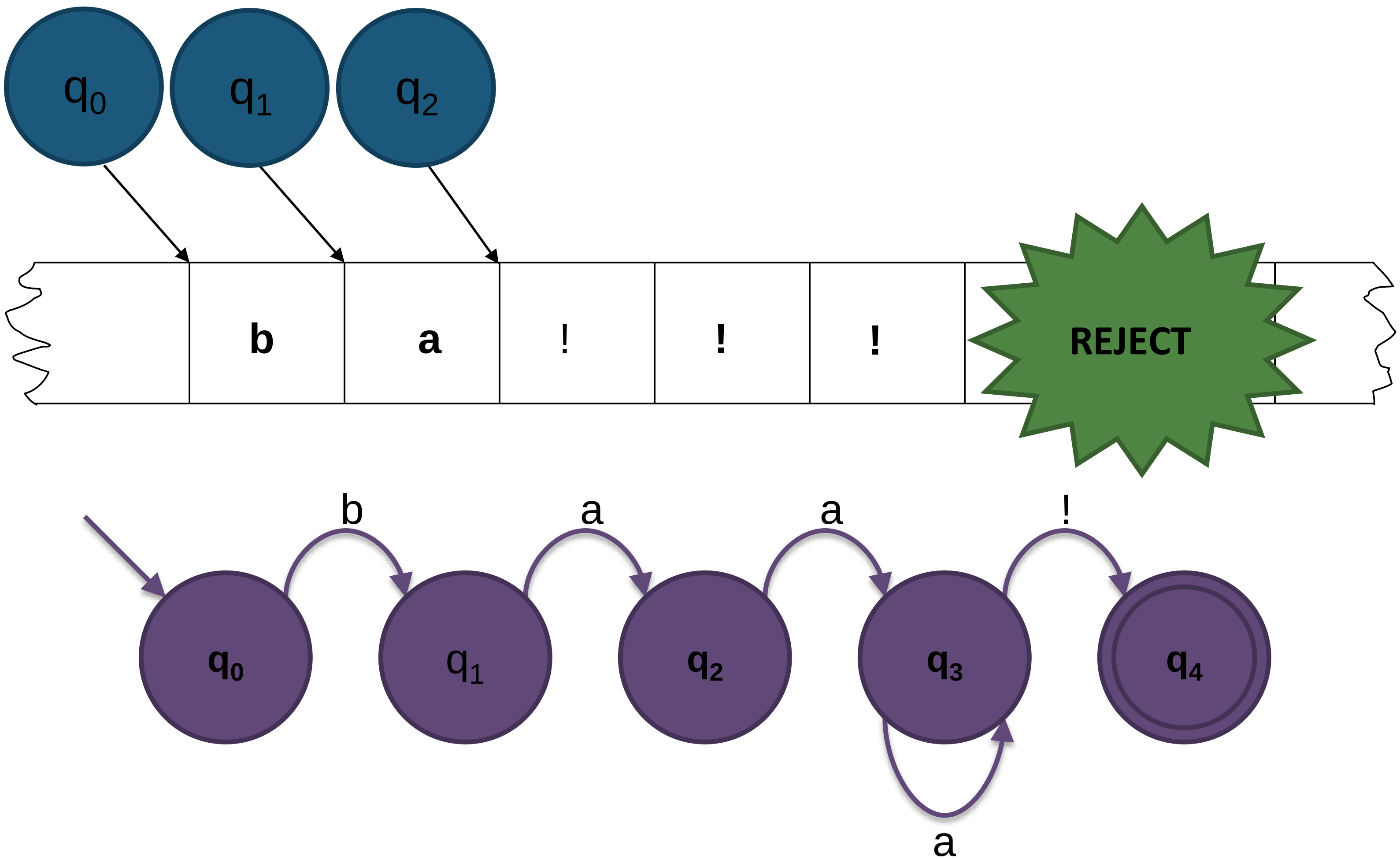
FSA: What do they do?

- Given a string, a FSA either rejects or accepts it
  - ba! → reject
  - baa! → accept
  - baaaz! → reject
  - baaaa! → accept
  - baaaaaa! → accept
  - baa → reject
  - moooo → reject
- What does this have to do with CL/NLP?

FSA: How do they work?



FSA: How do they work?



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
```

Accept or Generate?

- **Formal languages** are sets of strings
  - Strings composed of symbols drawn from a finite alphabet
- **Finite-state automata** define formal languages
  - Without having to enumerate all the strings in the language
- Two views of FSAs:
  - **Acceptors** that can tell you if a string is in the language
  - **Generators** to produce all and only the strings in the language

Exercise

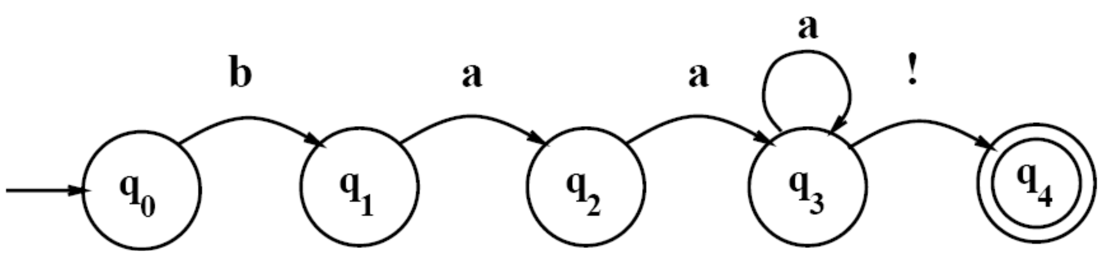
Define an FSA representing the language of all non-zero binary strings of even length

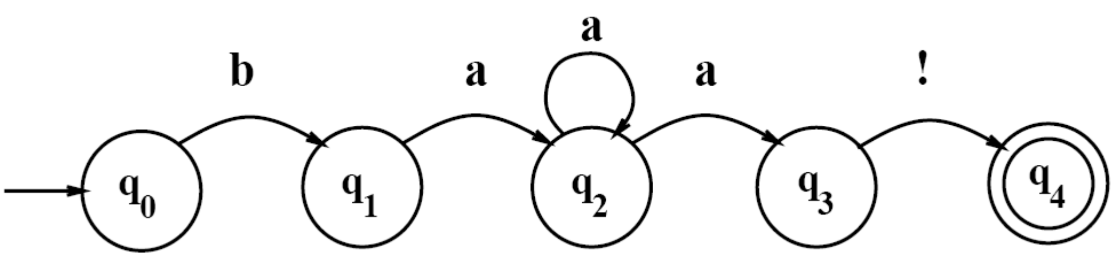
Exercise

Define an FSA representing the language of all non-zero binary strings of odd length

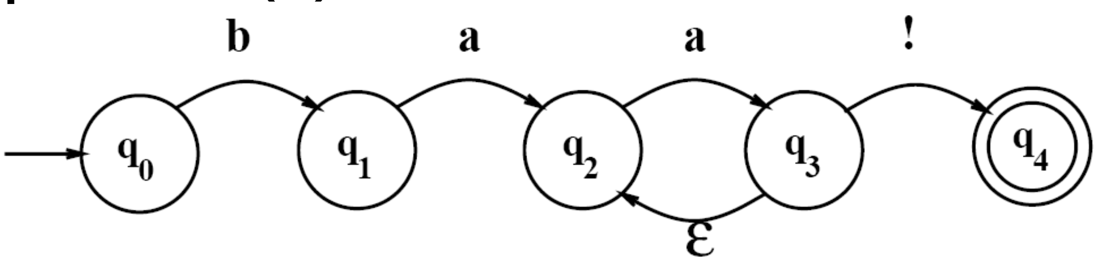
Introducing Non-Determinism

- Deterministic vs. Non-deterministic FSAs





- Epsilon (ε) transitions



Using NFSAs to Accept Strings

- What does it mean?
  - Accept: there exist at least one path (need not be all paths)
  - Reject: no paths exist
- General approaches
  - Backup: add markers at choice points, then possibly revisit unexplored arcs at marked choice point
  - Explore paths in parallel
  - Recognition with NFSAs as search through state space

What’s the point?

- NFSAs and DFSAs are equivalent
  - For every NFSA, there is a equivalent DFSA (and vice versa)

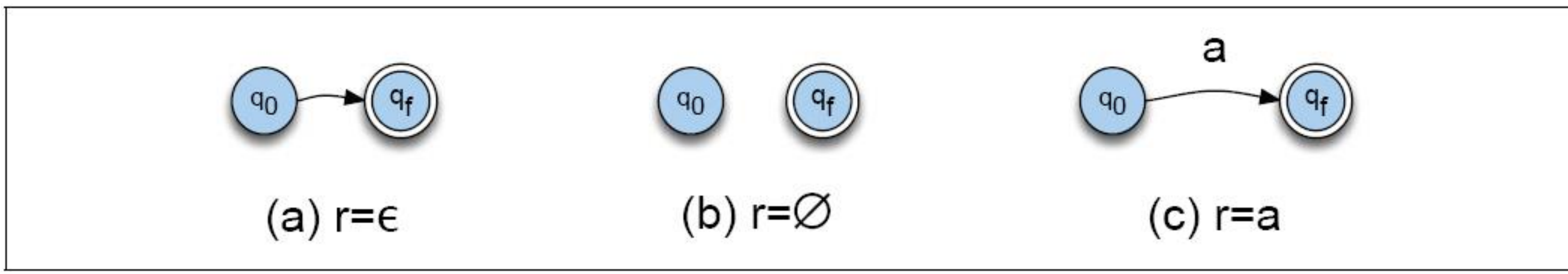
- Equivalence between regular expressions and FSA

- Why use NFSAs?

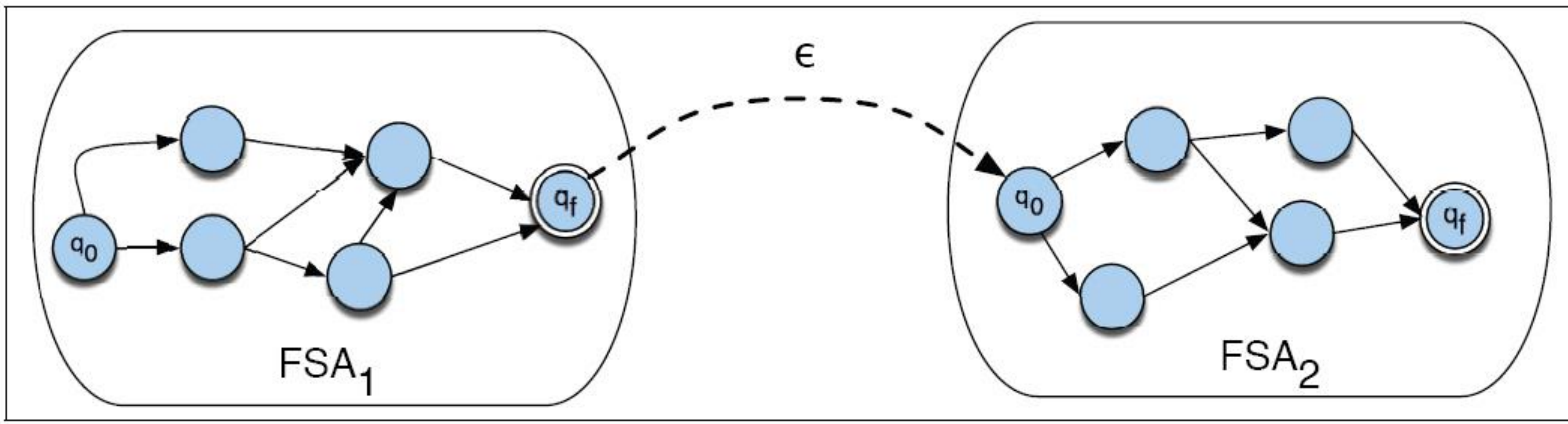
Regular Language: Definition

- $\emptyset$ is a regular language
- $\forall a \in \Sigma \cup \varepsilon$, $\{a\}$ is a regular language
- If L_1 and L_2 are regular languages, then so are:
  - $L_1 \cdot L_2 = \{x\, y \mid x \in L_1 , y \in L_2 \}$, the *concatenation* of L_1 and L_2
  - $L_1 \cup L_2$, the *union* or *disjunction* of L_1 and L_2
  - L_1*, the *Kleene closure* of L_1

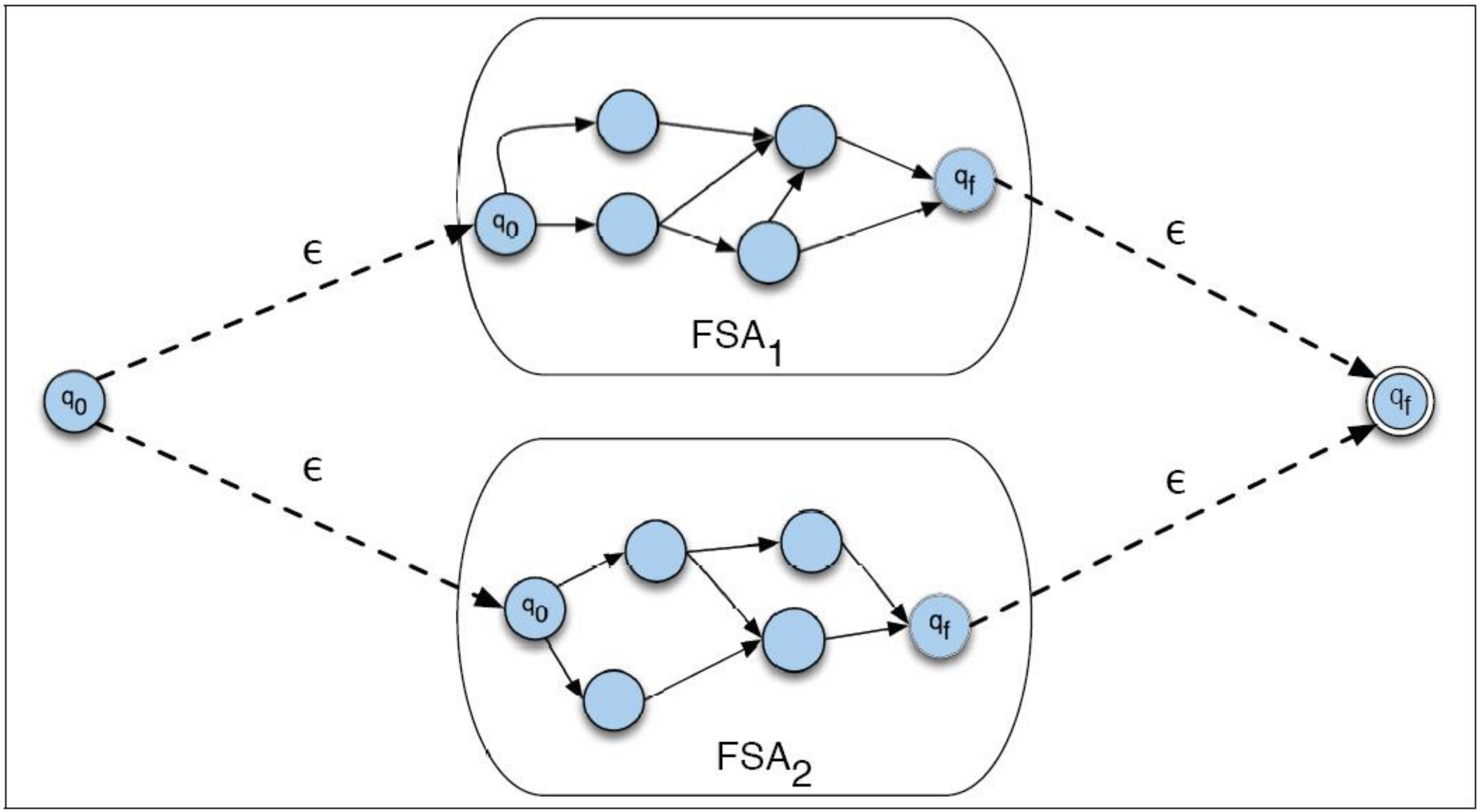
Regular Languages: Starting Points



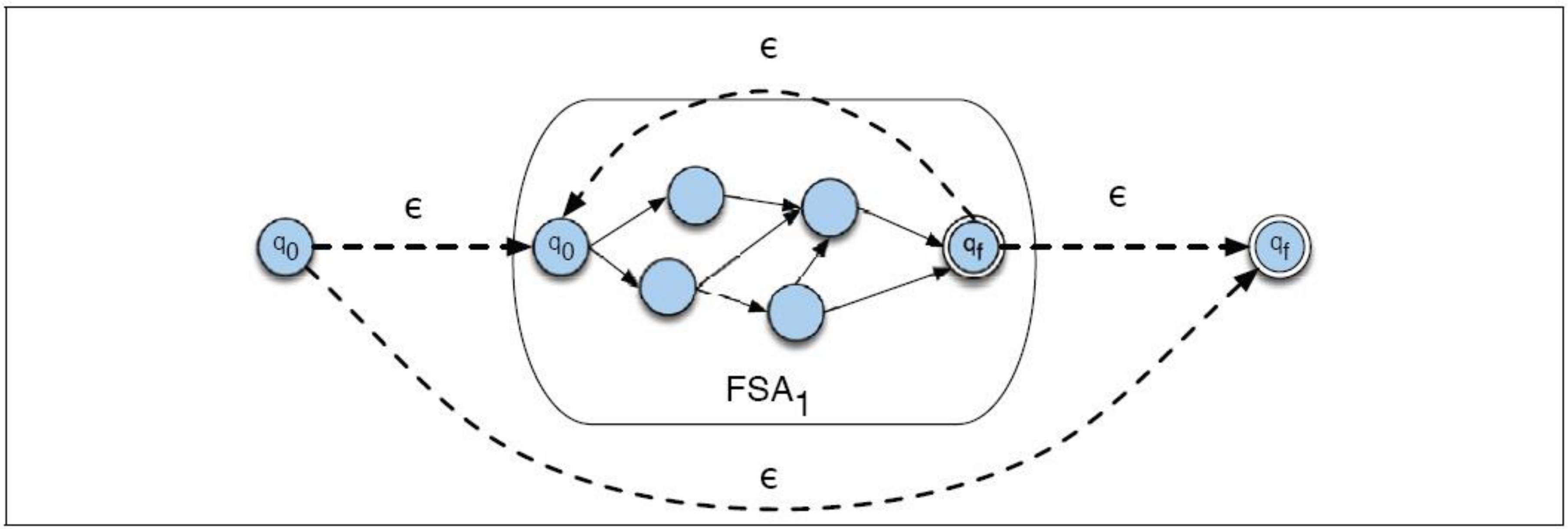
Regular Languages: Concatenation



Regular Languages: Disjunction

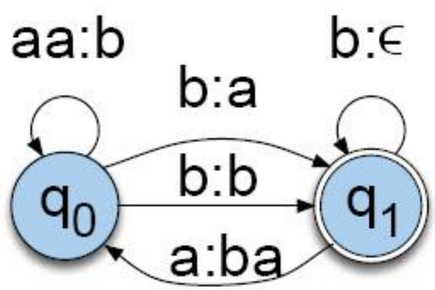


Regular Languages: Kleene Closure



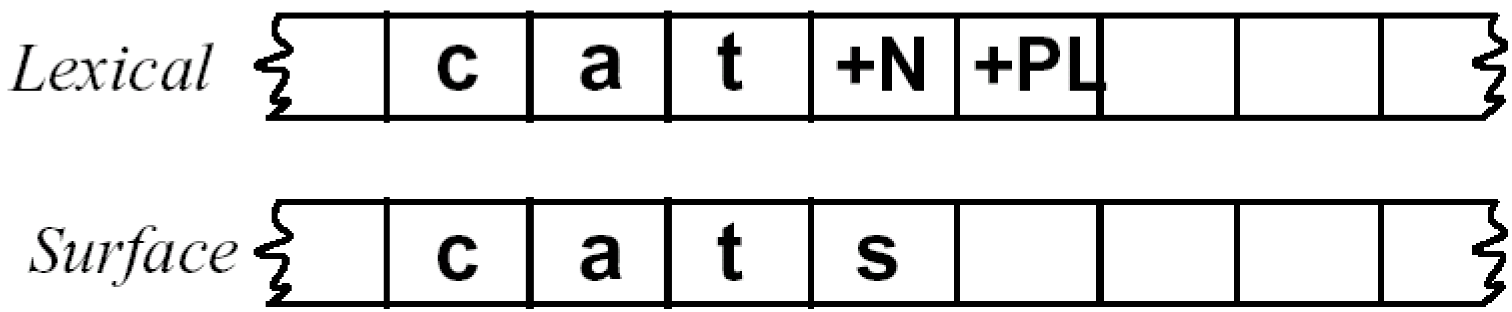
Finite-State Transducers (FSTs)

- A two-tape automaton that recognizes or generates pairs of strings
- Think of an FST as an FSA with two symbol strings on each arc



Four-fold view of FSTs

- As a recognizer
- As a generator
- As a translator
- As a set relater



Today

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- Morphology
  - Introduction to morphological processes
  - Computational morphology with finite-state methods

Computational Morphology

- Definitions and problems
  - What is morphology?
  - Topology of morphologies
- Computational morphology
  - Finite-state methods

Morphology

- Study of how words are constructed from smaller units of meaning
- Smallest unit of meaning = morpheme
  - fox has morpheme fox
  - cats has two morphemes cat and –s
  - Note: it is useful to distinguish morphemes from orthographic rules
- Two classes of morphemes:
  - Stems: supply the “main” meaning
    - Aka root / lemma
  - Affixes: add “additional” meaning

Topology of Morphologies

- Concatenative vs. non-concatenative
- Derivational vs. inflectional
- Regular vs. irregular

Concatenative Morphology

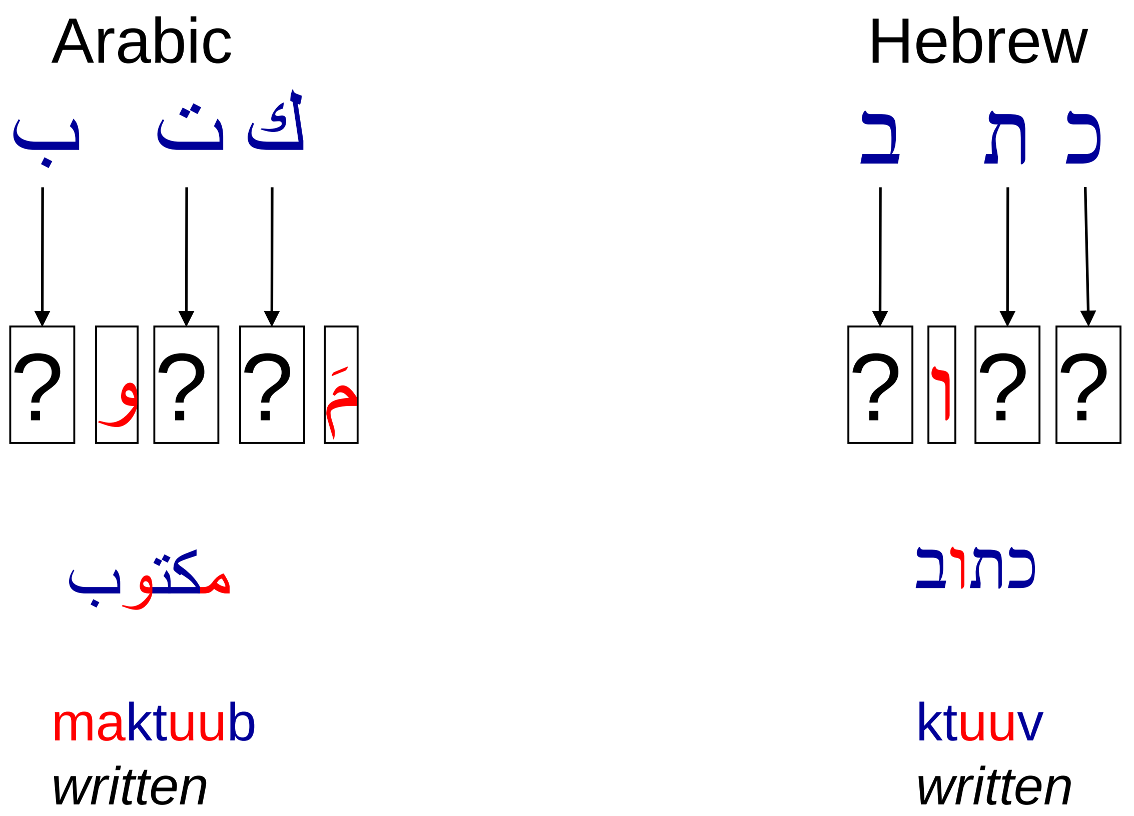
- Morpheme+Morpheme+Morpheme+…
- Stems (also called lemma, base form, root, lexeme):
  - hope+ing → hoping
  - hop+ing → hopping
- Affixes:
  - Prefixes: Antidis**establish**mentarianism
  - Suffixes: Antidis**establish**mentarianism
- Agglutinative languages (e.g., Turkish)
  - uygarlaştıramadıklarımızdanmışsınızcasına → uygar+laş+tır+ama+dık+lar+ımız+dan+mış+sınız+casına
  - Meaning: *behaving as if you are among those whom we could not cause to become civilized*

Non-Concatenative Morphology

- Infixes (e.g., Tagalog)
  - hingi (borrow)
  - humingi (borrower)
- Circumfixes (e.g., German)
  - sagen (say)
  - gesagt (said)
- Reduplication (e.g., Motu, spoken in Papua New Guinea)
  - mahuta (to sleep)
  - mahutamahuta (to sleep constantly)
  - mamahuta (to sleep, plural)

Templatic Morphologies

- Common in Semitic languages
- Roots and patterns



Derivational Morphology

- Stem + morpheme →
  - New word with different meaning or different part of speech
  - Exact meaning difficult to predict

- Nominalization in English:
  - -ation: computerization, characterization
  - -ee: appointee, advisee
  - -er: killer, helper

- Adjective formation in English:
  - -al: computational, derivational
  - -less: clueless, helpless
  - -able: teachable, computable

Inflectional Morphology

- Stem + morpheme →
  - Word with same part of speech as the stem
- Adds: tense, number, person,…

- Plural morpheme for English noun
  - cat+s
  - dog+s
- Progressive form in English verbs
  - walk+ing
  - rain+ing

Noun Inflections in English

- Regular
  - cat/cats
  - dog/dogs
- Irregular
  - mouse/mice
  - ox/oxen
  - goose/geese

Verb Inflections in English

Morphological Class	**Regularly Inflected Verbs**			
stem	walk	merge	try	map
-*s* form	walks	merges	tries	maps
-*ing* participle	walking	merging	trying	mapping
Past form or -*ed* participle	walked	merged	tried	mapped

Morphological Class	**Irregularly Inflected Verbs**		
stem	eat	catch	cut
-*s* form	eats	catches	cuts
-*ing* participle	eating	catching	cutting
preterite	ate	caught	cut
past participle	eaten	caught	cut

Morphological Parsing

- Computationally decompose input forms into component morphemes
- Components needed:
  - A lexicon (stems and affixes)
  - A model of how stems and affixes combine
  - Orthographic rules

Morphological Parsing: Examples

WORD	**STEM (+FEATURES)**
cats	cat +N +PL
cat	cat +N +SG
cities	city +N +PL
geese	goose +N +PL
ducks	(duck +N +PL) or (duck +V +3SG)
merging	merge +V +PRES-PART
caught	(catch +V +PAST-PART) or (catch +V +PAST)

Different Approaches

- Lexicon only
- Rules only
- Lexicon and rules
  - finite-state automata
  - finite-state transducers

Lexicon-only

- Simply enumerate all surface forms and analyses

```
acclaim          acclaim $N$
acclaim          acclaim $V+0$
acclaimed        acclaim $V+ed$
acclaimed        acclaim $V+en$
acclaiming       acclaim $V+ing$
acclaims         acclaim $N+s$
acclaims         acclaim $V+s$
acclamation      acclamation $N$
acclamations     acclamation $N+s$
acclimate        acclimate   $V+0$
acclimated       acclimate   $V+ed$
acclimated       acclimate   $V+en$
acclimates       acclimate   $V+s$
acclimating      acclimate   $V+ing$
```

Rule-only

- Cascading set of rules
  - s → ε
  - ation → e
  - ize → ε
  - …
- Example
  - generalizations
    → generalization
    → generalize
    → general
  - organizations
    → organization
    → organize
    → organ

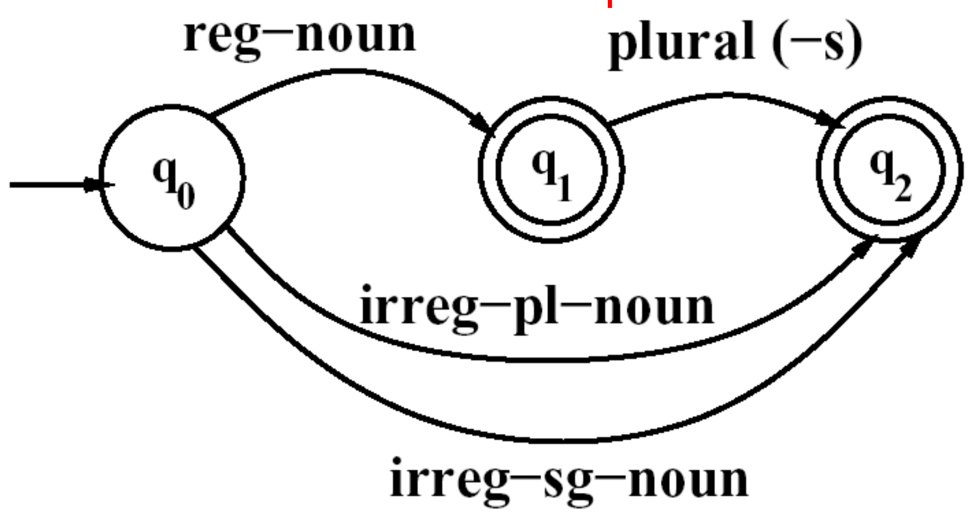
Lexicon + Rules

- FSA: for recognition
  - Recognize all grammatical input and only grammatical input
- FST: for analysis
  - If grammatical, analyze surface form into component morphemes
  - Otherwise, declare input ungrammatical

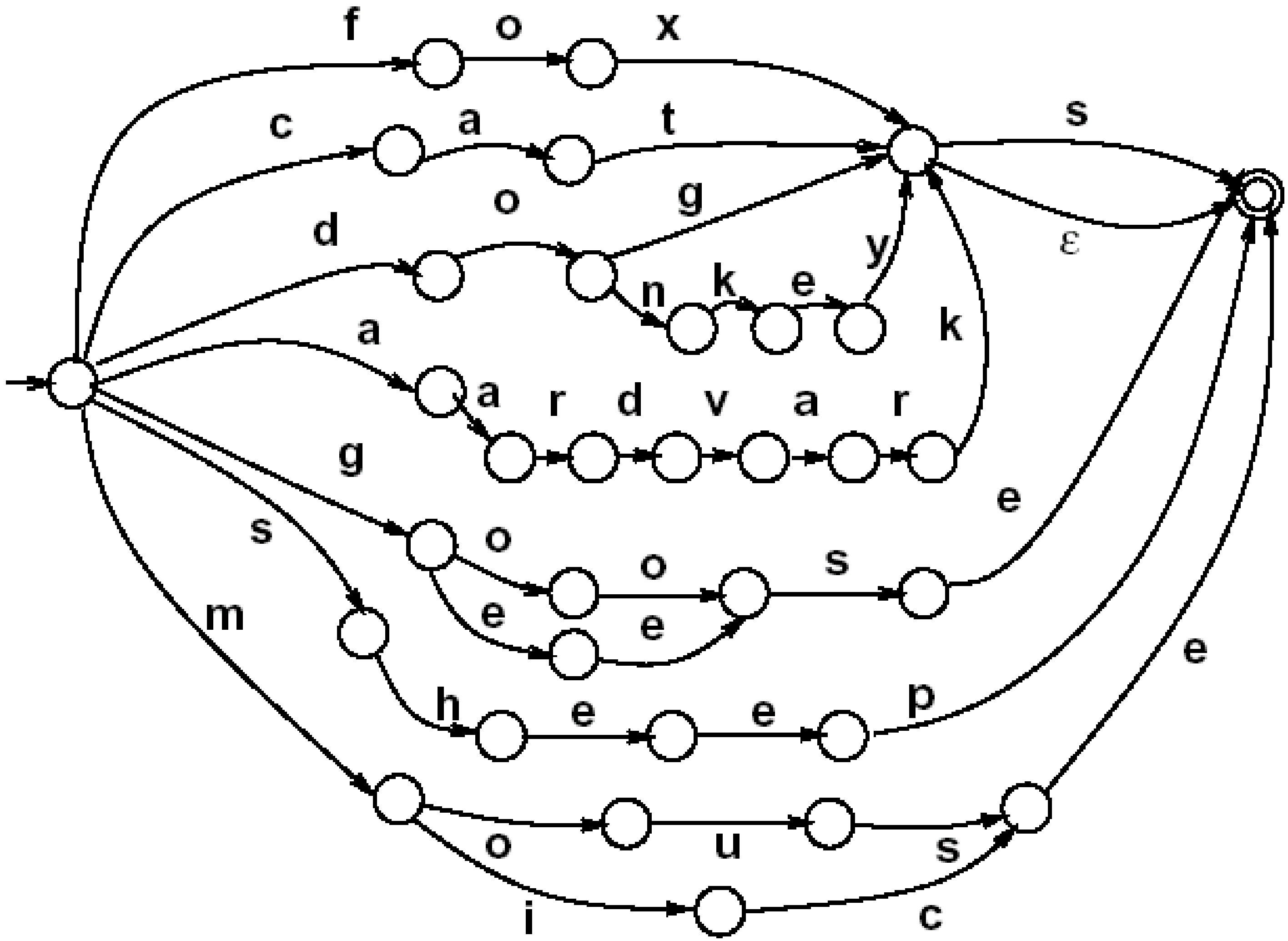
FSA: English Noun Morphology

reg-noun	irreg-pl-noun	irreg-sg-noun	plural
fox	geese	goose	-s
cat	sheep	sheep	
dog	mice	mouse	

Note problem with orthography!



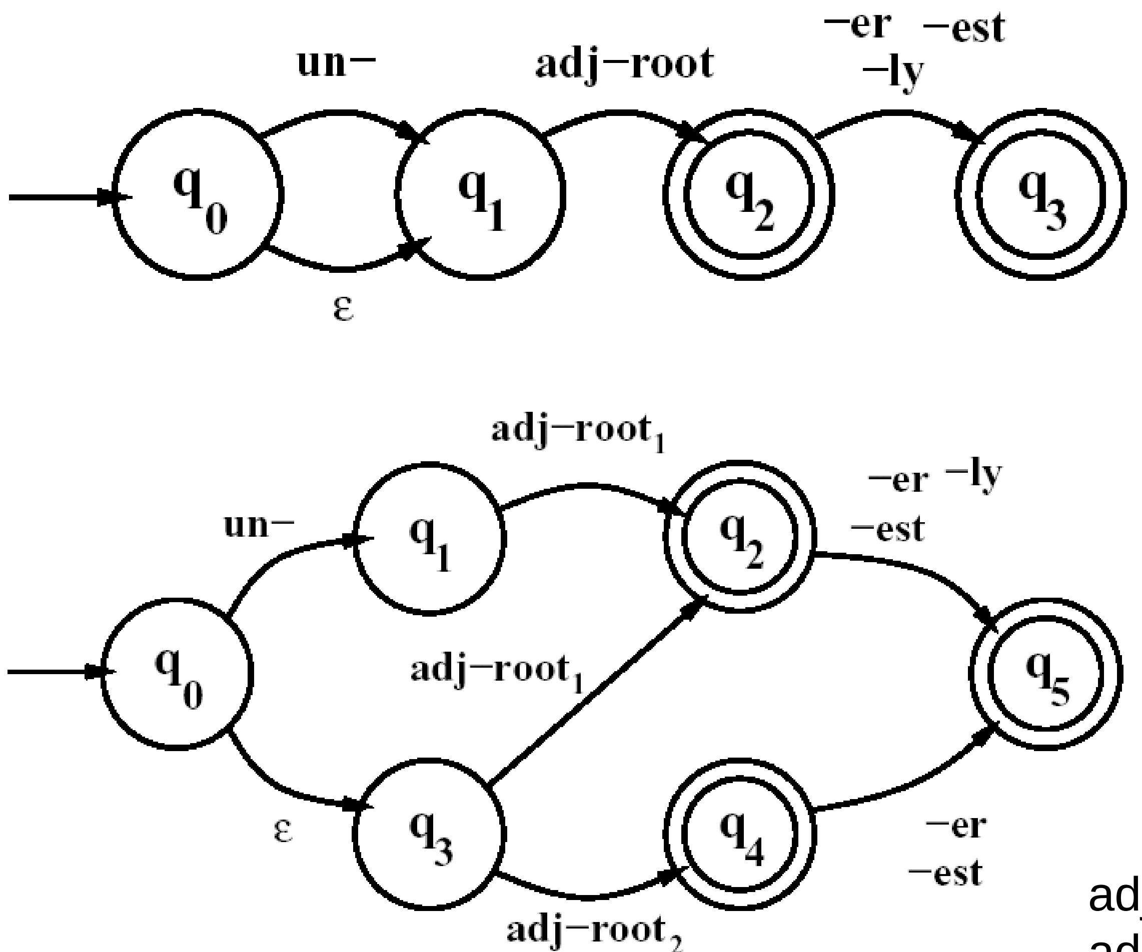
FSA: English Noun Morphology



FSA: English Adjectival Morphology

- Examples:
  - big, bigger, biggest
  - small, smaller, smallest
  - happy, happier, happiest, happily
  - unhappy, unhappier, unhappiest, unhappily
- Morphemes:
  - Roots: big, small, happy, etc.
  - Affixes: un-, -er, -est, -ly

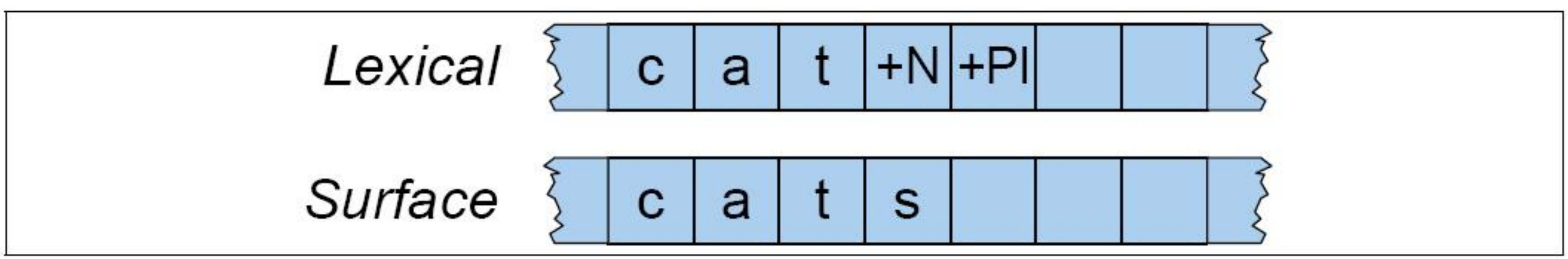
FSA: English Adjectival Morphology



adj-root$_1$: {happy, real, …}
adj-root$_2$: {big, small, …}

Morphological Parsing with FSTs

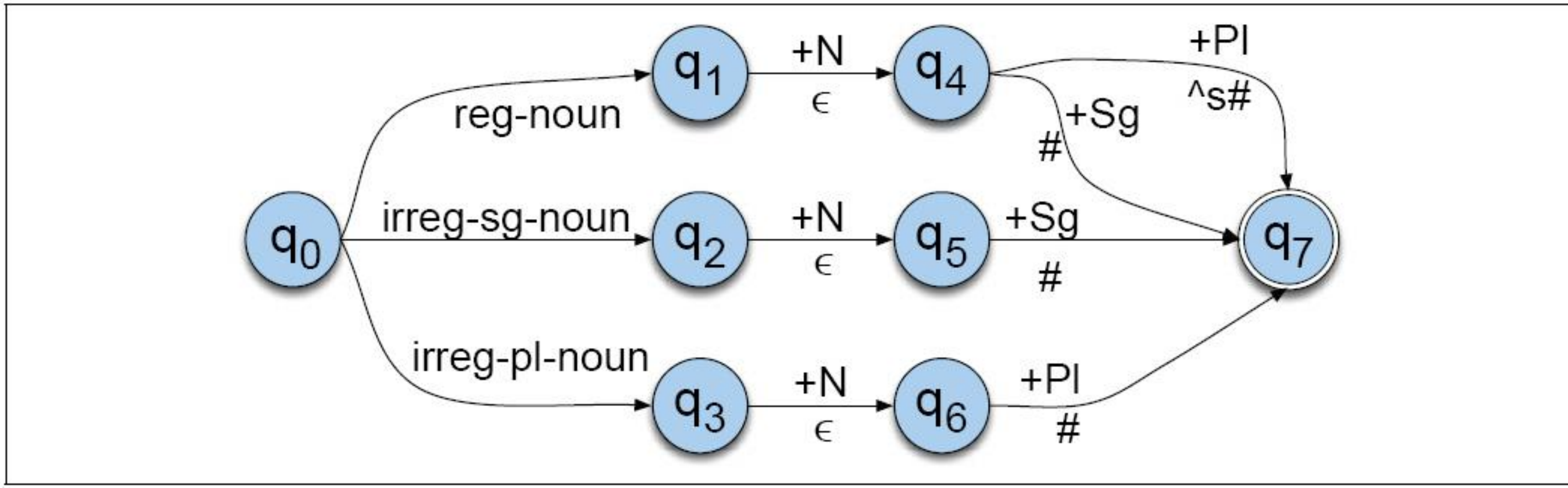
- Limitation of FSA:
  - Accepts or rejects an input… but doesn't actually provide an analysis
- Use FSTs instead!
  - One tape contains the input, the other tape as the analysis



Terminology

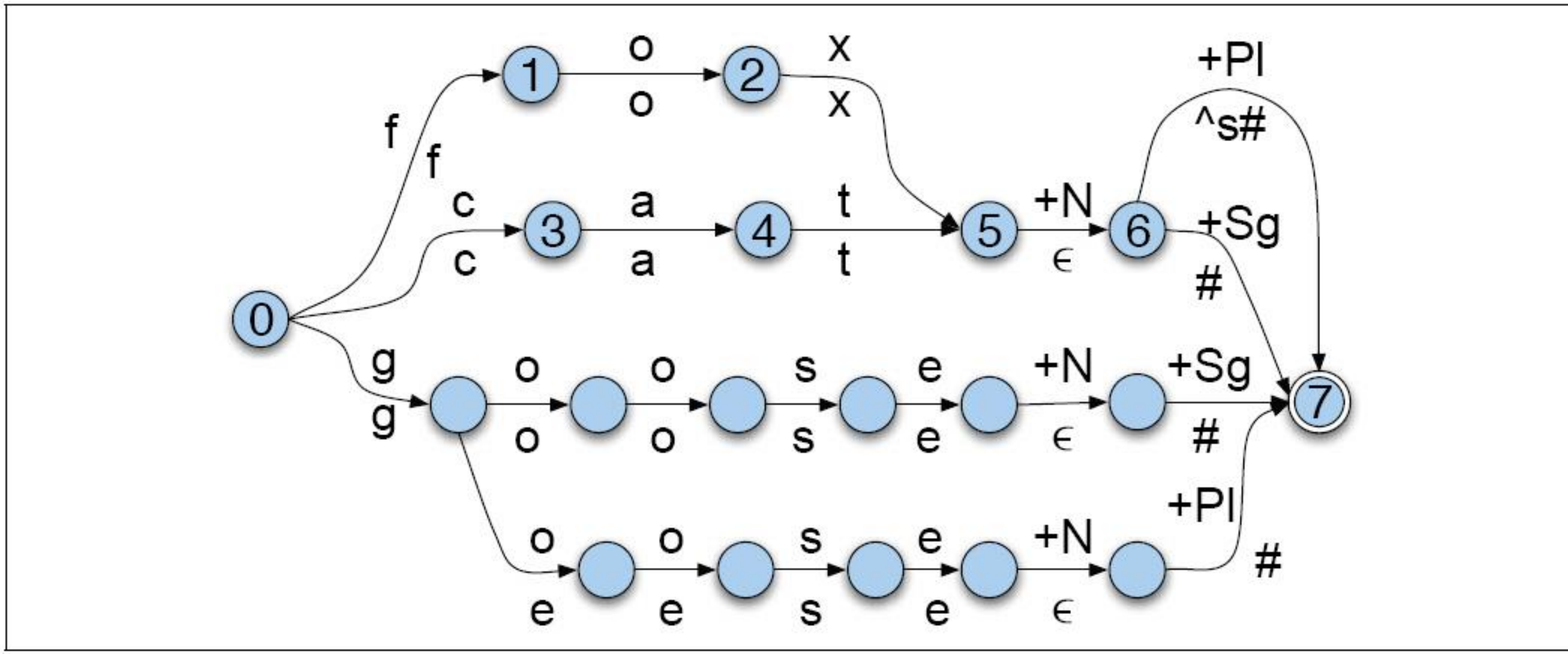
- Transducer alphabet (pairs of symbols):
  - a:b = *a* on the upper tape, *b* on the lower tape
  - a:ε = *a* on the upper tape, nothing on the lower tape
  - If a:a, write a for shorthand
- Special symbols
  - # = word boundary
  - ^ = morpheme boundary
  - (For now, think of these as mapping to ε)

FST for English Nouns

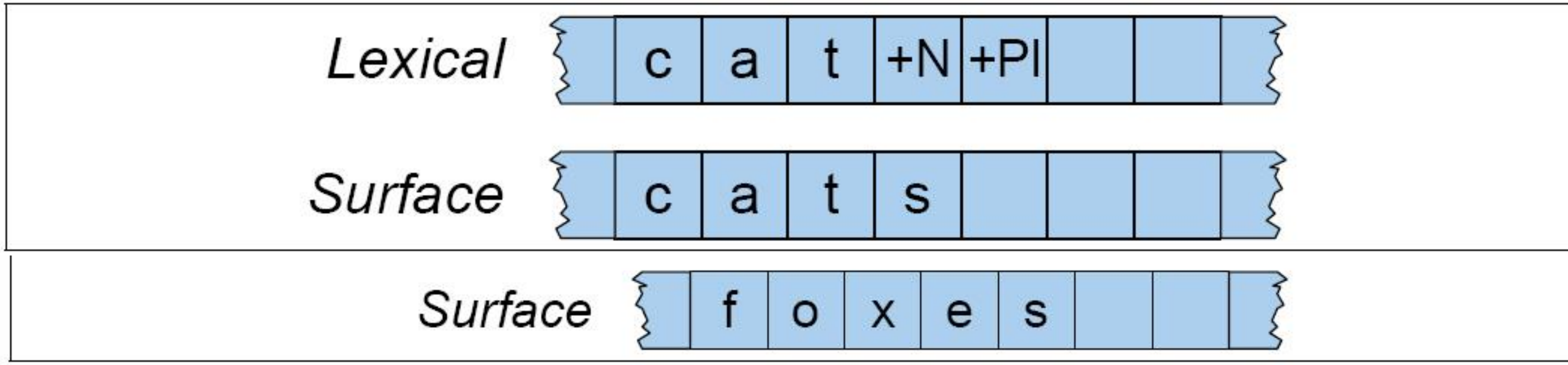


- What's the problem here?

FST for English Nouns

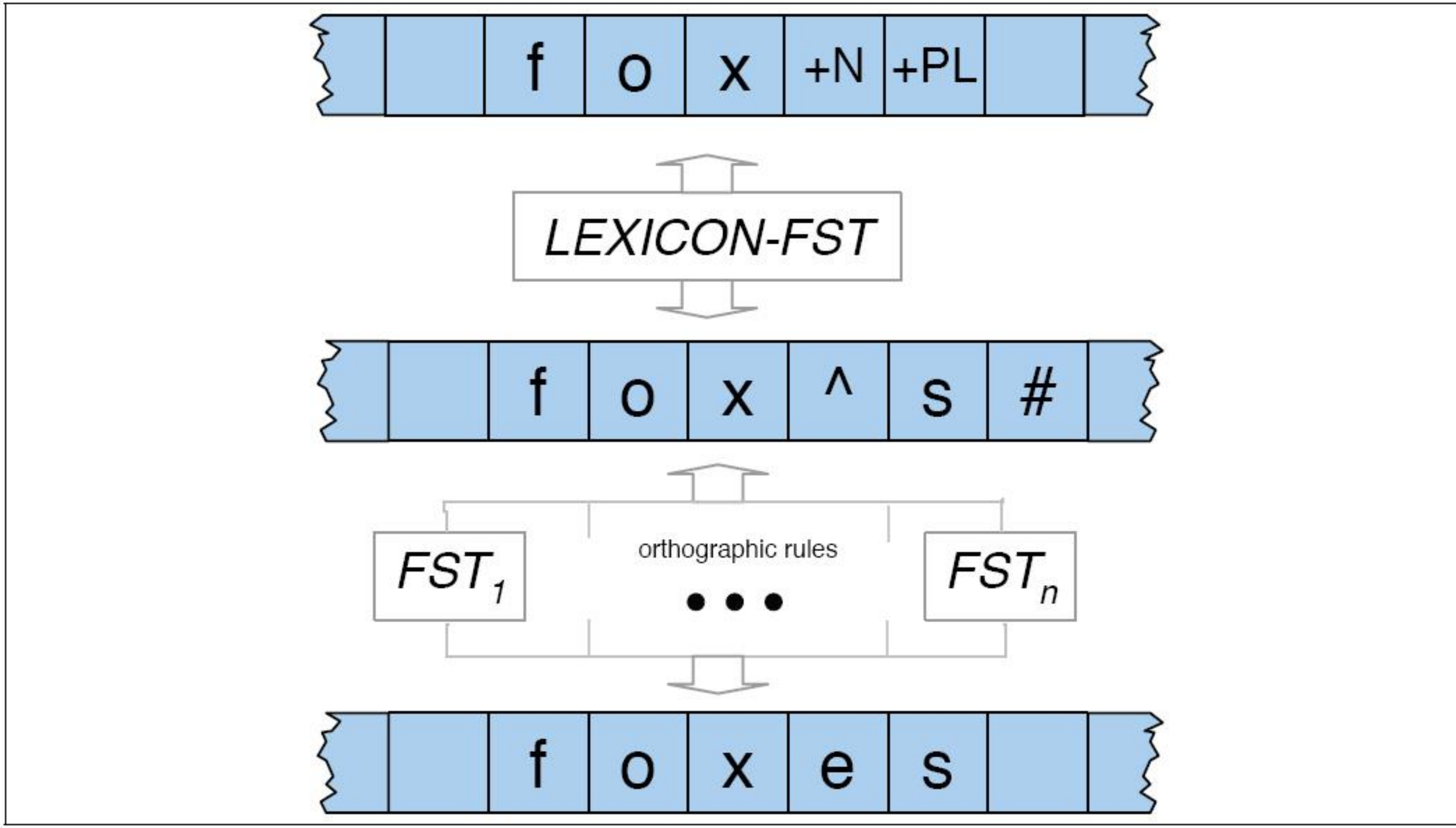


Handling Orthography



Name	Description of Rule	Example
Consonant doubling	1-letter consonant doubled before *-ing*/*-ed*	beg/begging
E deletion	silent e dropped before *-ing* and *-ed*	make/making
E insertion	e added after *-s*,*-z*,*-x*,*-ch*, *-sh* before *-s*	watch/watches
Y replacement	*-y* changes to *-ie* before *-s*, *-i* before *-ed*	try/tries
K insertion	verbs ending with *vowel* + *-c* add *-k*	panic/panicked

Complete Morphological Parser



FSTs and Ambiguity

- unionizable
  - **union** +ize +able
  - un+ **ion** +ize +able
- assess
  - **assess** +V
  - **ass** +N +essN

Practical NLP Applications

- In practice, it is almost never necessary to write FSTs by hand…
- Typically, one writes rules:
  - Chomsky and Halle Notation: $a \rightarrow b$ / c__d
    = rewrite a as b when occurs between c and d
  - E-Insertion rule

$$\varepsilon \rightarrow e \,/\, \left\{ \begin{array}{c} x \\ s \\ z \end{array} \right\} \hat{}\ \_\_\ s\ \#$$

- Rule → FST compiler handles the rest…

What we covered today…

- Computational tools
  - Finite-state automata (deterministic vs. non-deterministic)
  - Finite-state transducers

- Morphology
  - Overview of morphological processes
  - Computational morphology with finite-state methods

Before next class…

- Sign up for Piazza

https://piazza.com/umd/fall2015/cmsc723/home

- Email me dates of religious holidays you will observe this semester

- Do the readings
- Submit HW1