Morphology and Finite-State Transducers

Why this chapter?

- *Hunting for singular or plural of the word 'woodchunks' was easy, isn't it?*

- *Lets consider words like*
  - *Fox*
  - *Goose*
  - *Fish*
  - *etc*

- *What is their plural form?*

Knowledge required

- *Two kinds of knowledge is required to search for singulars and plurals of these forms*
- *Spelling rules*
  - *Words that end with 'y' changes to 'i+es' in the plural form*
- *Morphological rules*
  - *Fish has null plural and the plural of goose is formed by changing the vowel*

Morphological parsing.

- *The problem of recognizing that foxes breaks down into the two morphemes fox and -es is called* ***morphological parsing****.*

- ***Parsing*** *means taking an input and producing some sort of structure for it*

- *Similar problem of mapping foxes into fox in the information retrieval domain:* ***stemming***

Morphological parsing contd…

- *Applied to many affixes other than plurals*
  - *Takes verb form ending in –ing(going,talking…)*
  - *Parse it into verbal stem + -ing morpheme*

- *Given the **surface** or **input form** going, we might want to produce the parsed form: VERB-go + GERUND-ing*

In this chapter

- *Morphology*
- *Finite-State Transducers*

- *Finite-state transducers?*
- *The main component of an important algorithm for morphological parsing*

Morphological parsing contd…

- *It is quite inefficient to list all forms of noun and verb in the dictionary because the productivity of the forms.*
  - *Productive suffix*
  - *Applies to every verb*
  - *Example –ing*
- *Morphological parsing is necessary more than just IR, but also*
  - *Machine translation*
  - *Spelling checking*

Survey of English Morphology

- *Morphology is the study of the way words are built up from smaller meaning-bearing units, **morphemes**.*

- *Two broad classes of morphemes:*
  - ***The stems:** the "main" morpheme of the word, supplying the main meaning*
  - ***The affixes:** add "additional" meaning of various kinds.*

Affixes

- *Affixes are further divided into **prefixes**, **suffixes**, **infixes**, and **circumfixes**.*
  - *Suffix: eat-s*
  - *Prefix: un-buckle*
  - *Circumfix: ge-sag-t (said) (in German)*
  - *Infix:*
    - *hingi (borrow) + affix 'um' = h**um**ingi (in Philippine language)*

Another classification of morphology

- *Prefixes and suffixes are often called* ***concatenative morphology.***
  - *A word is composed of a number of morphemes concatenated together*

- *A number of languages have extensive* ***non-concatenative morphology***
  - *Morphemes are combined in a more complex way*
    - *The Tagalog infixation example*
  - *Another kind of non-concatenative morphology*
    - *Templatic morphology or root-and-pattern morphology*
    - *Common in Arabic, Hebrew, and other Semitic languages*

Ways to form words from morphemes

- *Two broad classes*

- ***Inflection:***
  - *the combination of a word stem with a grammatical morpheme usually resulting in a word of the same class as the original stem*

- ***Derivation**:*
  - *the combination of a word stem with a grammatical morpheme usually resulting in a word of a different class, often with a meaning hard to predict exactly*

Inflectional Morphology -NOUN

- *In English,*
  - *only nouns, verbs, and sometimes adjectives can be inflected*
  - *the number of affixes is quite small.*

- *Inflections of nouns in English:*
  - *An affix marking* ***plural****,*
    - *cat(-s)*
    - *ibis(-es),*
    - *thrush(-es)*
    - *waltz(-es), finch(-es), box(-es)*
    - *butterfly(-lies)*
    - *ox (oxen), mouse (mice) [irregular nouns]*

*An affix marking **possessive***

- *Regular singular noun- llama's*
- *Plural noun not ending in 's '-children's*
- *Regular plural noun –llamas'*
- *Names ending in 's' or 'z' - Euripides' comedies*

Inflectional Morphology- VERB

- *Verbal inflection is more complicated than nominal inflection.*

- *English has three kinds of verbs:*
  - ***Main verbs**, eat, sleep, impeach*
  - ***Modal verbs**, can will, should*
  - ***Primary verbs**, be, have, do*

- *Of these verbs a large class are regular*

- *All verbs of this class have the same endings marking the same functions.*

Morphological forms of regular verbs

- *Have four morphological form*

- *Just by knowing the stem we can predict the other forms*
  - *By adding one of the three predictable endings*
  - *Making some regular spelling changes*

- *These regular verbs and forms are significant in the morphology of English because of their majority and being productive.*

stem	walk	merge	try	map
-*s* form	walks	merges	tries	maps
-*ing* principle	walking	merging	trying	mapping
Past form or –*ed* participle	walked	merged	tried	mapped

Morphological forms of irregular verbs

- *Have five different forms*
- *But can have as many as eight (verb 'be')*
- *Or as few as three (verb 'cut')*

stem	eat	catch	cut
-*s* form	eats	catches	cuts
-*ing* principle	eating	catching	cutting
Past form	ate	caught	cut
–*ed* participle	eaten	caught	cut

the simple form: be
the -ing participle form: being
the past participle: been
the first person singular present tense form: am
the third person present tense (-s) form: is
the plural present tense form: are
the singular past tense form: was
the plural past tense form: were

Derivational Morphology

- ***Nominalization** in English:*
  - *The formation of new nouns, often from verbs or adjectives*

Suffix	Base Verb/Adjective	Derived Noun
-ation	computerize (V)	computerization
-ee	appoint (V)	appointee
-er	kill (V)	killer
-ness	fuzzy (A)	fuzziness

– Adjectives derived from nouns or verbs

Suffix	Base Noun/Verb	Derived Adjective
-al	computation (N)	computational
-able	embrace (V)	embraceable
-less	clue (A)	clueless

Derivational Morphology

- Derivation in English is more complex than inflection because
  - It is generally less productive
    - A nominalizing affix like –ation can not be added to absolutely every verb. eatation(*)
  - There are subtle and complex meaning differences among nominalizing suffixes.
    - For example, sincerity has a subtle difference in meaning from sincereness.

Finite-State Morphological Parsing

- *The problem of parsing English morphology*
- *Aim is to take input forms in the first column and produce output forms in the second column*

Input	**Morphological parsed output**
cats	`cat +N +PL`
cat	`cat +N +SG`
cities	`city +N +PL`
geese	`goose +N +PL`
goose	(`goose +N +SG`) or (`goose +V`)
gooses	`goose +V +3SG`
merging	`merge +V +PRES-PART`
caught	(`caught +V +PAST-PART`) or (`catch +V +PAST`)

Input form

Stems** and morphological **features

To build a morphological parser:

1. ***Lexicon**: the list of stems and affixes, together with basic information about them*
   - *Eg., Noun stem or Verb stem, etc.*
2. ***Morphotactics**: the model of morpheme ordering that explains which classes of morphemes can follow other classes of morphemes inside a word.*
   - *E.g., the rule that English plural morpheme follows the noun rather than preceding it.*
3. ***Orthographic rules**: these **spelling rules** are used to model the changes that occur in a word, usually when two morphemes combine*
   - *E.g., the y→ie spelling rule changes city* + *-s to cities.*

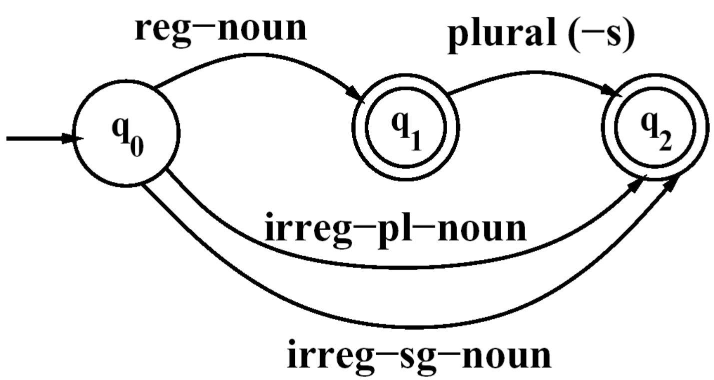
The Lexicon and Morphotactics

- *A lexicon is a repository for words.*
  - *The simplest one would consist of an explicit list of every word of the language.*
    - ***Incovenient or impossible!***

- *Computational lexicons are usually structured with*
    - *a list of each of the stems and*
    - *Affixes of the language together with a representation of morphotactics telling us how they can fit together.*

- *The most common way of modeling morphotactics is the finite-state automaton.*

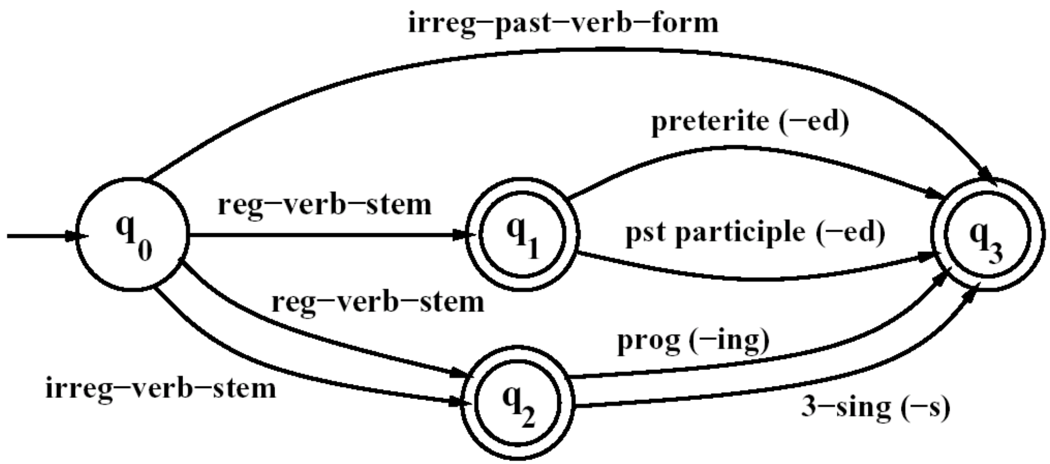
An FSA for English nominal inflection



Reg-noun	Irreg-pl-noun	Irreg-sg-noun	plural
fox fat fog fardvark	geese sheep Mice	goose sheep mouse	-s

3.2 Finite-State Morphological Parsing

The Lexicon and Morphotactics

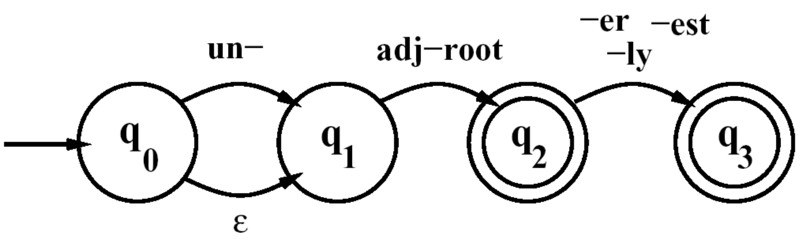


An FSA for English verbal inflection

Reg-verb-stem	Irreg-verb-stem	Irreg-past-verb	past	Past-part	Pres-part	3sg
walk fry talk impeach	cut speak sing sang spoken	caught ate eaten	-ed	-ed	-ing	-s

The Lexicon and Morphotactics

- *English derivational morphology is more complex than English inflectional morphology, and so automata of modeling English derivation tends to be quite complex.*
  - *Some even based on CFG*
- *A small part of morphosyntactics of English adjectives*

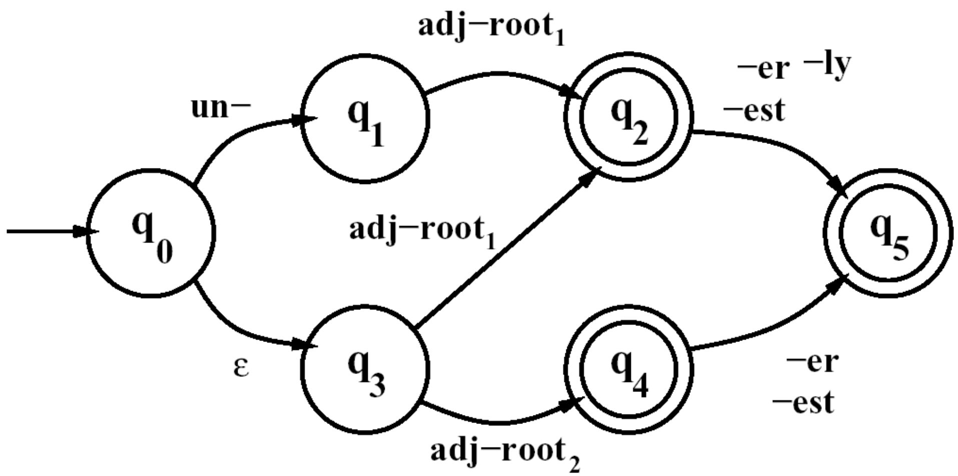


An FSA for a fragment of English adjective Morphology #1

big, bigger, biggest
cool, cooler, coolest, coolly
red, redder, reddest
clear, clearer, clearest, clearly, unclear, unclearly
happy, happier, happiest, happily
unhappy, unhappier, unhappiest, unhappily
real, unreal, really

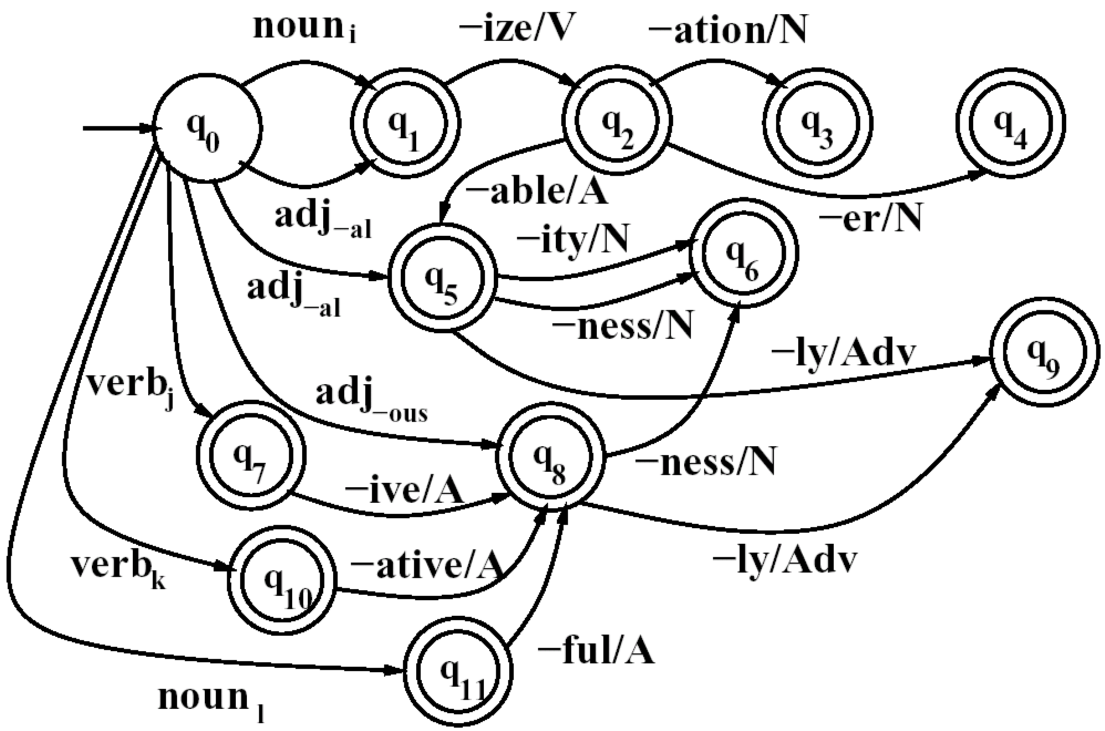
Finite-State Morphological Parsing

- The FSA#1 recognizes all the listed adjectives, and ungrammatical forms like *unbig*, *redly*, and *realest*.
- Thus #1 is revised to become #2.
- The complexity is expected from English derivation.



An FSA for a fragment of English adjective Morphology #2

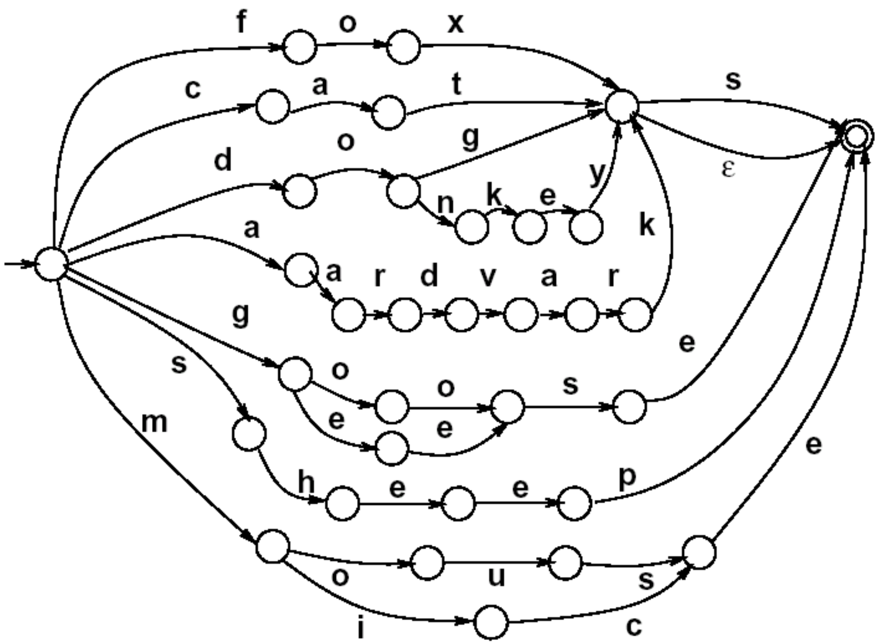
Finite-State Morphological Parsing



An FSA for another fragment of English derivational morphology

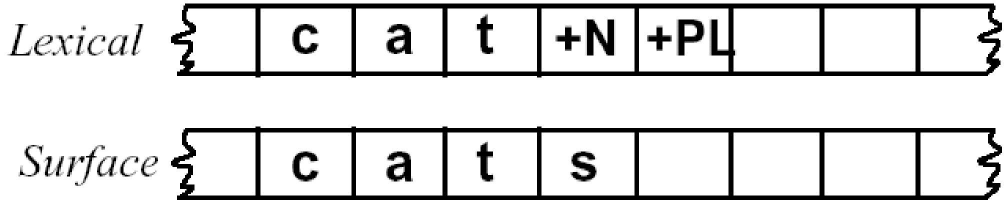
Finite-State Morphological Parsing

- *We can now use these FSAs to solve the problem of **morphological recognition**:*
  - *Determining whether an input string of letters makes up a legitimate English word or not*
  - *We do this by taking the morphotactic FSAs, and plugging in each "sub-lexicon" into the FSA.*
  - *The resulting FSA can then be defined as the level of the individual letter.*



Morphological Parsing with FST

- *Given the input, for example, **cats**, we would like to produce **cat +N +PL**.*
- *Two-level morphology, by Koskenniemi (1983)*
  - *Representing a word as a correspondence between a **lexical level***
    - *Representing a simple concatenation of morphemes making up a word, and*
  - *The **surface level***
    - *Representing the actual spelling of the final word.*
- *Morphological parsing is implemented by building mapping rules that maps letter sequences like cats on the surface level into morpheme and features sequence like cat +N +PL on the lexical level.*



Morphological Parsing with FST

- *The automaton we use for performing the mapping between these two levels is the **finite-state transducer** or **FST**.*
  - *A transducer maps between one set of symbols and another;*
  - *An FST does this via a finite automaton.*

- *Thus an FST can be seen as a two-tape automaton which **recognizes** or **generates pairs** of strings.*

- *The FST has a more general function than an FSA:*
  - *An FSA defines a formal language*
  - *An FST defines a relation between sets of strings.*
- *Another view of an FST:*
  - *A machine reads one string and generates another.*

Morphological Parsing with FST

- ***FST as recognizer:***
  - *a transducer that takes a pair of strings as input and output accept if the string-pair is in the string-pair language, and a reject if it is not.*
- ***FST as generator:***
  - *a machine that outputs pairs of strings of the language. Thus the output is a yes or no, and a pair of output strings.*
- ***FST as transducer:***
  - *A machine that reads a string and outputs another string.*
- ***FST as set relater:***
  - *A machine that computes relation between sets.*

Morphological Parsing with FST

- *A formal definition of FST (based on the* ***Mealy machine*** *extension to a simple FSA):*
  - *Q: a finite set of N states* $q_0, q_1, \ldots, q_N$
  - *Σ: a finite alphabet of complex symbols. Each complex symbol is composed of an input-output pair i : o; one symbol I from an input alphabet I, and one symbol o from an output alphabet O, thus* $\Sigma \subseteq I \times O$*. I and O may each also include the epsilon symbol ε.*
  - q_0*: the start state*
  - *F: the set of final states,* $F \subseteq Q$
  - $\delta(q, i{:}o)$*: the transition function or transition matrix between states. Given a state* $q \in Q$ *and complex symbol* $i{:}o \in \Sigma$*,* $\delta(q, i{:}o)$ *returns a new state* $q' \in Q$*.* δ *is thus a relation from* $Q \times \Sigma$ *to Q.*

Morphological Parsing with FST

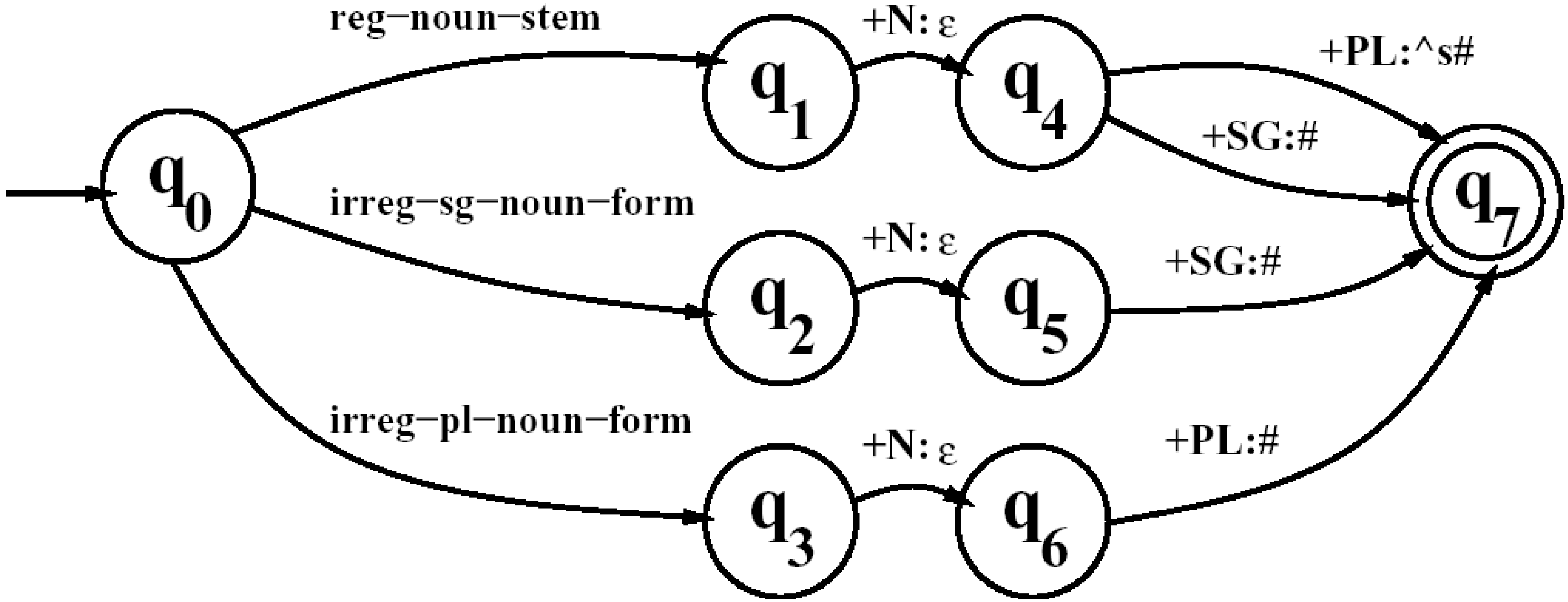
- FSAs are isomorphic to regular languages, FSTs are isomorphic to **regular relations.**
  - Regular relations are sets of pairs of strings, a natural extension of the regular language, which are sets of strings.
- FSTs are closed under union, but generally they are not closed under difference, complementation, and intersection.
- Two useful closure properties of FSTs:
  - **Inversion:** If T maps from I to O, then the inverse of T, T^{-1} maps from O to I.
  - **Composition:** If T_1 is a transducer from I_1 to O_1 and T_2 a transducer from I_2 to O_2, then $T_1 \circ T_2$ maps from I_1 to O_2

Morphological Parsing with FST

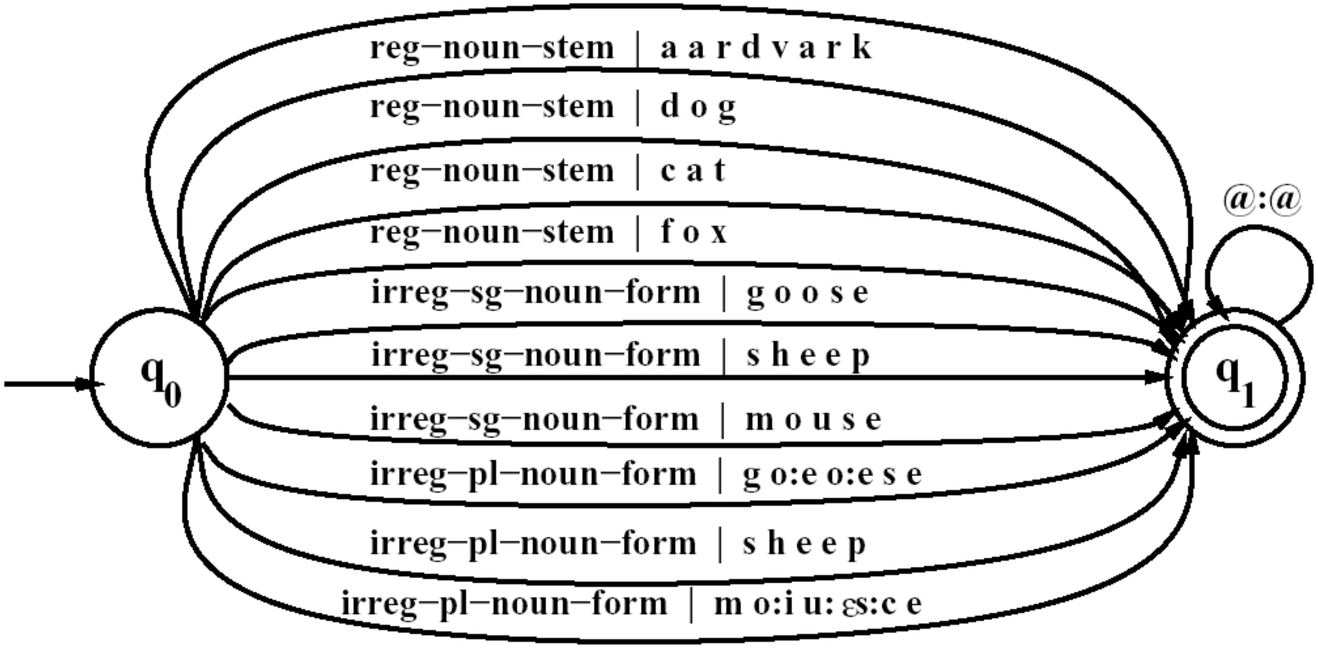
- *Inversion is useful because it makes it easy to convert a FST-as-parser into an FST-as-generator.*
- *Composition is useful because it allows us to take two transducers than run in series and replace them with one complex transducer.*
  - $T_1 \circ T_2(S) = T_2(T_1(S))$

Reg-noun	**Irreg-pl-noun**	**Irreg-sg-noun**
fox fat fog aardvark	g o:e o:e s e sheep m o:i u:εs:c e	goose sheep mouse

A transducer for English nominal number inflection T_{num}

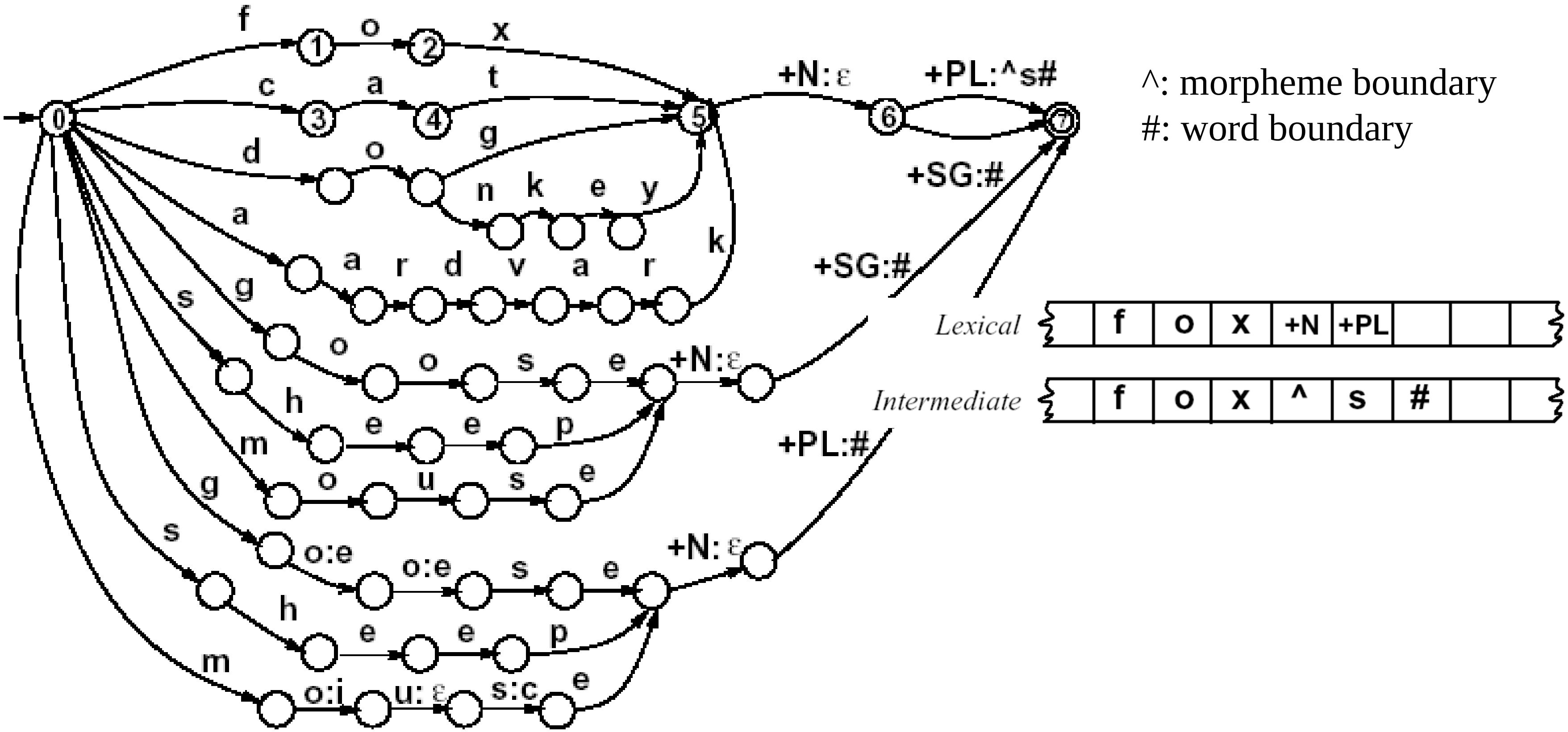


Morphological Parsing with FST



The transducer T_{stems}, which maps roots to their root-class

Morphological Parsing with FST



A fleshed-out English nominal inflection FST

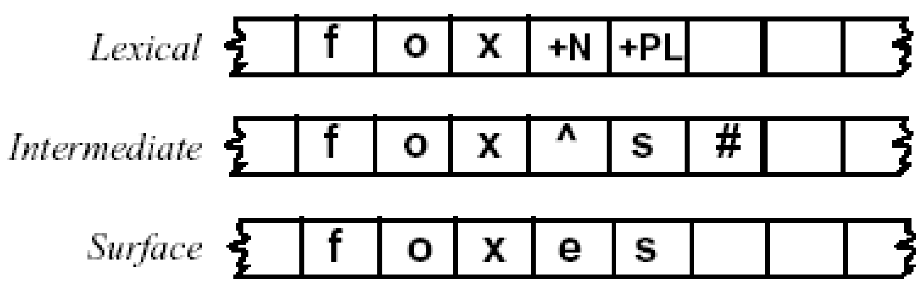
$T_{lex} = T_{num} \circ T_{stems}$

Orthographic Rules and FSTs

- ***Spelling rules*** (*or* ***orthographic rules***)

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	Verb ending with *vowel* + *-c* add *-k*	panic/panicked

– These spelling changes can be thought as taking as input a simple concatenation of morphemes and producing as output a slightly-modified concatenation of morphemes.



Orthographic Rules and FSTs

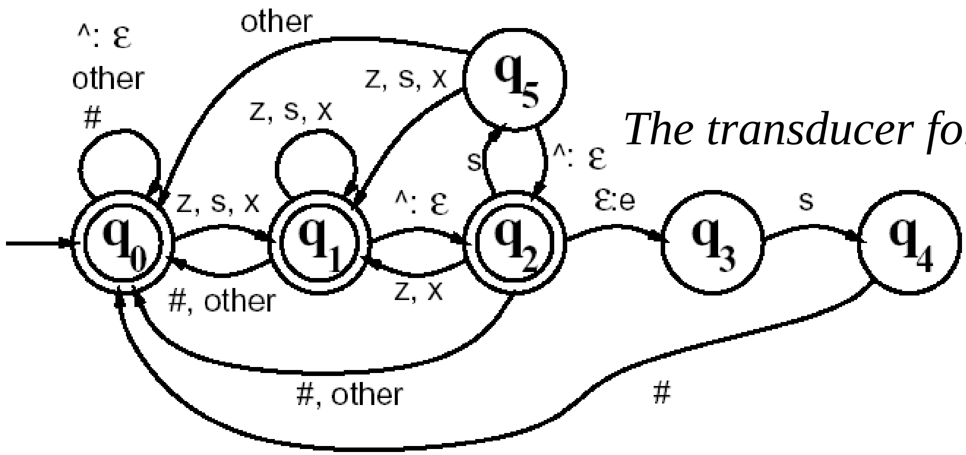
- *"insert an e on the surface tape just when the lexical tape has a morpheme ending in x (or z, etc) and the next morphemes is -s"*

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

- "rewrite *a* as *b* when it occurs between *c* and *d*"

$$a \rightarrow b \ / \ c \ \_ d$$

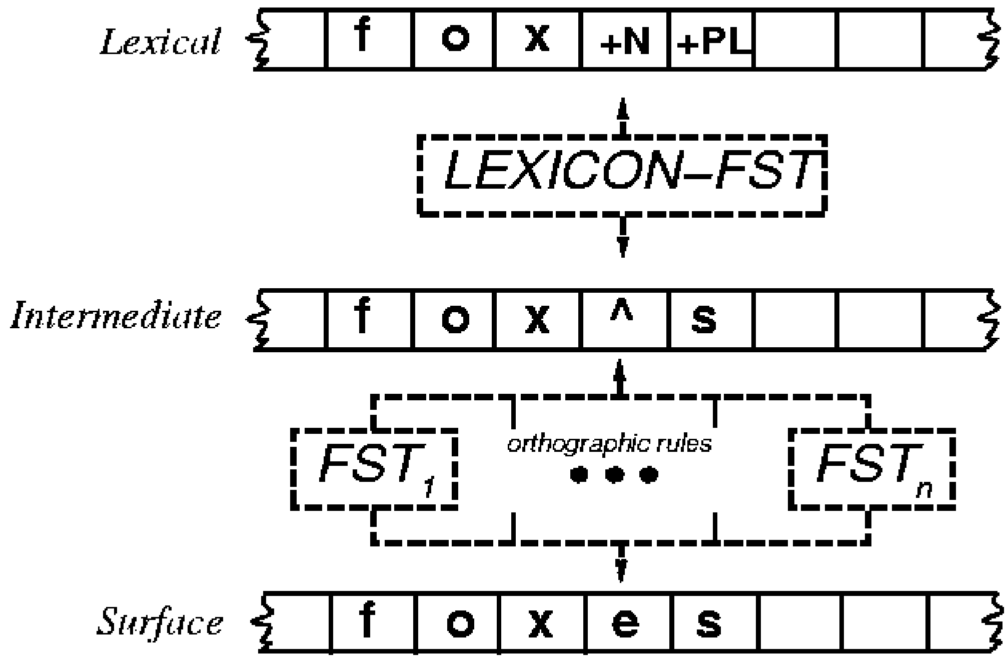
Orthographic Rules and FSTs



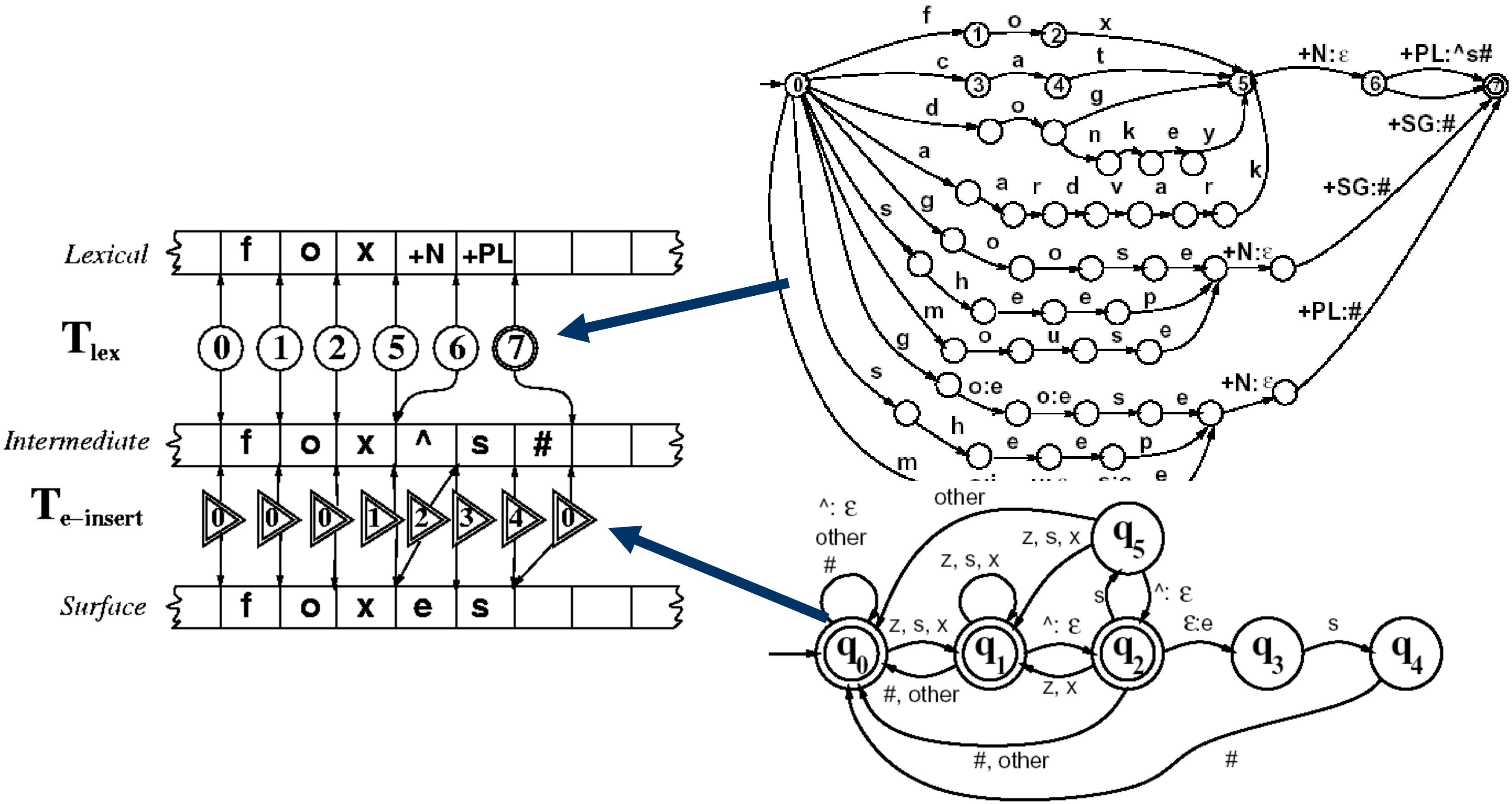
The transducer for the E-insertion rule

State\Input	s:s	x:x	z:z	^:ε	ε:e	#	other
q_0:	1	1	1	0	-	0	0
q_1:	1	1	1	2	-	0	0
q_2:	5	1	1	0	3	0	0
q_3	4	-	-	-	-	-	-
q_4	-	-	-	-	-	0	-
q_5	1	1	1	2	-	-	0

Combining FST Lexicon and Rules



Combining FST Lexicon and Rules



Combining FST Lexicon and Rules

- *The power of FSTs is that the exact same cascade with the same state sequences is used*
  - *when machine is generating the surface form from the lexical tape, or*
  - *When it is parsing the lexical tape from the surface tape.*

- *Parsing can be slightly more complicated than generation, because of the problem of **ambiguity.***
  - *For example, foxes could be fox* +*V* +*3SG as well as fox* +*N* +*PL*

Lexicon-Free FSTs: the Porter Stemmer

- *Information retrieval*
- *One of the mostly widely used **stemmming** algorithms is the simple and efficient Porter (1980) algorithm, which is based on a series of simple cascaded rewrite rules.*
  - *ATIONAL → ATE (e.g., relational → relate)*
  - *ING → εif stem contains vowel (e.g., motoring → motor)*
- *Problem:*
  - *Not perfect: error of commision, omission*
- *Experiments have been made*
  - *Some improvement with smaller documents*
  - *Any improvement is quite small*