Morphology

11-711 Algorithms for NLP

21 November 2017 – Part I

(Some slides from Lori Levin, David Mortenson)

Types of Lexical and Morphological Processing

- Tokenization
  - Input: raw text
  - Output: sequence of **tokens** normalized for further processing

- Recognition
  - Input: a string of characters
  - Output: is it a legal word? (yes or no)
- Morphological Parsing
  - Input: a word
  - Output: an analysis of the structure of the word

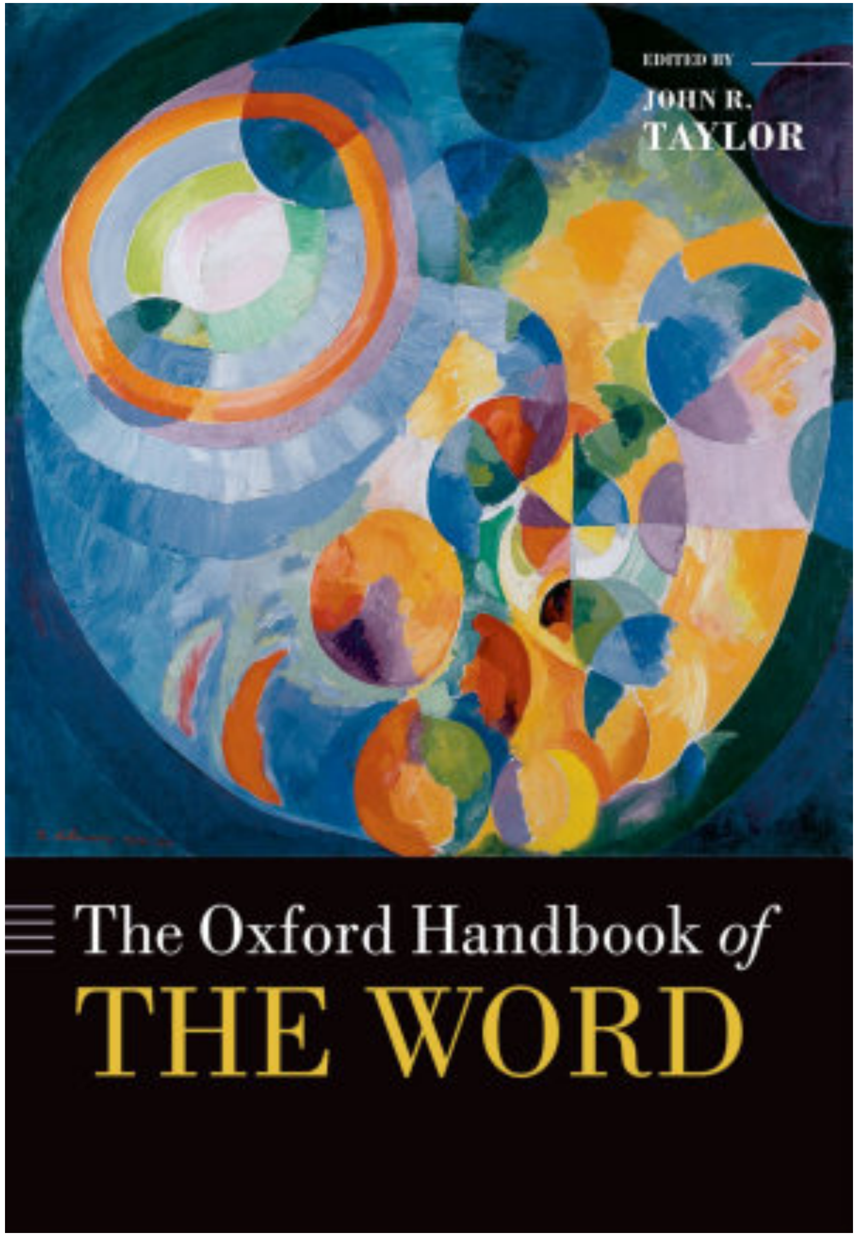
- Morphological Generation
  - Input: an analysis of the structure of the word
  - Output: a word

But first: What is a word?

- The things that are in the dictionary?
  - But how did the lexicographers decide what to put in the dictionary?
- The things between spaces and punctuation?
- The smallest unit that can be uttered in isolation?
  - You could say this word in isolation: *Unimpressively*
  - This one too: *impress*
  - But you probably wouldn’t say these in isolation, unless you were talking about morphology:
    - *un*
    - *ive*
    - *ly*

So what is a word?

- Can get pretty tricky:
  - didn’t
  - would’ve
  - gonna
  - shoulda woulda coulda
  - Ima
  - blackboard (*vs*. school board)
  - baseball (*vs*. golf ball)
  - the person who left**’s** hat; Jim and Gregg**’s** apartment
  - acct.
  - LTI



About 1000 pages. $139.99

You don't have to read it.

The point is that it takes 1000 pages just to survey the issues related to what words are.

So what is a word?

- It is up to you or the software you use for processing words.
- Take linguistics classes.
- Make good decisions in software design and engineering.

Tokenization

Tokenization

Input: raw text

Output: sequence of **tokens** normalized for easier processing.

Tokenization

- Some Asian languages have obvious issues:

  利比亚“全国过渡委员会”执行委员会主席凯卜22日在首都的黎波里公布“过渡政府”内阁名单，宣告过渡政府正式成立。

- But German too: Noun-noun compounds:

  Gesundheitsversicherungsgesellschaften

- Spanish clitics: *Darmelo*
- Even English has issues, to a small degree: *Gregg and Bob’s house*

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  Gesundheits-versicherungs-gesellschaften (health insurance companies)

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  Gesundheitsversicherungsgesellschaften

- Spanish clitics: *Dar-me-lo (To give me it)*
- Even English has issues, to a smaller degree: *Gregg and Bob’s house*

Tokenization

Input: raw text

```
Dr. Smith said tokenization of English is "harder than you've thought."
When in New York, he paid $12.00 a day for lunch and wondered what it would
be like to work for AT&T or Google, Inc.
```

Output from Stanford Parser: http://nlp.stanford.edu:8080/parser/index.jsp
with part-of-speech tags:

```
Dr./NNP Smith/NNP said/VBD tokenization/NN of/IN English/NNP
is/VBZ ``/`` harder/JJR than/IN you/PRP 've/VBP thought/VBN ./.
''/''

When/WRB in/IN New/NNP York/NNP ,/, he/PRP paid/VBD $/$ 12.00/CD
a/DT day/NN for/IN lunch/NN and/CC wondered/VBD what/WP it/PRP
would/MD be/VB like/JJ to/TO work/VB for/IN AT&T/NNP or/CC
Google/NNP ,/, Inc./NNP ./.
```

Morphological Phenomena

What is Linguistic Morphology?

- Morphology is the study of the internal structure of words.
  - **Derivational morphology.** How new words are created from existing words.
    - *[grace]*
    - *[[grace]ful]*
    - *[un[grace]ful]]*
  - **Inflectional morphology.** How features relevant to the syntactic context of a word are marked on that word.
    - This example illustrates number (singular and plural) and tense (present and past).
    - Green indicates irregular. Blue indicates zero marking of inflection. Red indicates regular inflection.
    - This student walks.
    - These students walk.
    - These students walked.
  - ***Compounding.*** Creating new words by combining existing words
    - With or without spaces: surfboard, golf ball, blackboard

Morphemes

- **Morphemes.** Minimal pairings of form and meaning.
  - **Roots.** The “core” of a word that carries its basic meaning.
    - *apple* : ‘apple’
    - *walk* : ‘walk’
  - **Affixes** (**prefixes**, **suffixes**, **infixes**, and **circumfixes**). Morphemes that are added to a base (a root or stem) to perform either derivational or inflectional functions.
    - *un-* : ‘NEG’
    - -*s* : ‘PLURAL’

Language Typology

Types of Languages:

- In order of morphological complexity:
  - Isolating (or Analytic)
  - Fusional (or Inflecting)
  - Agglutinative
  - Polysynthetic
  - Others

Isolating Languages: Chinese

Little morphology other than compounding

- Chinese inflection
  - few affixes (prefixes and suffixes):
    - 们：　我们，　你们，　他们，　。　。　。同志们
      mén: *wǒmén, nǐmén, tāmén, tóngzhìmén*
      plural: we, you (pl.), they comrades, LGBT people
    - “suffixes” that mark aspect: 着 -*zhě* ‘continuous aspect’
- Chinese derivation
  - 艺术家 ***yìshù**jiā* **‘artist’**
- Chinese is a champion in the realm of compounding—up to 80% of Chinese words are actually compounds.

毒	+	贩	→	毒贩
dú		*fàn*		*dúfàn*
‘poison, drug’		‘vendor’		‘drug trafficker’

Agglutinative Languages: Swahili

Verbs in Swahili have an average of 4-5 morphemes, http://wals.info/valuesets/22A-swa

Swahili	English
m-tu a-li-lala	'The person slept'
m-tu a-ta-lala	'The person will sleep'
wa-tu wa-li-lala	'The people slept'
wa-tu wa-ta-lala	'The people will sleep'

- Words written without hyphens or spaces between morphemes.
- Orange prefixes mark noun class (like gender, except **Swahili** has nine instead of two or three).
  - Verbs agree with nouns in noun class.
  - Adjectives also agree with nouns.
  - Very helpful in parsing.
- Black prefixes indicate tense.

Turkish

Example of extreme agglutination

But most Turkish words have around three morphemes

uygarlaştıramadıklarımızdanmışsınızcasına

"(behaving) as if you are among those whom we were not able to civilize"

uygar	"civilized"
+laş	"become"
+tır	"cause to"
+ama	"not able"
+dık	past participle
+lar	plural
+ımız	first person plural possessive ("our")
+dan	ablative case ("from/among")
+mış	past
+sınız	second person plural ("y' all")
+casına	finite verb → adverb ("as if")

Operationalization

- operate (opus/opera + ate)
- ion
- al
- ize
- ate
- ion

Fusional Languages: Spanish

	Singular			Plural		
	1st	2nd	3rd formal 2nd	1st	2nd	3rd
Present	*am-o*	*am-as*	am-a	*am-a-mos*	*am-áis*	*am-an*
Imperfect	*am-ab-a*	*am-ab-as*	*am-ab-a*	*am-áb-a-mos*	*am-ab-ais*	*am-ab-an*
Preterit	*am-é*	*am-aste*	*am-ó*	*am-a-mos*	*am-asteis*	*am-aron*
Future	*am-aré*	*am-arás*	*am-ará*	*am-are-mos*	*am-aréis*	*am-arán*
Conditional	*am-aría*	*am-arías*	*am-aría*	*am-aría-mos*	*am-aríais*	*am-arían*

Polysynthetic Languages: Yupik

- Polysynthetic morphologies allow the creation of full “sentences” by morphological means.
- They often allow the incorporation of nouns into verbs.
- They may also have affixes that attach to verbs and take the place of nouns.
- Yupik Eskimo
  untu-ssur-qatar-ni-ksaite-ngqiggte-uq
  reindeer-hunt-FUT-say-NEG-again-3SG.INDIC
  ‘He had not yet said again that he was going to hunt reindeer.’

Root-and-Pattern Morphology: Arabic

- **Root-and-pattern**. A special kind of fusional morphology found in Arabic, Hebrew, and their cousins.
- Root usually consists of a sequence of consonants.
- Words are derived and, to some extent, inflected by patterns of vowels intercalated among the root consonants.
  - **kitaab** ‘book’
  - **kaatib** ‘writer; writing’
  - **maktab** ‘office; desk’
  - **maktaba** ‘library’

Other Non-Concatenative Morphological Processes

Non-concatenative morphology involves operations other than the concatenation of affixes with bases.

- Infixation. A morpheme is inserted inside another morpheme instead of before or after it.
- Reduplication. Can be prefixing, suffixing, and even infixing.
    - Tagalog:
    - sulat (write, imperative)
    - susulat (reduplication) (write, future)
    - sumulat (infixing) (write, past)
    - sumusulat (infixing and reduplication) (write, present)
- **Apophony**, including the umlaut in English *tooth* → *teeth*; **subtractive morphology**, including the truncation in English nickname formation (*David* → *Dave*); and so on.
- Tone change; stress shift. And more...

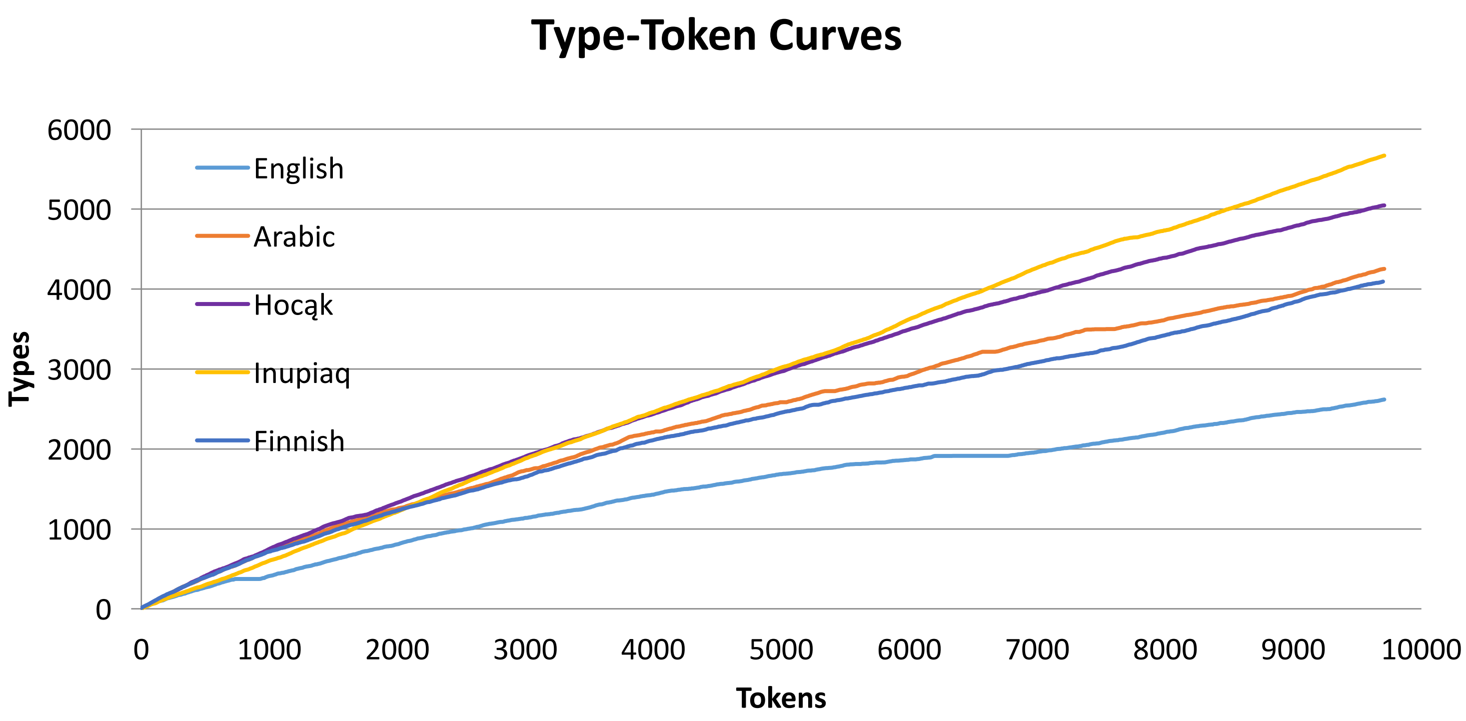
Type-Token Curves

Finnish is agglutinative
Iñupiaq is polysynthetic

Types and Tokens:
"I like to walk. I am walking now. I took a long walk earlier too."

The type *walk* occurs twice. So there are two tokens of the type *walk*.

Walking is a different type that occurs once.



Morphological Processing

Recognizing the words of a language

- Input: a string (from some alphabet)
- Output: is it a legal word? (yes or no)

FSA for English Nouns

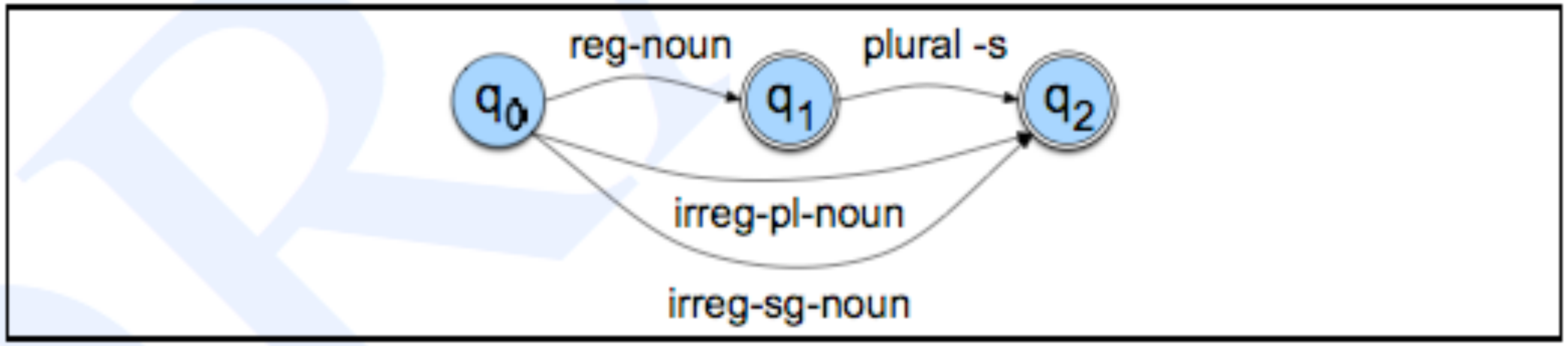


Figure 3.3 A finite-state automaton for English nominal inflection.

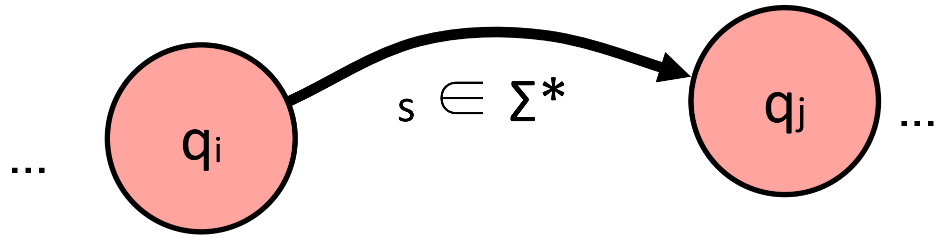
Lexicon:

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

Note: “fox” becomes plural by adding “es” not “s”. We will get to that later.

Finite-State Automaton

- Q: a finite set of states
- $q_0 \in Q$: a special start state
- $F \subseteq Q$: a set of final states
- Σ: a finite alphabet
- Transitions:



- Encodes a **set** of strings that can be recognized by following paths from q_0 to some state in F.

FSA for English Adjectives

Big, bigger, biggest
Happy, happier, happiest, happily
Unhappy, unhappier, unhappiest, unhappily
Clear, clearer, clearest, clearly
Unclear, unclearly

Cool, cooler, coolest, coolly
Red, redder, reddest
Real, unreal, really

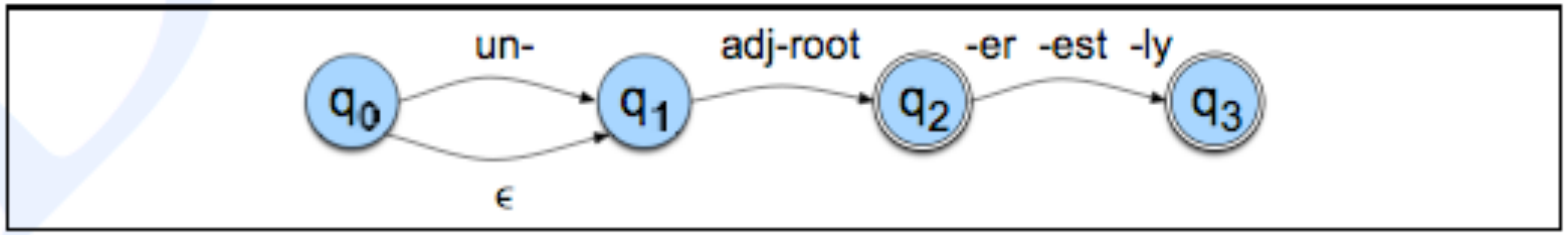


Figure 3.5 An FSA for a fragment of English adjective morphology: Antworth's Proposal #1.

But note that this accepts words like "unbig".

FSA for English Derivational Morphology

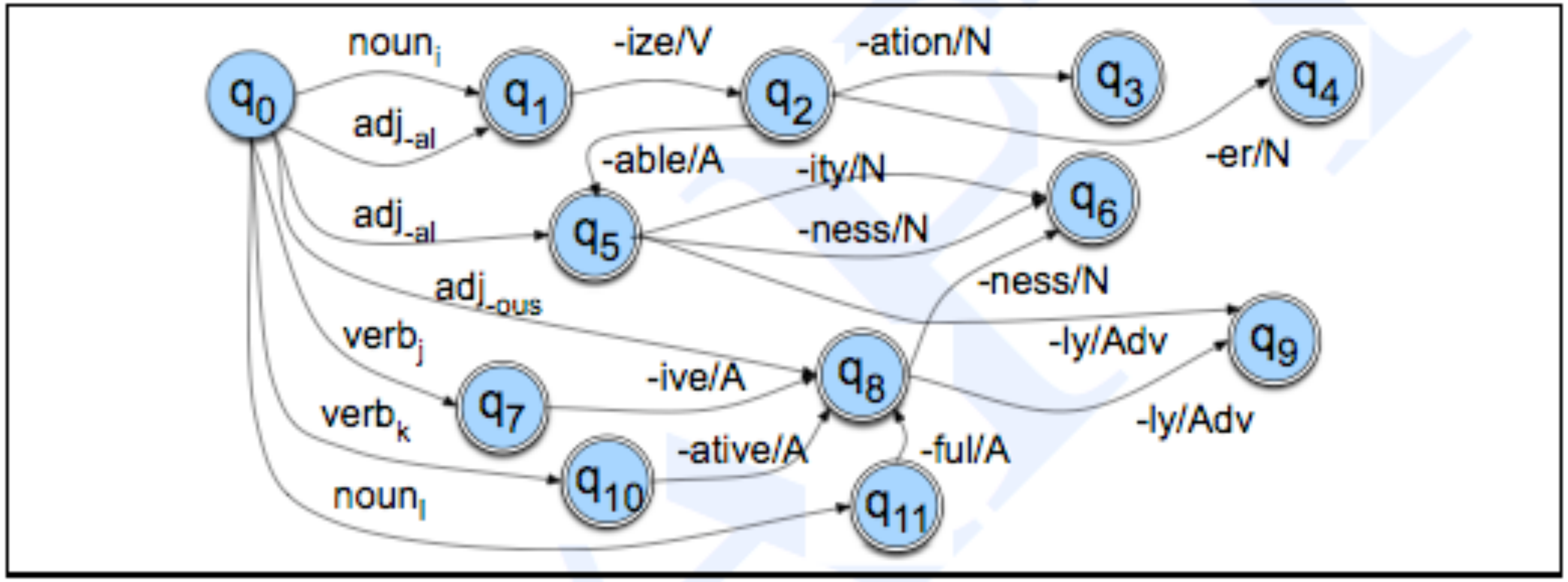


Figure 3.6 An FSA for another fragment of English derivational morphology.

How big do these automata get? Reasonable coverage of a language takes an expert about two to four months.

What does it take to be an expert? Study linguistics to get used to all the common and not-so-common things that happen, and then practice.

Morphological *Parsing*

Input: a word

Output: the word's stem(s) and features expressed by other morphemes.

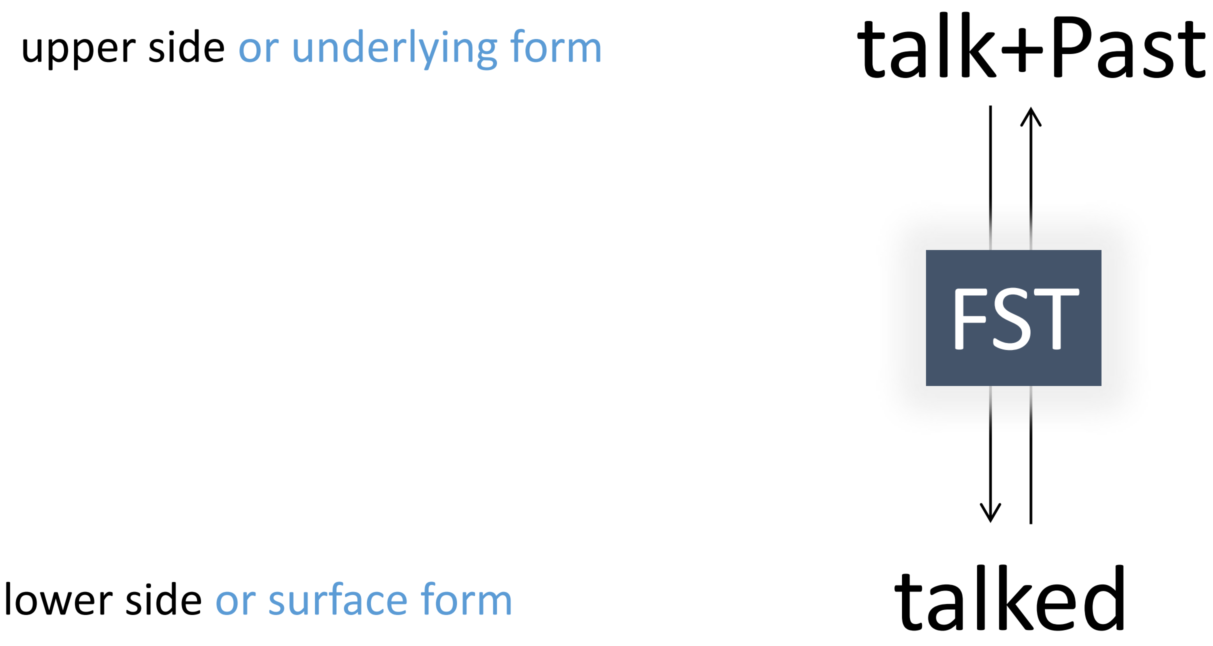
Example: geese → goose +N +Pl

gooses → goose +V +3P +Sg

dog → {dog +N +Sg, dog +V}

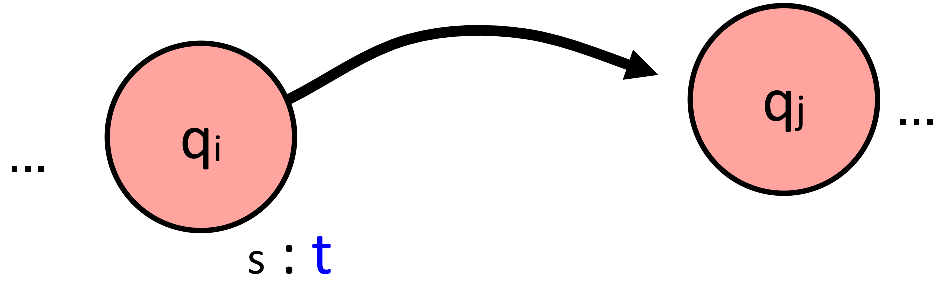
leaves → {leaf +N +Pl, leave +V +3P +Sg}

Upper Side/Lower Side



Finite State Transducers

- Q: a finite set of states
- $q_0 \in Q$: a special start state
- $F \subseteq Q$: a set of final states
- Σ and Δ: two finite alphabets
- Transitions:



$s \in \Sigma^*$ and $t \in \Delta^*$

Morphological Parsing with FSTs

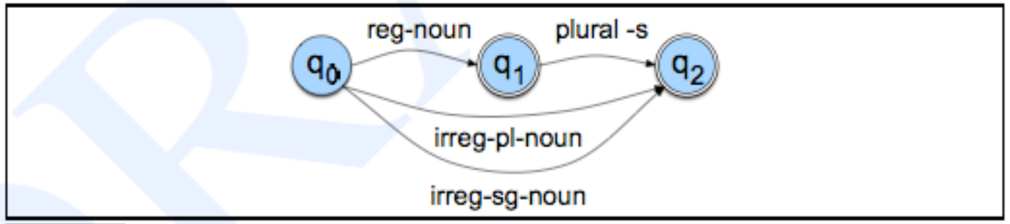


Figure 3.3 A finite-state automaton for English nominal inflection.

reg-noun	irreg-pl-noun	irreg-sg-noun	plural
fox	geese	goose	-s
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reg-noun	irreg-pl-noun	irreg-sg-noun
fox	g o:e o:e s e	goose
cat	sheep	sheep
aardvark	m o:i u:ϵ s:c e	mouse

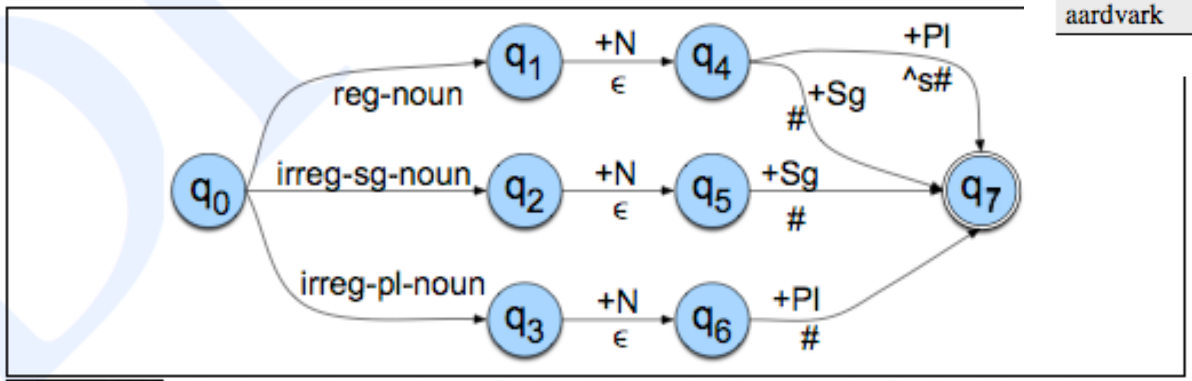


Figure 3.13 A schematic transducer for English nominal number inflection T_{num}. The symbols above each arc represent elements of the morphological parse in the lexical tape; the symbols below each arc represent the surface tape (or the intermediate tape, to be described later), using the morpheme-boundary symbol ^ and word-boundary marker #. The labels on the arcs leaving q_0 are schematic, and need to be expanded by individual words in the lexicon.

Note "same symbol" shorthand.

^ denotes a morpheme boundary.

# denotes a word boundary.

English Spelling

Getting back to fox+s = foxes

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

The E Insertion Rule as a FST

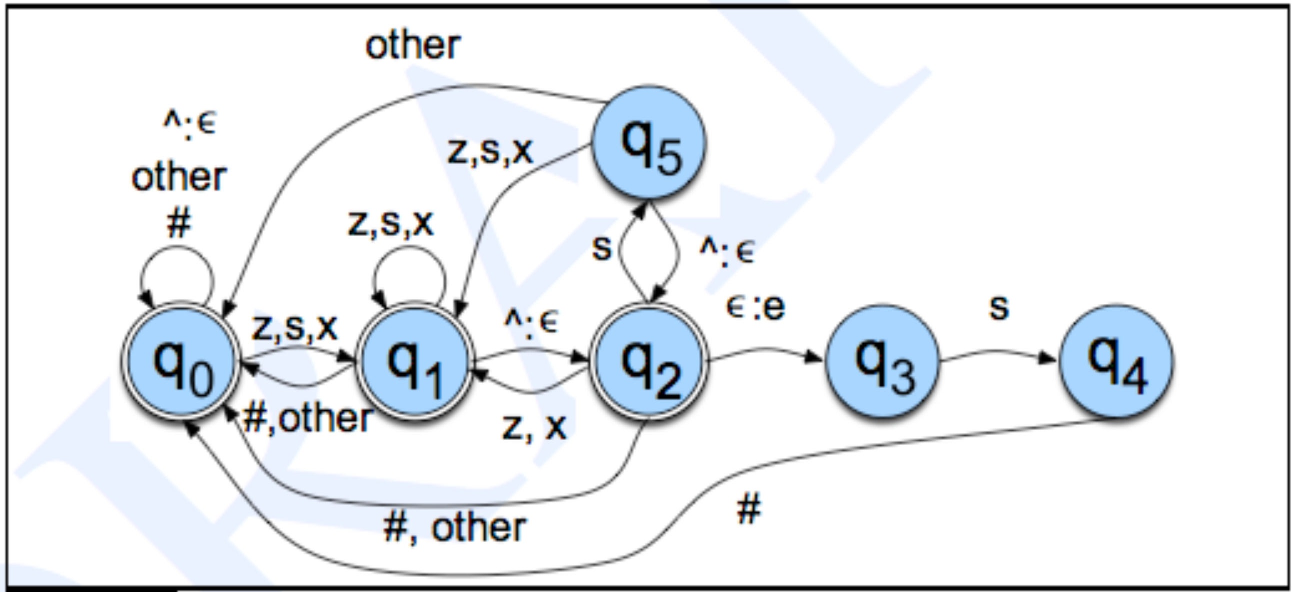


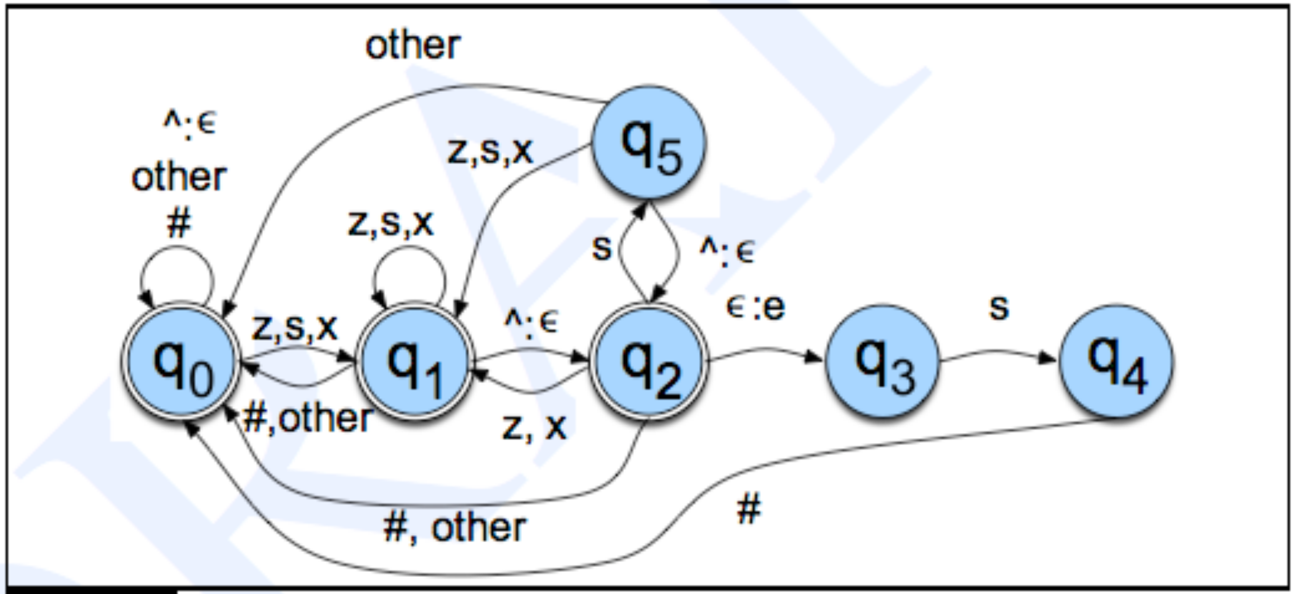
Figure 3.17 The transducer for the E-insertion rule of (3.4), extended from a similar transducer in Antworth (1990). We additionally need to delete the # symbol from the surface string; this can be done either by interpreting the symbol # as the pair #:ϵ, or by postprocessing the output to remove word boundaries.

Generate a normally spelled word from an abstract representation of the morphemes:

Input: fox^s# (fox^εs#)
Output: foxes# (foxεes#)

$$\epsilon \rightarrow e / \left\{ \begin{array}{c} s \\ x \\ z \end{array} \right\} \wedge \_s\#$$

The E Insertion Rule as a FST



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Parse a normally spelled word into an abstract representation of the morphemes:

Input: foxes# (foxεes#)
Output: fox^s# (fox^εs#)

$$\epsilon \rightarrow e / \left\{ \begin{array}{c} s \\ x \\ z \end{array} \right\} \wedge \_s\#$$

Combining FSTs

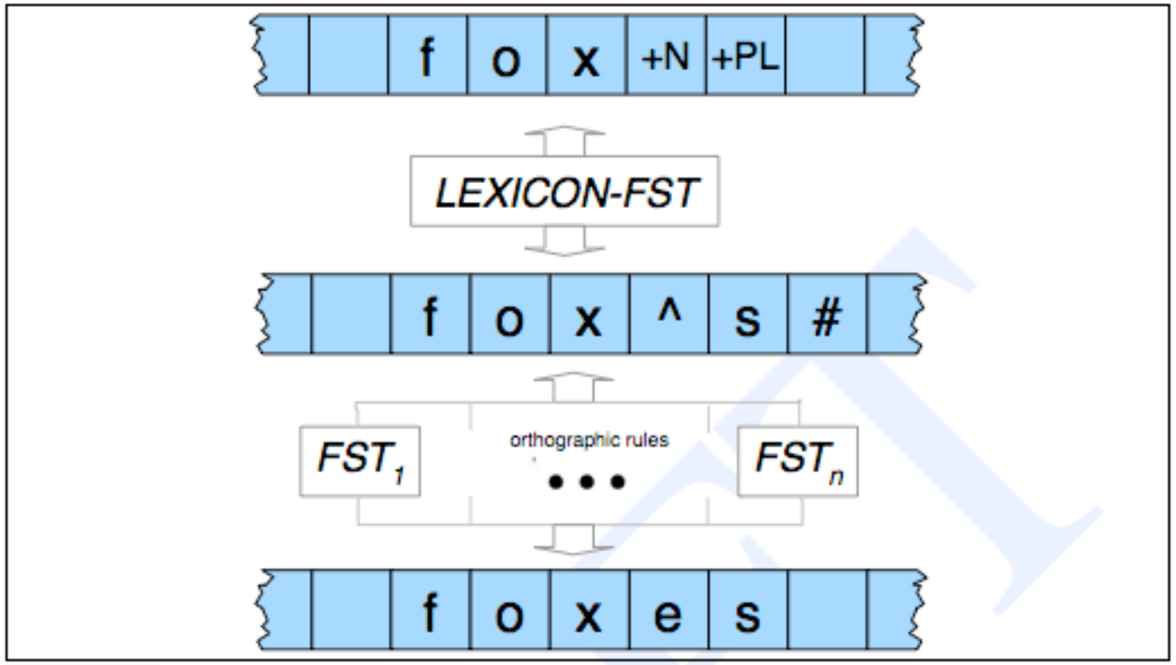
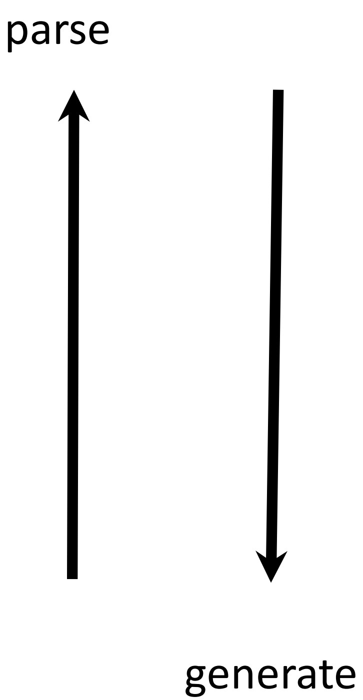


Figure 3.19 Generating or parsing with FST lexicon and rules



FST Operations

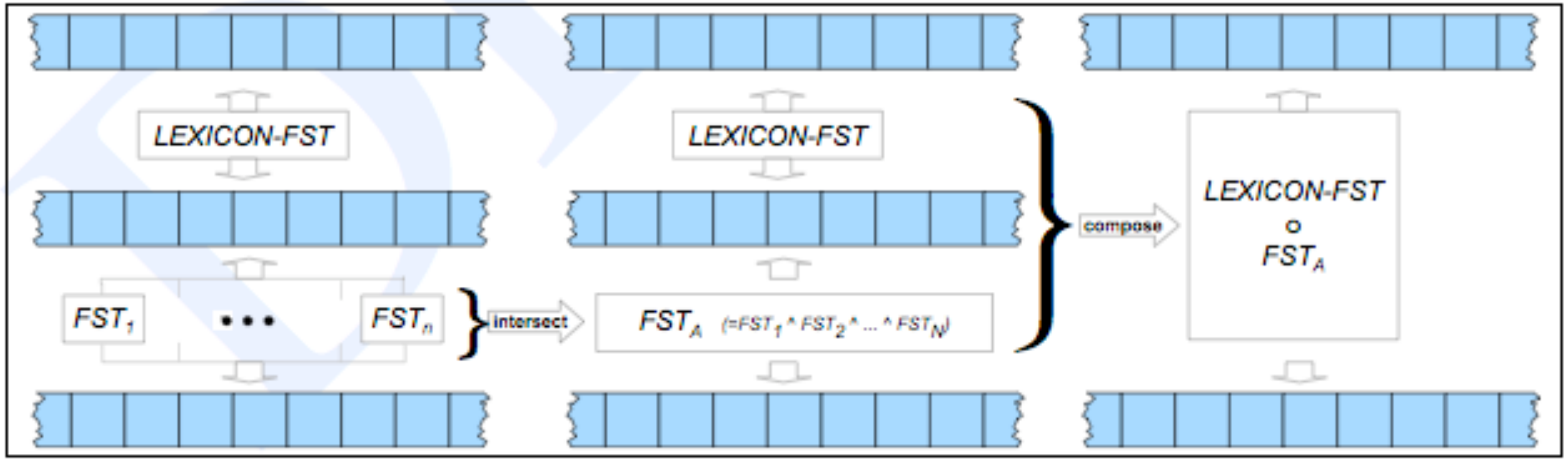


Figure 3.21 Intersection and composition of transducers.

Input: fox +N +pl
Output: foxes#

Language Type Comparison wrt FSTs

- Morphologies of all types can be analyzed using finite state methods.
- Some present more challenges than others:
  - **Analytic languages**. Trivial, since there is little or no morphology (other than compounding).
  - **Agglutinating languages**. Straightforward—finite state morphology was “made” for languages like this.
  - **Polysynthetic languages**. Similar to agglutinating languages, but with blurred lines between morphology and syntax.
  - **Fusional languages.** Easy enough to analyze using finite state method as long as one allows “morphemes” to have lots of simultaneous meanings and one is willing to employ some additional tricks.
  - **Root-and-pattern languages.** Require some very clever tricks.

Stemming (“Poor Man’s Morphology”)

Input: a word

Output: the word’s stem (approximately)

Examples from the Porter stemmer:

- -sses → -ss
- -ies → i
- -ss → s

no	no
noah	noah
nob	nob
nobility	nobil
nobis	nobi
noble	nobl
nobleman	nobleman
noblemen	noblemen
nobleness	nobl
nobler	nobler
nobles	nobl
noblesse	nobless
noblest	noblest
nobly	nobli
nobody	nobodi
noces	noce
nod	nod
nodded	nod
nodding	nod
noddle	noddl
noddles	noddl
noddy	noddi
nods	nod

The Good News

- More than almost any other problem in computational linguistics, morphology is a solved problem (as long as you can afford to write rules by hand).
- Finite state methods provide a simple and powerful means of generating and analyzing words (as well as the phonological alternations that accompany word formation/inflection).
- Finite state morphology is one of the great successes of natural language processing.
- One brilliant aspect of using FSTs for morphology: the same code can handle both analysis and generation.