Unit 3

Morphology and Finite-State Transducers

Morphology

- Study of Words
  - Their **internal structure**

    washing → wash + -ing

  - How they are **formed**?

    bat → bats :: rat → rats

    write → writer :: browse → browser

- Morphology tries to formulate rules

What is Morphology

- **Morph** = form or shape, **ology** = study of
- Morphology is the study of the way words are built up from smaller meaning-bearing units, ***morphemes***.
- A morpheme is often defined as the minimal meaning-bearing unit in a language.

Example:

Singular	Plural
Fox	Foxes
Peccary	Peccaries
Goose	Geese
Fish	Fish

- The word fox consists of a single morpheme (the morpheme fox)
- The word cats consists of two: the morpheme cat and the morpheme -s

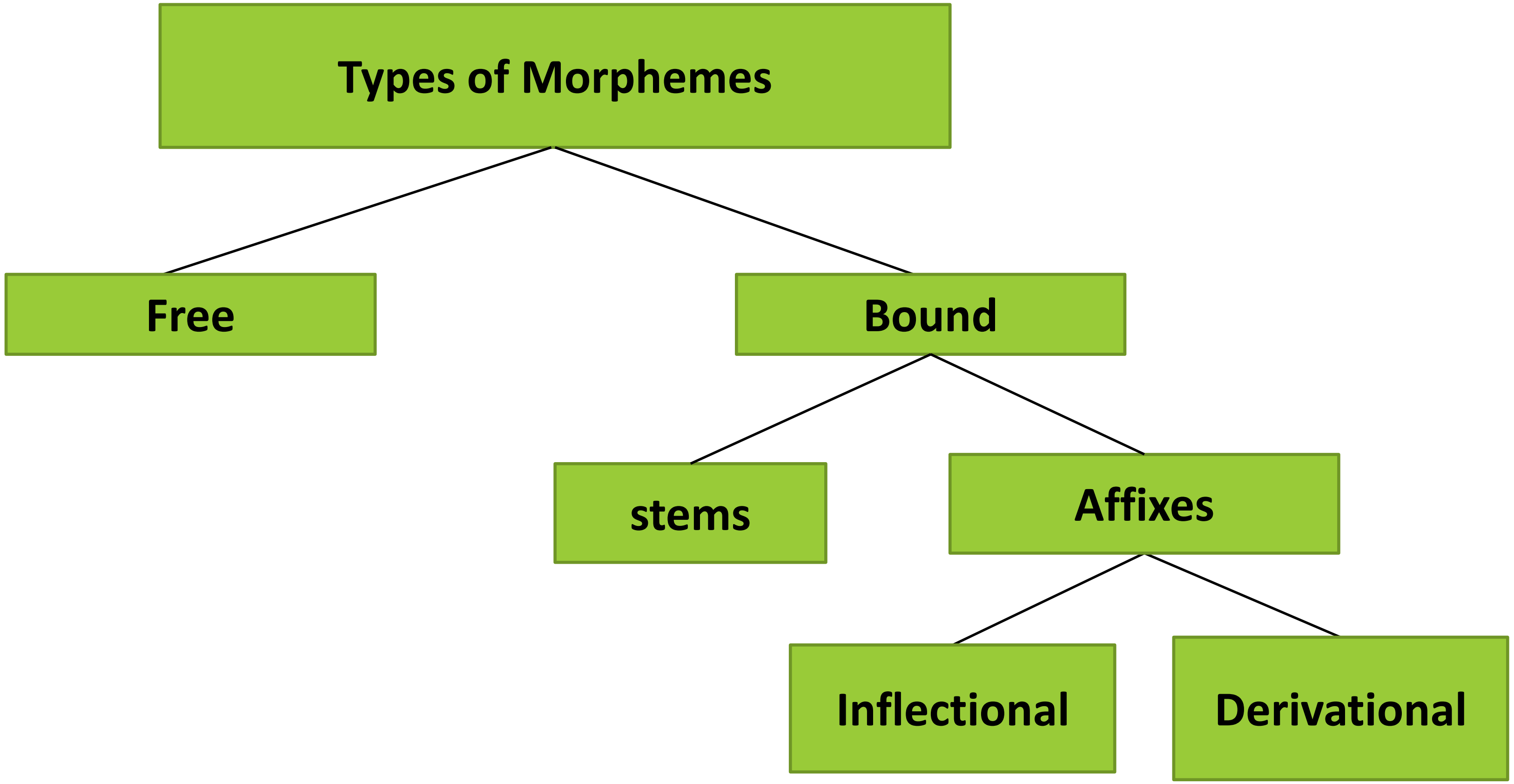
Morphological Parsing

The problem of recognizing that foxes break down into two morphemes fox and -es is called morphological parsing

- ***Parsing*** means taking an input and producing some sort of structure for it
- In information retrieval domain, the similar problem of mapping from ***foxes*** to ***fox*** is called ***stemming***

- It takes two kinds of knowledge to correctly search for singulars and plurals of these forms:
  - **Spelling rules :** tells that English words ending in **-y** are pluralized by changing the **-y** to **-i** and adding an **- es**.
  - **Morphological rules :** tells that **fish** has null plural, and the plural of **goose** is formed by changing the vowel.

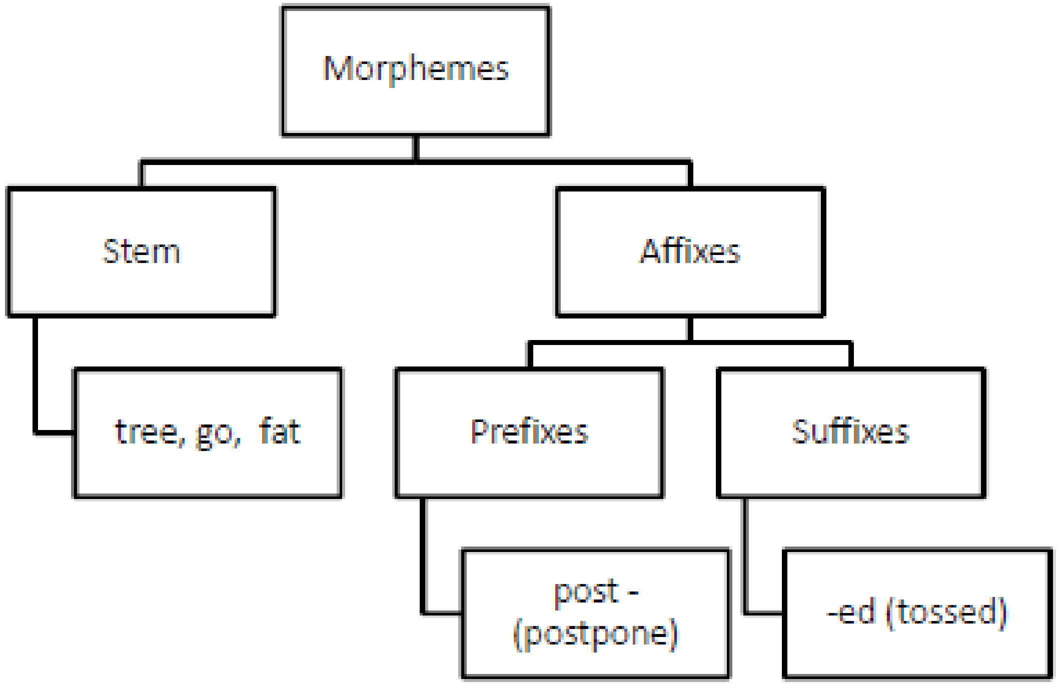
Types of morphemes

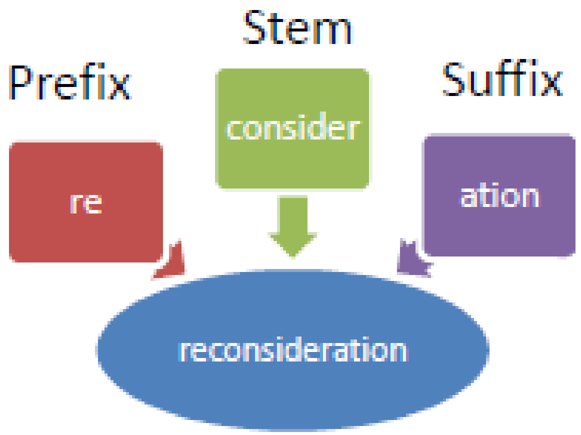


Survey of English Morphology

- Two broad classes of morphemes
  - **Stems** – is the "***main***" morpheme of the word, supplying the main meaning
  - **Affixes** – add "***additional***" meanings of various kinds
    - **Prefixes** – precede the stem Eg: the word **unbuckle** composed of ***buckle*** and prefix ***-un***
    - **Suffixes** – follow the stem   Eg: the word **eats** composed of stem ***eat*** and suffix ***-s***
    - **Circumfixes** – do both prefix and suffix operation Ex: the word **enlighten** has ***en*** as prefix and suffix
    - **Infixes** – inserted inside the stem and generally found in plural forms in English. Eg: plural form of ***cupful*** is ***cupsful*** and ***spoonful*** is ***spoonsful***.

Survey of English Morphology





Survey of English Morphology - Another classification of morphology

- **Concatenative morphology** – word is composed of a number of morphemes concatenated together or two morphemes are ordered one after another.
  i.e. affixation and compounding
  - ***Affixation***: involves attachment of morphemes to stems. (Suffix, prefix, circumfixes, infix)
    - Example: multiple affixations: **anti- inter- govern -ment -al-ist .** Here govern is root or stem.

  - ***Compounding***: New words formed by combining two stems. Can be formed with many parts of speech.
    - Example**: noun-noun : horse-shoe,**

      noun-verb : trouble-shoot,

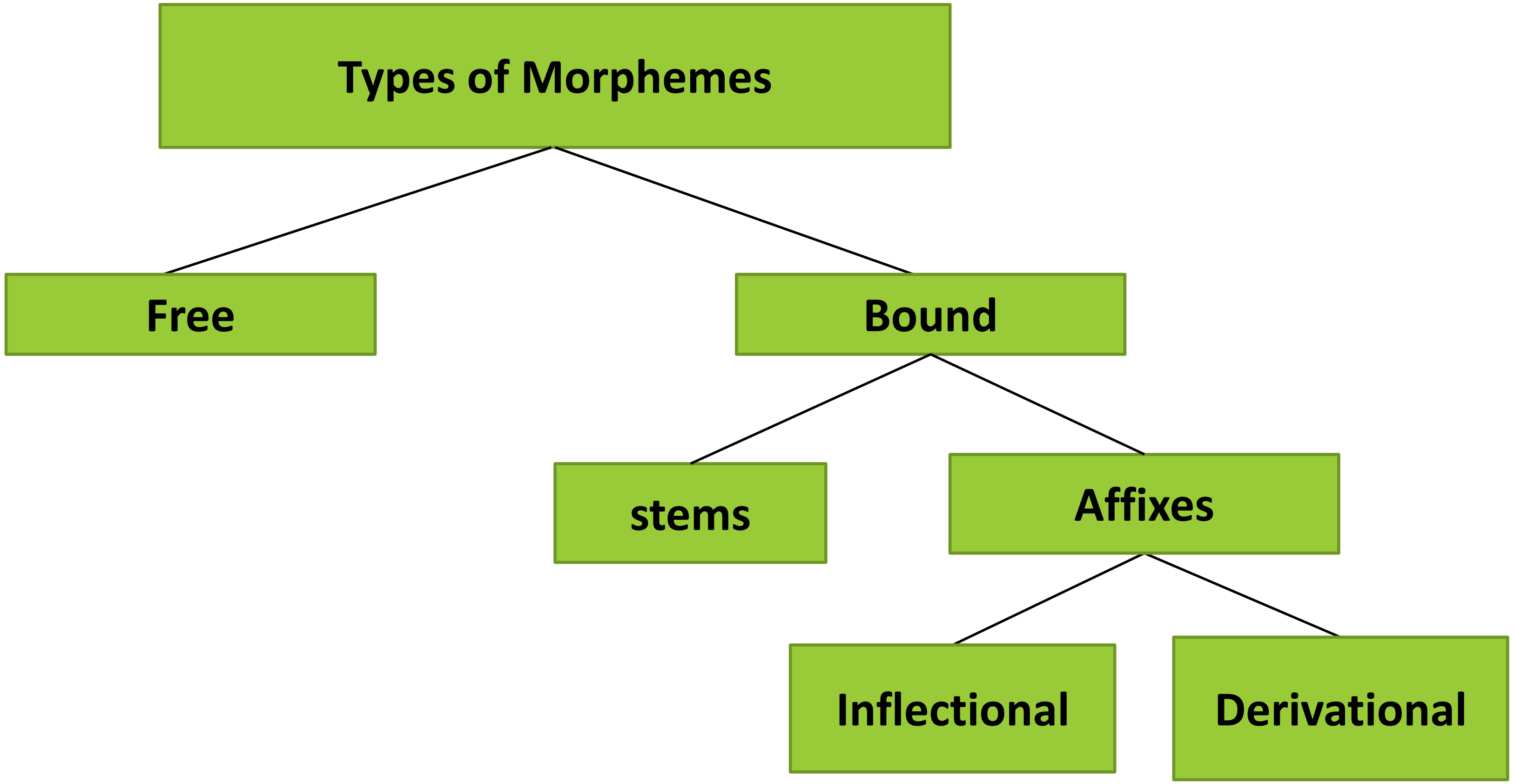
      adjective- verb : high-jump,

      adjective-adjective: bitter - sweet

Survey of English Morphology - Another classification of morphology Contd.

- **Non-Concatenative morphology (templatic morphology)-** morphemes are combined in more complex ways
  - ***Reduplication*** : process that involves taking part of the base and attaching it as an affix; description involves how much is copied.
    - Examples: *bang-bang* : sound of a gun when firing, *bye-bye* : goodbye
  - ***Internal modification (vowel modification)*** : grammatical opposition expressed via a vowel alternation
    - Examples: *sing – sang – sung- song, begin-began, goose-geese , bind- bound*
  - ***Consonant modification :*** changes made for other than vowel
    - Examples: *belief-believe, grief-grieve*
  - ***Mixed modification :*** present/past , verb/noun
    - Examples: *catch-caught, seek-sought, live-life, defence-defend, bent-bend*

Types of morphemes



Ways to form words from Morphemes

Two broad classes:

I. **Inflectional Morphology** : the combination of a word stem with a grammatical morpheme usually resulting in a word of the same class as the original stem

II. **Derivational Morphology** : 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

- In English, only nouns, verbs, and sometimes adjectives can be inflected. The number of affixes is small
- English nouns have only two kinds of inflection:
  - An affix that marks plural
  - An affix that marks possessive
- Regular nouns are nouns that can be converted into their plural form by simply adding **"-s"** and **"-es"** to their end, whereas irregular nouns are nouns that do not follow a standard rule in converting plurals.

An affix marking plural

cat(-s)	finch(-es),
ibis(-es),	box(-es)
thrush(-es)	butterfly(-lies)
ox (oxen) [irregular nouns]	waltz(-es)
mouse (mice) [irregular nouns]	

An affix that marks possessive (realized by apostrophe's)

Regular singular noun	Llama's
Plural nouns not ending in –s	Children's
Regular plural nouns	Llamas'
Names ending in –s or –z	Euripides' , comedies'

Inflectional morphology Contd.

Morphological forms of Irregular verbs

Irregular verbs are those that have some more or less peculiar forms of inflection.

- Often have five different forms, but can have as many as eight (eg. Verb ***be***) or as few as three (eg. ***cut*** or ***hit***).

Morphological Form Classes	**Irregularly Inflected Verbs**		
Stem	eat	catch	cut
-*s* form	eats	catches	cuts
-*ing* participle	eating	catching	cutting
Past form	ate	caught	cut
-*ed* participle	eaten	caught	cut

Derivational Morphology

- **Nominalization in English:** 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 can also be derived from nouns and verbs.

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

Derivational Morphology

- Derivation in English is more complex than inflection because
  - It is generally less productive
  - A nominalizing affix like *–ation* cannot be added to every verb. Thus, cannot be said as *eatation, spellation*
  - There are subtle and complex meaning differences among nominalizing suffixes.

Finite-State Morphological Parsing

- Aim is to take the input forms like those in first column and produce output forms like those in second column
- Second column contains stem of each word and asserted morphological features. (asserted features specify additional information of the stem)
  - Example: *+N for Noun, +SG for singular, +PL for plural.*

Input	Morphological Parsed Output
cats	cat + N + PL
cat	cat + N + SG
cities	city + N + PL
geese	goose + N + PL
goose	(goose + N + SG)
merging	(merge + V + PRES-PART)
caught	(catch + V + PAST-PART) or (catch + V + PAST)

Finite-State Morphological Parsing

To build a morphological parser, the following are needed:

i. **Lexicon:** the list of stems and affixes, together with basic information about them

   Eg., Noun stem or Verb stem, etc.

ii. **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.

iii. **Orthographic rules:** **spelling rules** are used to model the changes that occur in a word, usually when two morphemes combine

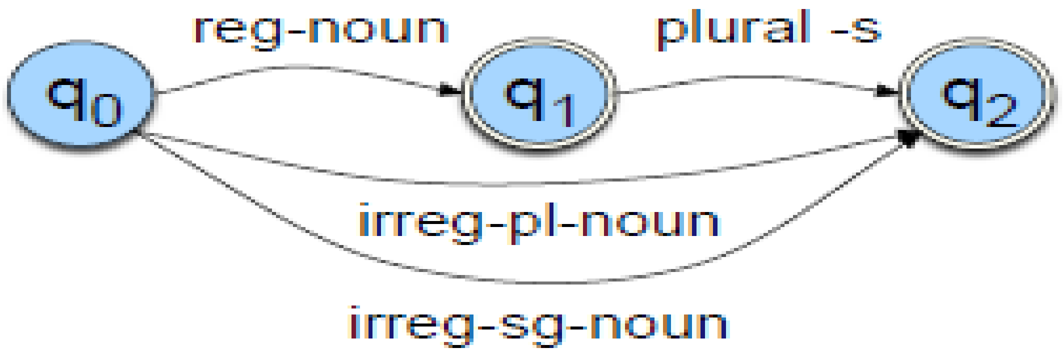
   E.g., the **y→ie** spelling rule changes **city + -s** to **cities** instead of **citys**.

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. i.e. including abbreviations and proper names.
  - Example: a, AAA, AA, Aachen, aardvark, aba, abaca, ……
- 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**.

Lexicon and Morphotactics Contd…

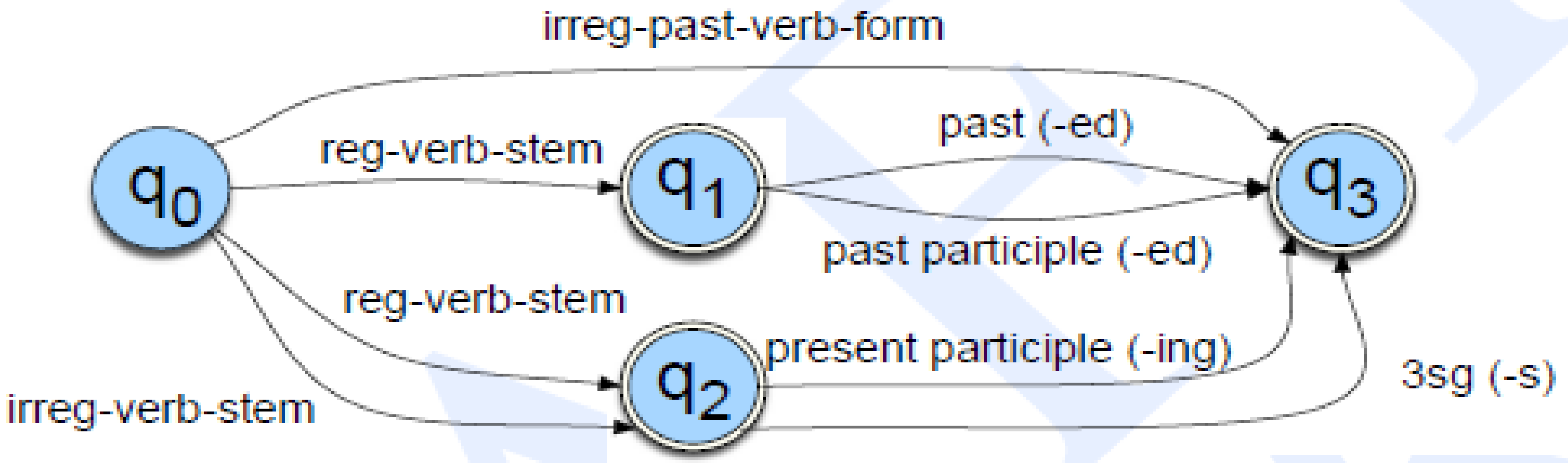
A finite-state automaton for English nominal inflection



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

Lexicon and Morphotactics Contd.

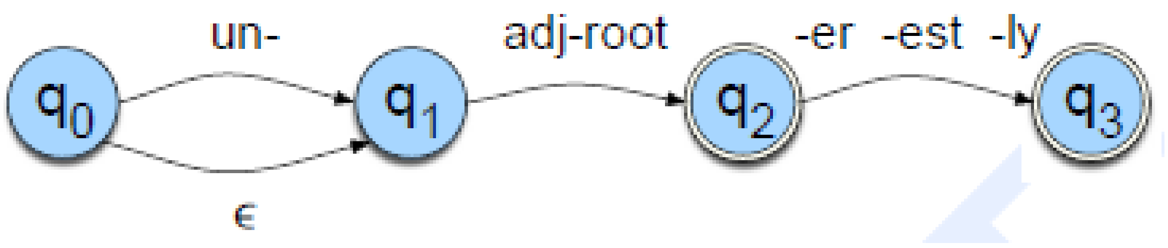
A finite-state automaton for English verbal inflection



reg-verb-stem	irreg-verb-stem	irreg-past-verb	past	past-part	pres-part	3sg
walk fry talk impeach	cut speak sing	caught ate eaten sang	-ed	-ed	-ing	-s

Lexicon and Morphotactics Contd.

- English derivational morphology is more complex than English inflectional morphology, and so automata of modeling English derivation tends to be quite complex.
  - Some are even based on Context free Grammers
- A small part of morphosyntactics of English adjectives is shown:



An FSA for a fragment of English adjective morphology: #1

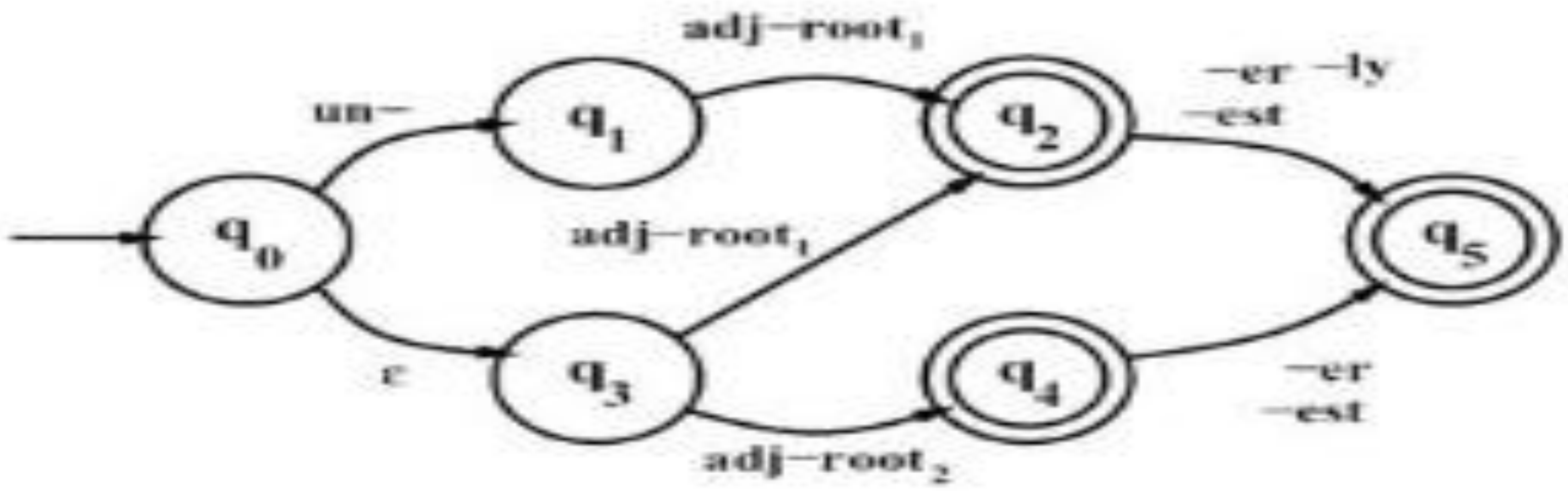
big, bigger, biggest
cool, cooler, coolest, coolly
red, redder, reddest
clear, clearer, clearest, clearly, unclear, unclearly
happy, happier, happiest, happily
unhappy, unhappier, unhappiest, unhappily
real, unreal, really

Lexicon and Morphotactics Contd.

- The FSA#1 recognizes all the listed adjectives, and ungrammatical forms like unbig, redly, and realest.
- Need to setup classes of roots and specify which can occur with which suffixes. Thus #1 is revised to become #2.
  - adj-root$_1$ would include adjectives that can occur with un- and -ly (clear, happy)
  - adj-root$_2$ will include adjectives that can't occur with un- and -ly (big, red)

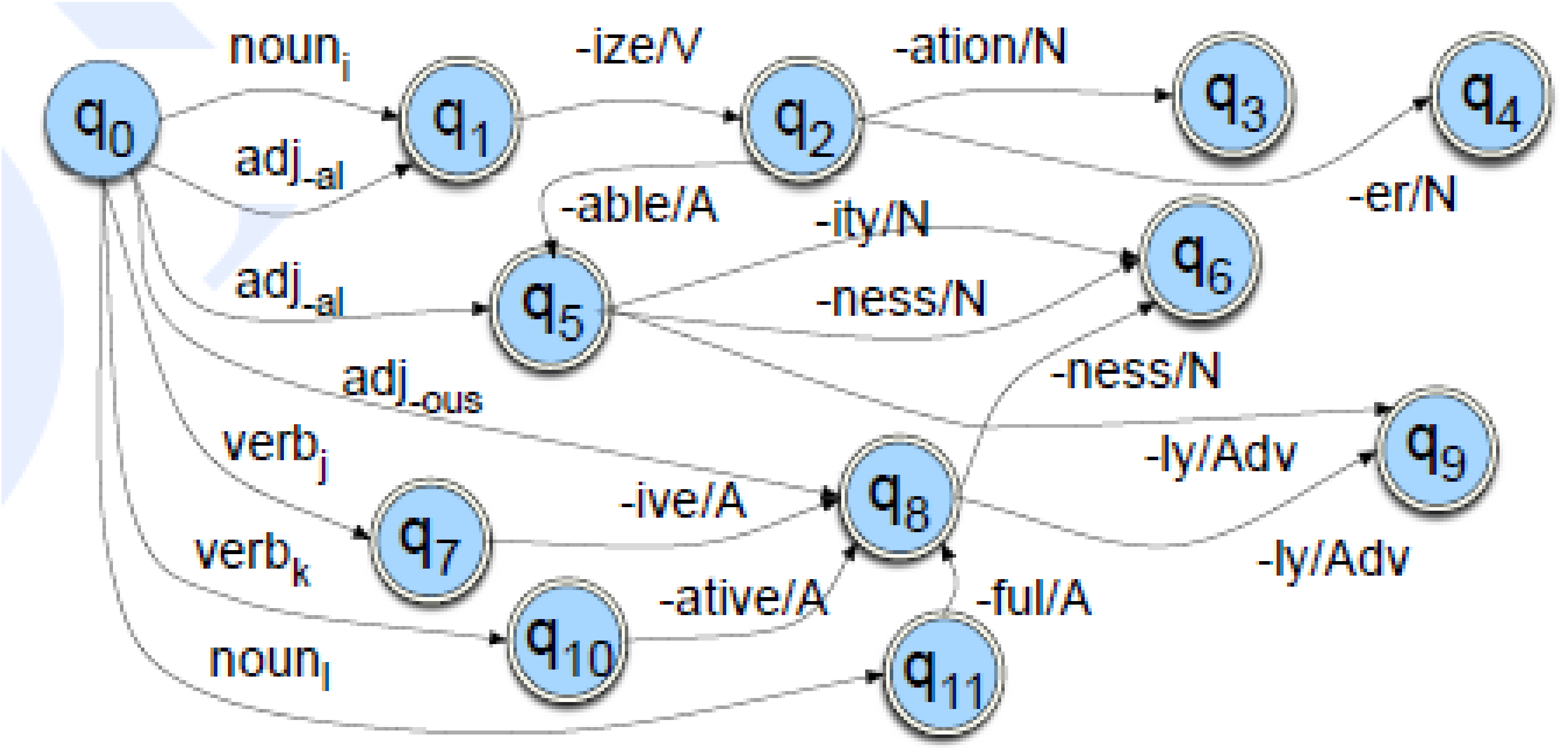
An FSA for a fragment

of English adjective Morphology #2



Lexicon and Morphotactics Contd.

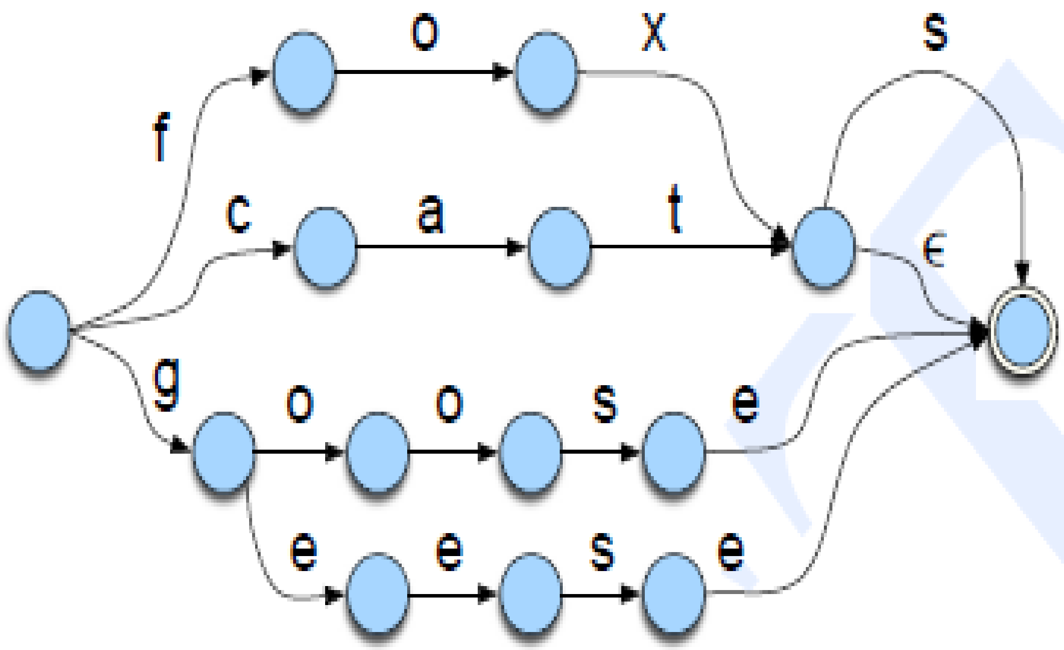
An FSA for English nominal and verbal derivational morphology



- Verb ending with ***-ize*** can be followed by nominalizing suffix ***-ation***
- For the word ***fossilize*** , the word ***fossilization*** can be predicted by following the states q_0, q_1, q_2.

Lexicon and Morphotactics Contd.

- FSAs can be used to solve the problem of **morphological recognition**.
- **Morphological recognition**: determining whether an input string of letters makes up a legitimate English word or not.
- This is done by taking morphotactic FSAs, and plugging in each "***sub-lexicon***" into FSA. (i.e. expand each arc (eg. the **reg-noun-stem** arc)with all the morphemes that make up the set of **reg-noun-stem**.)
- The resulting FSA can then be defined at the level of the individual user.



Compiled FSA for a few English nouns with their inflections

Finite State Transducers

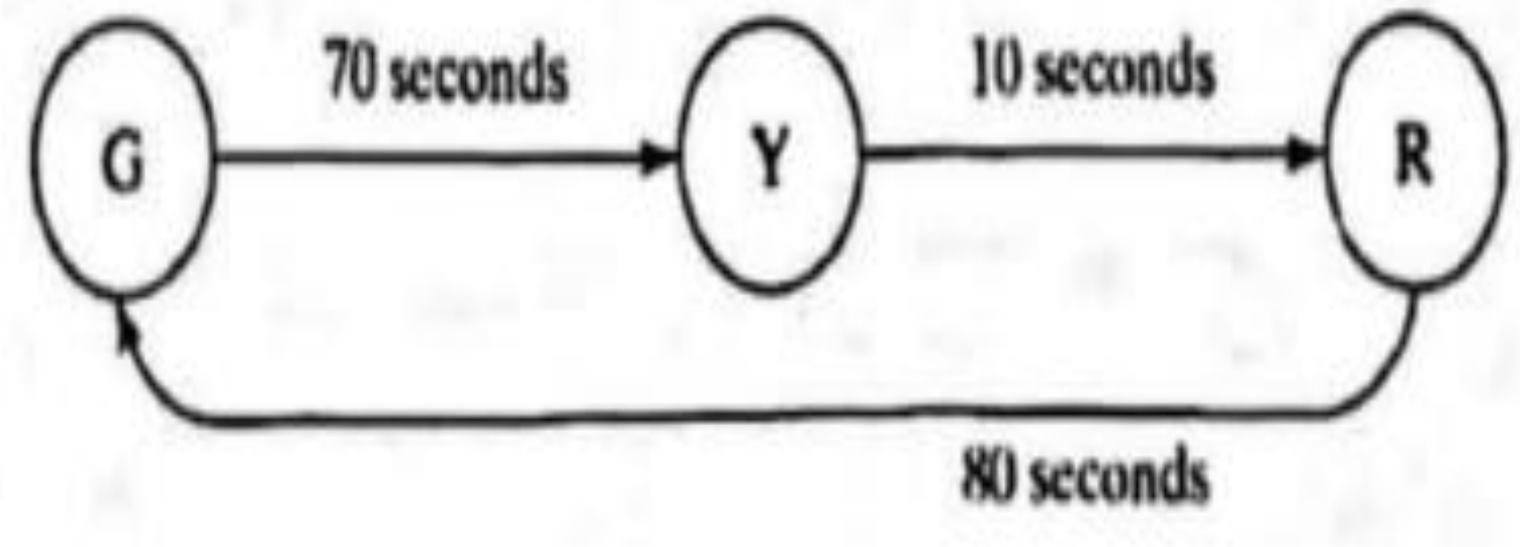
Finite State Transducers are loops that simply run forever, processing inputs

- An automaton that produces outputs based on current input and/or previous state is called a transducer
- Transducers can be of two types:
  - Moore Machine -The output depends only on the current state
  - Mealy Machine- The output depends both on the current state and the current input

Finite State Transducers

Moore Machine: The output depends only on the current state.

Example: Traffic light

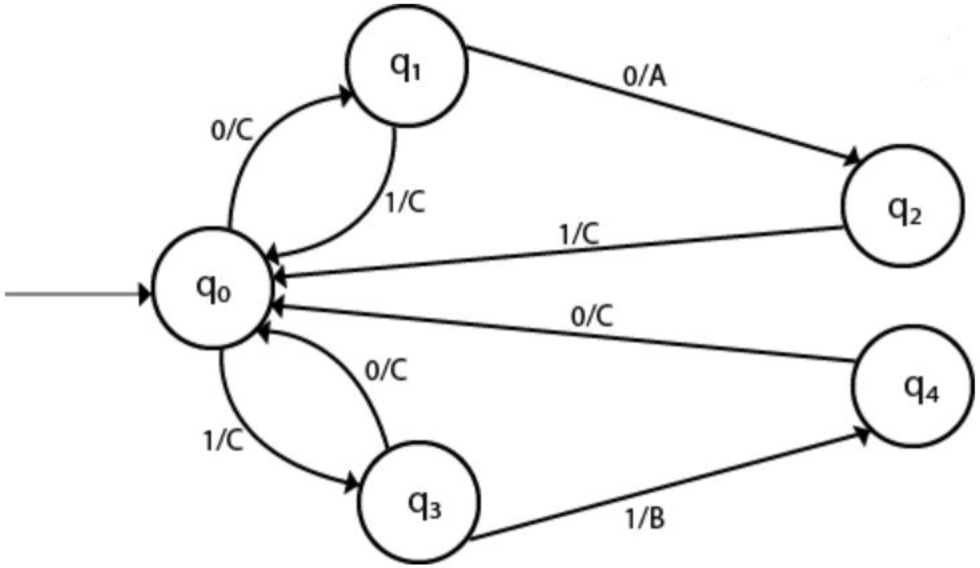


Finite-State Transducers

2. ***Mealy Machine:*** The output depends both on the current state and the current input

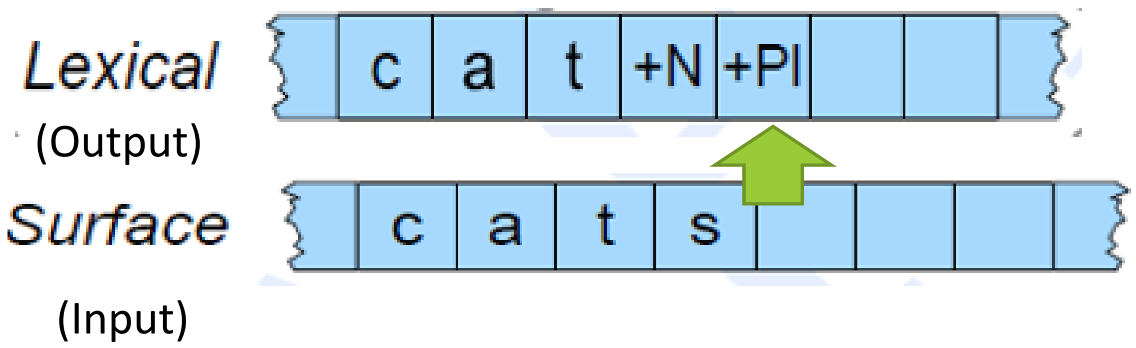
I. Generating parity bits (adds odd parity bit after every four bits)

II. Design a mealy machine that scans sequence of input of 0 and 1 and generates output 'A' if the input string terminates in 00, output 'B' if the string terminates in 11, and output 'C' otherwise



Morphological Parsing with Finite-State Transducers

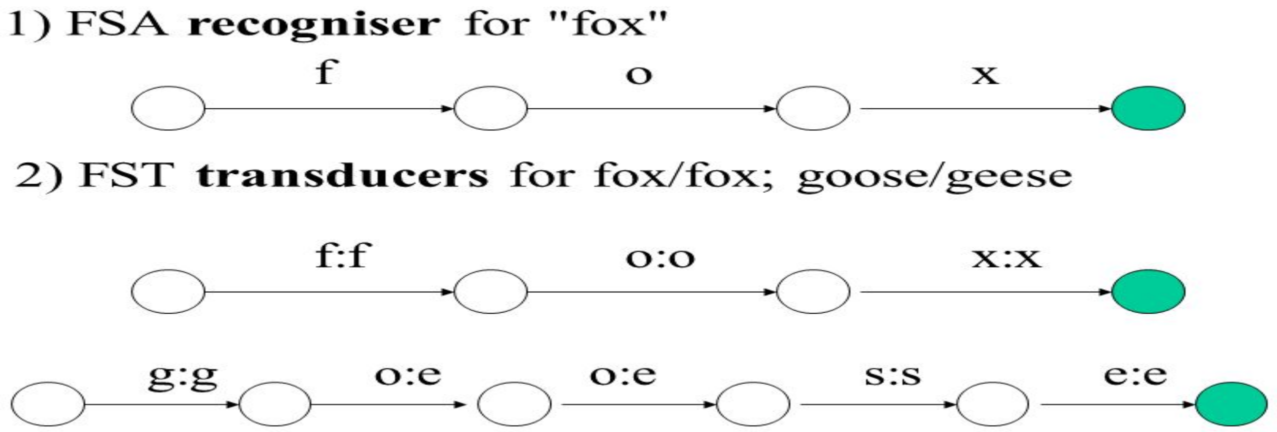
- Given the input, for example, ***cats***, we would like to produce ***cat +N +PL***.
- **Two-level morphology**, by Koskenniemi (1983)
  - **The lexical level** represents a simple concatenation of morphemes making up a word
  - **The surface level** which represents the actual spelling of the final 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.



- Figure shows two levels: lexical and surface level for the word ***cats***.
- Lexical level has the stem word followed by morphological information ***+N +PL*** that tells ***cats*** is a plural noun

Morphological Parsing with Finite-State Transducers

- The automaton we use for performing the mapping between these two levels is the **Finite-State Transducer or FST**.
- A transducer maps one set of symbols with another set 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 by defining set of strings, whereas FST defines a relation between sets of strings.



Morphological Parsing with Finite-State Transducers

- Another view of an FST is that it is a machine that reads one string and generates another.

L_{IN} = {cat, cats, fox ,foxes, …}

L_{out}={cat +N +SG, cat +N +PL, fox +N +SG, fox +N +PL …}

T = {<cat, cat +N +SG>,< cats, cat +N +PL>, < fox, fox +N +SG>, < foxes, fox +N +PL >…}

Morphological Parsing with Finite-State Transducers

Four-fold way thinking about transducers

- **FST as recognizer:** a transducer that takes (recognizes) a pair of strings as input and outputs ***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(translator):** A machine that reads a string and outputs another string.
  - Morphological parsing: letter(input), morphemes (output)
- **FST as set relater:** A machine that computes relations between sets.

Morphological Parsing with Finite-State Transducers

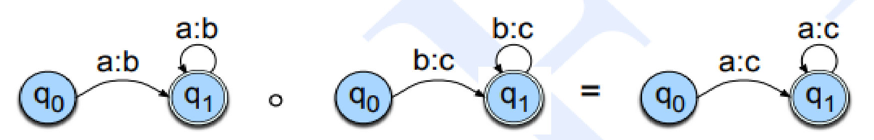
- A formal definition of FST (Mealy machine extension to a simple FSA):
  - **Q**: a finite set of N states $q_0, q_1, \ldots, q_N$
  - **Σ**: a finite alphabet of complex symbols.

    Each complex symbol is composed of an input-output pair i : o. I and O may each also include the epsilon symbol ε.
  - **q_0**: the start state
  - **F**: the set of final states, $F \subseteq Q$
  - **δ(q, i:o):** the transition function or transition matrix between states. Given a state **q ϵ Q** and complex symbol **i:o ϵ Σ**, **δ(q, i:o)** returns a new state **q' ϵ Q**. **δ** is thus a relation from **Q x Σ** to **Q**

Morphological Parsing with Finite-State Transducers

- **Two useful closure properties of FSTs:**
  - ***Inversion:*** Inversion of transducers switches input and output labels. Thus, If **T** maps from Input alphabet **I** to output alphabet **O**, then the inverse of **T**, $\mathbf{T}^{-1}$ maps from **O** to **I**.
  - Inversion is useful because it makes it easy to convert a **FST-as-parser into an FST-as-generator**.

  - ***Composition:*** If $\mathbf{T_1}$ is a transducer from $\mathbf{I_1}$ to $\mathbf{O_1}$ and $\mathbf{T_2}$ a transducer from $\mathbf{I_2}$ to $\mathbf{O_2}$, then $\mathbf{T_1}$ **o** $\mathbf{T_2}$ maps from $\mathbf{I_1}$ to $\mathbf{O_2}$
  - Composition is useful because it allows us to take two transducers that run in series and replace them with one complex transducer.
  - $\mathbf{T_1 \circ T_2(S) = T_2(T_1(S))}$



The composition of [a:b]+ with [b:c]+ to produce [a:c]+.

Morphological Parsing with Finite-State Transducers

- Morphological parser maps the surface forms to lexical forms by ***cascading*** the lexicon with singular or plural automaton.
- **Cascading:** running two automata in series with the output of first feeding the input to the second
- lexicon of stems are represented as FST T_{stems} . Example: dog to ***reg-noun-stem***
- For suffixes: $\mathbf{T_{stems}}$ allows the forms to be followed by ***@:@*** (any feasible pair)
- Alternative to cascading is **composing** the transducer using **composition operator**.
- ***Composing*** is a way of taking a cascade of transducers with many different levels of inputs and outputs and converting them into single ***"two level"*** transducer with one input tape and one output tape.
- Composed automaton is $\mathbf{T_{lex}=T_{num} \circ T_{stems}}$

Morphological Parsing with Finite-State Transducers

- Regular expressions can be written in the complex alphabet **Σ** as in FSA
- For two-level morphology, FST is viewed as having two level tapes.
  - **The upper or lexical tape, The lower or surface tape**
- Each symbol **a:b** in the transducer alphabet **Σ** expresses how the symbol ***a*** from one tape is mapped to the symbol ***b*** on the another tape
  - Example: ***a:ε*** means ***a*** on the upper tape will correspond to nothing in lower tape.
- Generally, symbols map to themselves, in two level morphology. Hence called as ***default pairs.*** Example: **a:a (referred to this by single letter a)**
- A simple pair of symbols in Σ are called ***feasible pairs***. Example**: a:!, a:ε**

Morphological Parsing with Finite-State Transducers

- FSA accepts a language stated over a finite alphabet of single symbols.

  Example: alphabet of sheep language **Σ={b,a,!}**

- FST accepts a language stated over a pair of symbols

  Example: **Σ={a:a, b:b, !:!, a:!, a: ε, ε:!}**

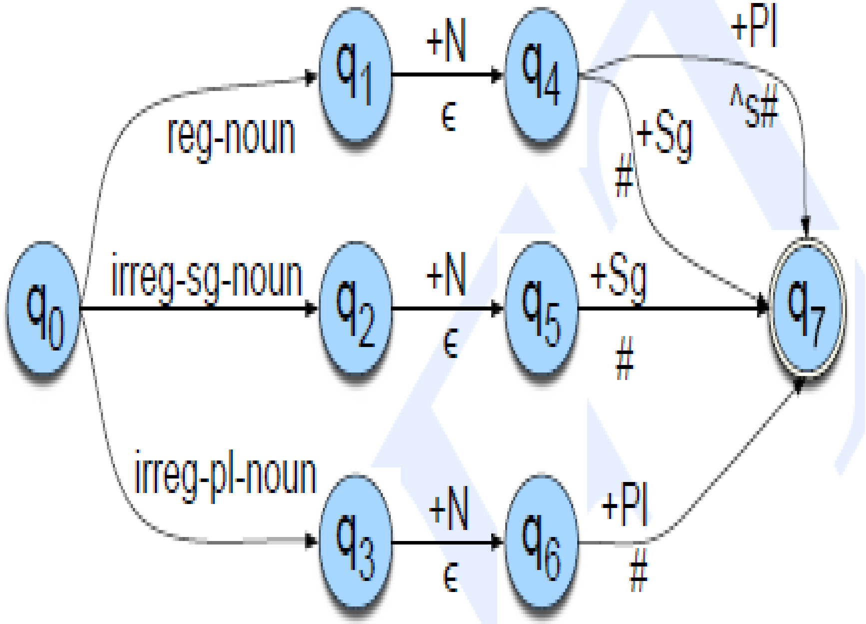
- FSAs are isomorphic to regular languages, FSTs are isomorphic to regular relations.
  - Regular relations are sets of pairs of strings, an extension of the regular language, which are sets of strings.

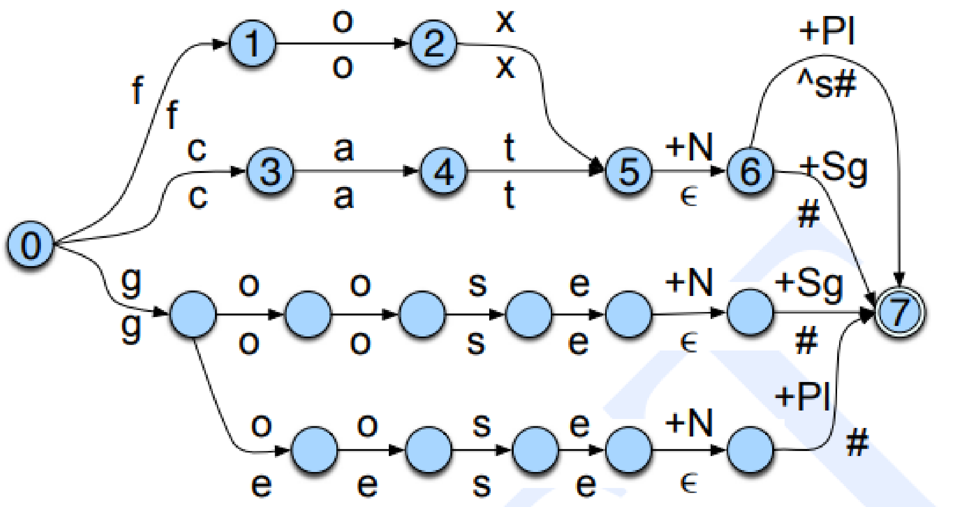
Morphological Parsing with Finite-State Transducers

- **Application**

- An FST morphological parser is built for earlier morphotactic FSAs and lexica by adding an extra ***"lexical"*** tape and appropriate morphological features.
  - Nominal morphological features map to the empty string **ε** or the word/morpheme boundary symbol **#** since there is no segment corresponding to them on the output tape.

Morphological Parsing with Finite-State Transducers





A fleshed-out English nominal inflection FST T_{lex}, expanded from T_{num} by replacing the three arcs with individual word stems (only a few sample word stems are shown).

Morphological Parsing with Finite-State Transducers

- For morphological noun parser, all the individual regular and irregular noun stems are augmented.
  - Lexicon of the transducer is updated so that regular plurals like **geese** will parse into correct stem **goose +N +PL**.

    Example: surface geese maps to underlying goose, the new lexical entry will be "g:g o:e o:e s:s e:e".

  - Regular forms are simpler. Two level entry for fox will be **"f:f o:o x:x"**, but relying on orthographic convention that **f** stands for **f:f**, **o** stands for **o:o** etc. it can be referred to as "**fox**" and goose as **"g o:e o:e s e"**.

Morphological Parsing with Finite-State Transducers

- Maps plural nouns into stem plus the morphological marker **+PL**, and singular nouns into stem plus **+SG**.

- Thus, surface cats will map to **cat +N +PL** as :
  c:c a:a t:t +N: ε +PL: ^ s #

- Symbol **^** indicates morpheme boundary
- Symbol **#** indicates word boundary.

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

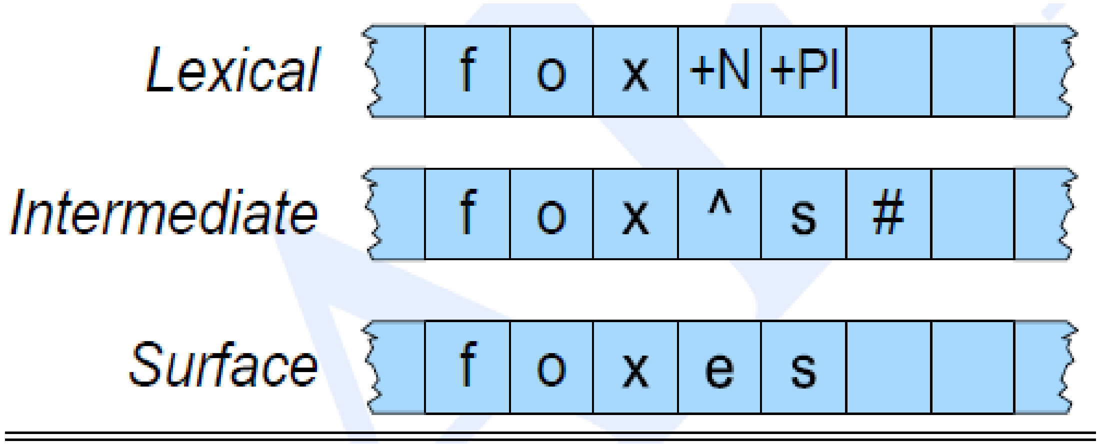
Orthographic rules and Finite-State Transducers

- Concatenating the morphemes can work to parse the words like **"dog", "cat".**
- But this simple method does not work. *Example:* **"foxes"** is to be parsed into lexicons **"fox +N +PL"** etc.
- This requires introduction of spelling rules (also called orthographic rules).
- Some of the spelling 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	verbs ending with *vowel* + *-c* add *-k*	panic/panicked

Orthographic rules and Finite-State Transducers

- To account for the spelling rules, another tape is introduced, called intermediate tape.
- ***Intermediate tape:*** produces the output slightly modified, thus going from 2-level to 3-level morphology
- Between each level of tapes is a two-level transducer.
  - **Lexical transducer** - between lexical and intermediate levels
  - **E-insertion spelling rule** - between the intermediate and surface levels



  - E-insertion spelling rule inserts an **e** on the surface tape when the intermediate tape has a morpheme boundary **^** followed by the morpheme **-s**

Orthographic rules and Finite-State Transducers

- The E-insertion rule states that : “*insert an e on the surface tape just when the lexical tape has a morpheme ending in x (or z, etc) and the next morpheme is -s*”.

Formalization of the rule :

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

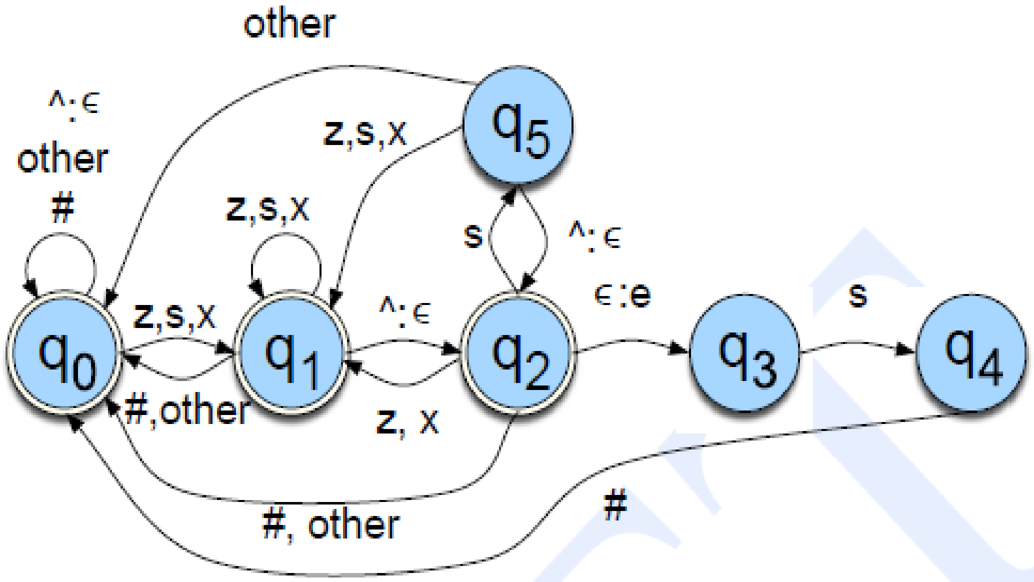
Meaning: Insert e after a morpheme-final x, s, or z, and before the morpheme s

This follows the rule notation of Chomsky and Halle(1968); (***a*** $\longrightarrow$ ***b/c ___d*** means ***“rewrite a as b when it occurs between c and d”***)

- **ε** is the empty transition, replacing it means inserting something.
- the symbol **^** indicates morpheme boundary. Boundaries are deleted by including the symbol **^: ε** in the default pairs of transducer. Thus morpheme boundary markers are deleted on the surface level by default.
- The **#** symbol marks the word boundary.

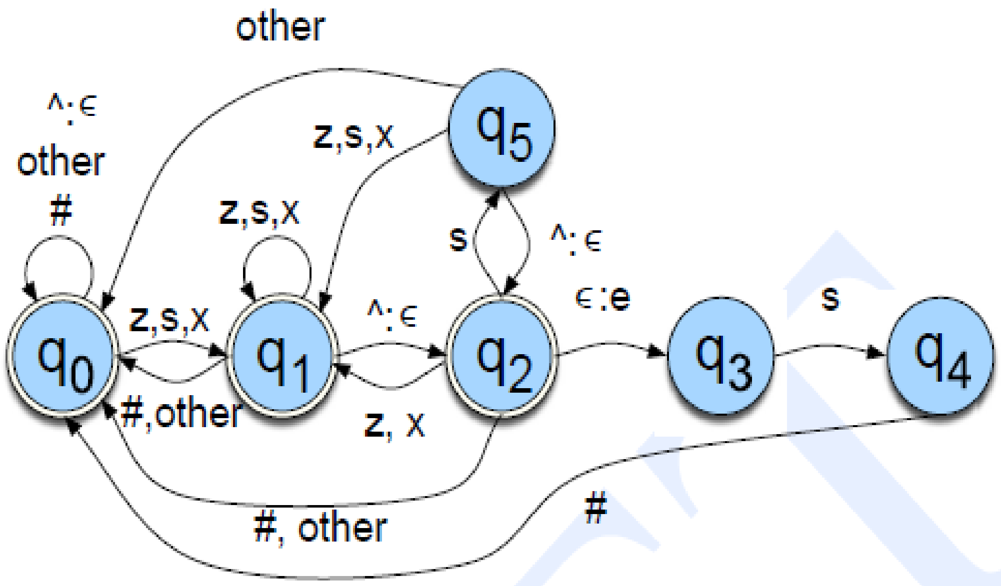
Orthographic rules and Finite-State Transducers

- Building a transducer for any rule is to express only the constraints necessary for that rule, allowing any other strings of symbols to pass through unchanged. (i.e. it ensures only ***ε:e*** pair is seen in proper context)
- State q_0 models when seeing only default pairs unrelated to the rule. It is an accepting state.
- State q_1 models having seen **z, s,** or **x** and it's an accepting state
- State q_2 models having seen the morpheme boundary. It is also an accepting state
- State q_3 models having seen the **E-insertion**; ***it is not an accepting state since the insertion is only allowed if it is followed by the s morpheme and then the end-of-the-word symbol #***



Orthographic rules and Finite-State Transducers

- The ***other*** symbol is used to pass through any parts of words that don't have a role in E-insertion rule. ***(other means "any feasible pair that is not in this transducer")***

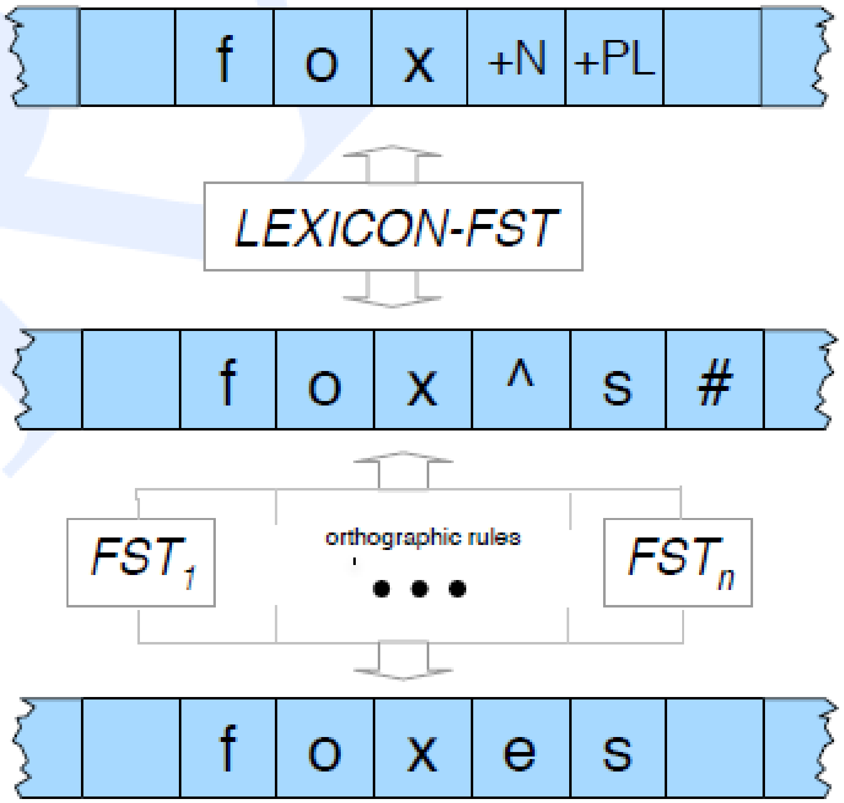


State\Input	s:s	x:x	z:z	^:ϵ	ϵ:e	#	other
q_0:	1	1	1	0	-	0	0
q_1:	1	1	1	2	-	0	0
q_2:	5	1	1	0	3	0	0
q_3	4	-	-	-	-	-	-
q_4	-	-	-	-	-	0	-
q_5	1	1	1	2	-	-	0

State-transition table for E-insertion rule

Combining FST Lexicon and Rules

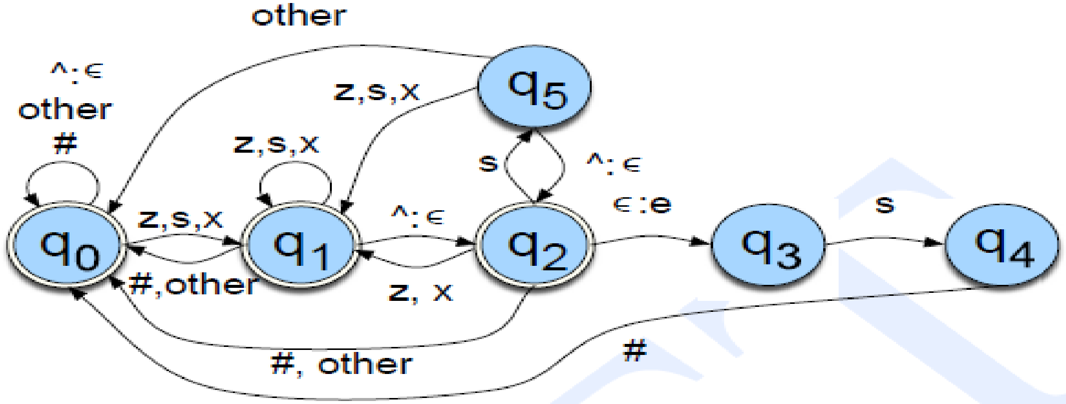
- Two-level morphology system used for **parsing or generating.**
- **Lexicon transducer** – maps between the ***lexical level*** (stems and morphological features) and an ***intermediate level*** (represents concatenation of morphemes)
- **Host of transducers** – ***(each represents a single spelling rule)*** – run in parallel; maps between ***intermediate level*** and ***surface level***
- ***Putting the spelling rules in parallel or in series (cascading) is a design choice.***
- The architecture is a **two level cascade of transducers**
- The output from one transducer acts as an input to another transducer
- ***The cascade can be run top-down to generate a string, or bottom-up to parse it***

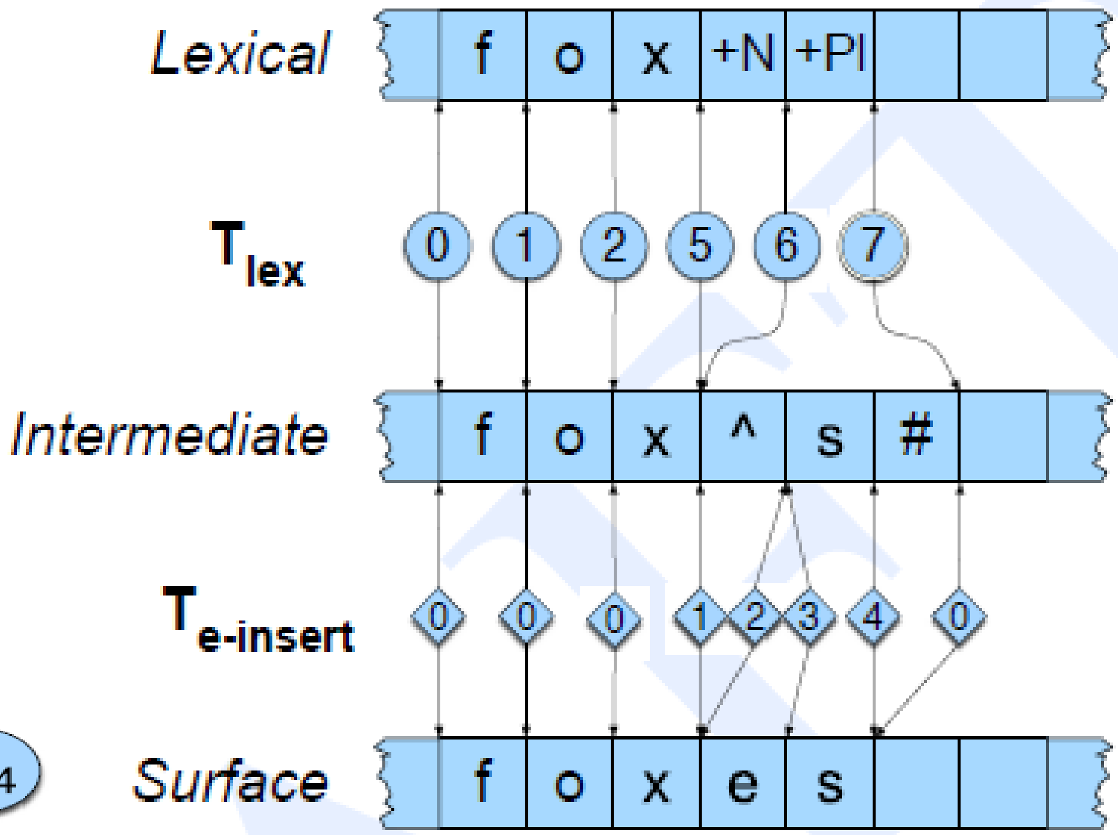


Generating or parsing with FST lexicon and rules

Combining FST Lexicon and Rules

- Figure shows a trace of the system ***accepting*** the mapping from **fox +N +PL** to ***foxes***.
- <u>**Generation:**</u> **(surface tape from lexical tape)**
  - Running lexicon transducer, for ***fox +N +PL***, it will produce ***fox^#*** on the intermediate tape.
  - Running all possible orthographic transducers to run in parallel, will produce the ***foxes*** in the surface tape.





Generating or parsing with FST lexicon and rules

Combining FST Lexicon and Rules

- **Parsing:** Complicated because of the problem of **"ambiguity"**
- Example: ***foxes*** can be verb and hence lexical parse for ***foxes*** could be ***foxes +V +3SG*** or ***fox +N +PL***

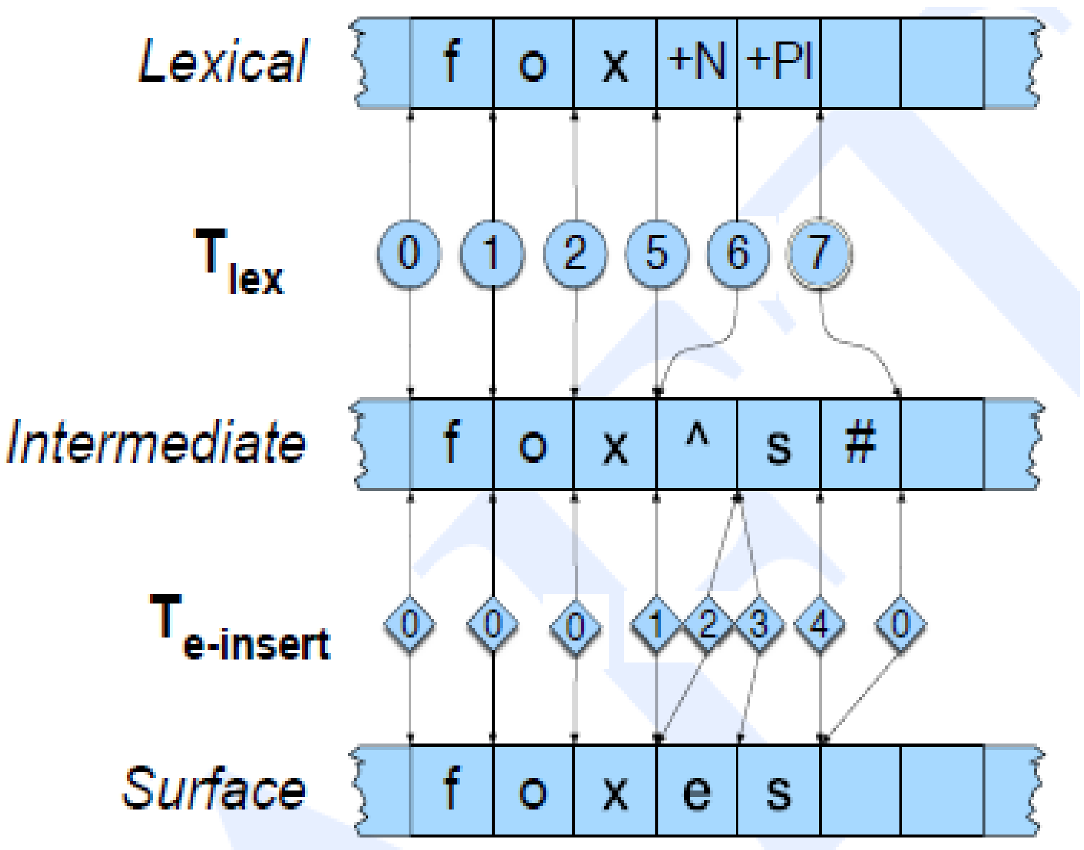
(Cant decide on the correct parse by the transducer)

- **Disambiguating:** require external evidence such as surrounding words

Example: ***"I saw two foxes yesterday". (Foxes will be noun)***

"That trickster foxes me every time!" (Foxes will be verb)

Disambiguation algorithms are used to solve this. If not both the choices are considered. (Noun and verb)



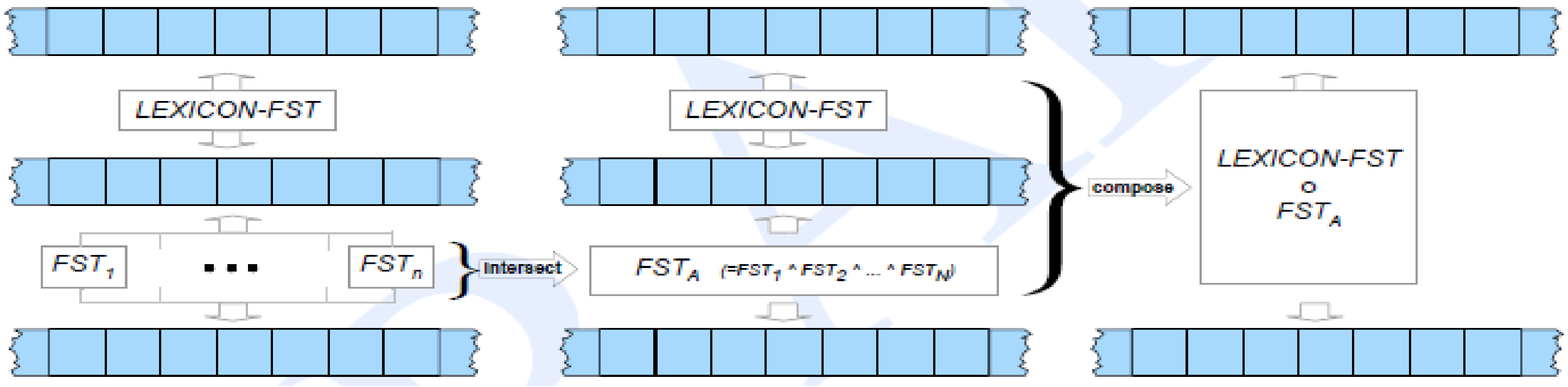
Generating or parsing with FST lexicon and rules

Combining FST Lexicon and Rules

- **Local ambiguity**: occurs during the process of parsing
- **Example**:
  - Parsing the input verb *“assess”*
  - E-insertion transducer, after seeing the word ***“ass”*** may propose that, **e** that follows is inserted by spelling rule. Hence, the word ***“asses”*** would be parsed instead of ***“assess”***
  - But ***#*** symbol is not present after ***“asses”*** instead another ***s*** is seen. Then its realized that wrong word is parsed
- Solution: FST-parsing algorithm need to incorporate search algorithms.

Combining FST Lexicon and Rules

- ***Composing a cascade of transducers in series into a single complex transducer***
- Transducers running in parallel can be combined by **automaton intersection**
- **Automaton intersection algorithm takes cartesian product of the states.**
  - i.e. for each state q_i in machine 1 and state q_j in machine 2, we create a new state q_{ij} . Then for any input symbol a, if machine 1 would transition to state q_n and machine 2 would transition to state q_m, we transition to state q_{nm}.



Intersection and composition of transducers

Lexicon-Free FSTs: The Porter Stemmer

- **Information Retrieval (IR) tasks** like web search - a query such as a Boolean combination of relevant **keywords or phrases**, e.g., ***(kangaroo)*** returns documents that have these words in them.
- A document with the word ***kangaroos*** might not match the keyword ***kangaroo.*** Hence, some IR systems first **run a stemmer on the query and document words.**
- Morphological information in IR is used to determine that two words have the **same stem**; the suffixes are thrown away.
- The most widely used such **stemming algorithm** is the ***Porter algorithm (1980) .***

Human Morphological Processing

- Modern experimental evidence suggests that both the theories (full listing and minimum redundancy) are not completely true
- Instead it states that some kinds of morphological relationships are mentally represented for some words (inflections and certain derivations) and for others, words are being fully listed.
  - **Example**: derived forms **happiness**, **happily** are stored separately from their stem **happy**
- But regularly inflected forms (**pouring**) are distinct in the lexicon from their stems (**pour**). This is done by using a **repetition priming experiment**.
  - *Repetition priming* – word is recognized faster if it has been seen before (**primed**)
- ***Marslen-Wilson (1994)*** found that spoken words can prime their stems, but only if the meaning of the derived form is closely related to the stem
  - **Example:** ***Government*** primes ***govern***, but ***department*** does not prime ***depart***

Human Morphological Processingc

Speech errors (slips of the tongue)

- In normal conversation, speakers often mix up the order of the words or initial sounds:

  Example:

  - *If you break it it'll drop*
  - *I don't have time to work to watch television because I have to work*

- Inflectional and derivational affixes can appear separately from their stems:

  Example:

  - *Easily enoughly (for "easily enough")*
  - *Words of rule formation (for "rules of word formation")*

  This shows that mental lexicon must contain some representation of the morphological structure of these words

  Hence, Morphology play a role in the human lexicon

Summary

1. Morphological Parsing
2. Affixes: prefixes, suffixes
3. Survey of English Languages
4. Inflectional and Derivational morphology
5. Finite-state Morphological parsing
6. Lexicon and Morphotactics
7. Finite-state Transducers (FST) – FST Morphological parsing
8. Spelling rules (Orthographic rules) and Finite-state Transducers
9. Combining FST lexicon and spelling rules (composing and intersecting)
10. Lexicon-Free FSTs - (Porter stemmer algorithm)
11. Human Morphology processing

END