Unit 2
Word and Morphology
Morphology, Word Construction

Natural Language Processing (NLP)
MDS 555

Objective

- Morphology
- Word Construction
- Use of FST in NLP taks
- Lexicon
- Further Study
  - Chapter 2 , 3 of Text book

Finite State Transducers (FST)

- A finite state transducer essentially is a finite state automaton that works on two (or more) tapes.
  - The most common way to think about transducers is as a kind of “translating machine”.
- They read from one of the tapes and write onto the other.
  - This, for instance, is a transducer that translates a into b

FST: Formal Defination

Finite State Transducer (FST) is a 6-tuple $T = (Q, \Sigma, \Gamma, \delta, s, \gamma)$ where

- Q is a finite set of states,
- Σ is a finite set of input symbols,
- Γ is a finite set of output symbols,
- $\delta: Q \times \Sigma \rightarrow Q$ is the transition function,
- $s \in Q$ is the start state.
- $\gamma: Q \rightarrow \Gamma^*$ is the output function.

FST: Formal Defination

Our definition of FST is similar to that of a DFA, with the following differences:

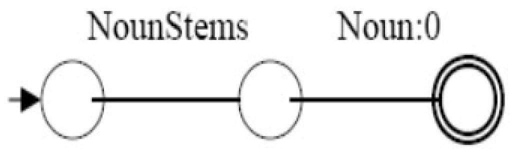
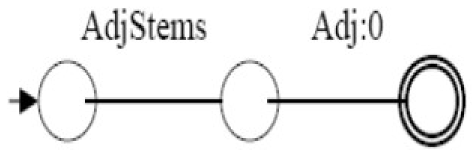
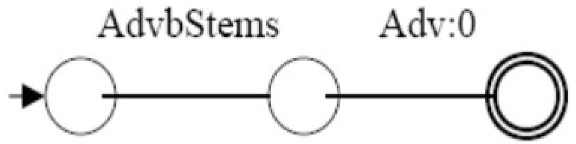
- The FST includes not only an input alphabet Σ, but also an output alphabet Γ. Using different alphabets for input and output may be used to define transducers that convert between different alphabets.
- Instead of a set of accepting states F , an FST as an output function $\gamma: Q \rightarrow \Gamma^*$

FST

- The important property of FSTs is that they are in principle bi-directional, meaning that they can also be applied backwards.
- The bi-directionality feature of the FST can be applied to the morphological analysis and generation

FST – Operations (Union)

- There are three FSTs for nouns, adjectives and adverbs

		
FST for nouns	FST for adjectives	FST for adverbs

FST – Operations (Union)

- When operation union is performed on these three FSTs. it results into a single FST.

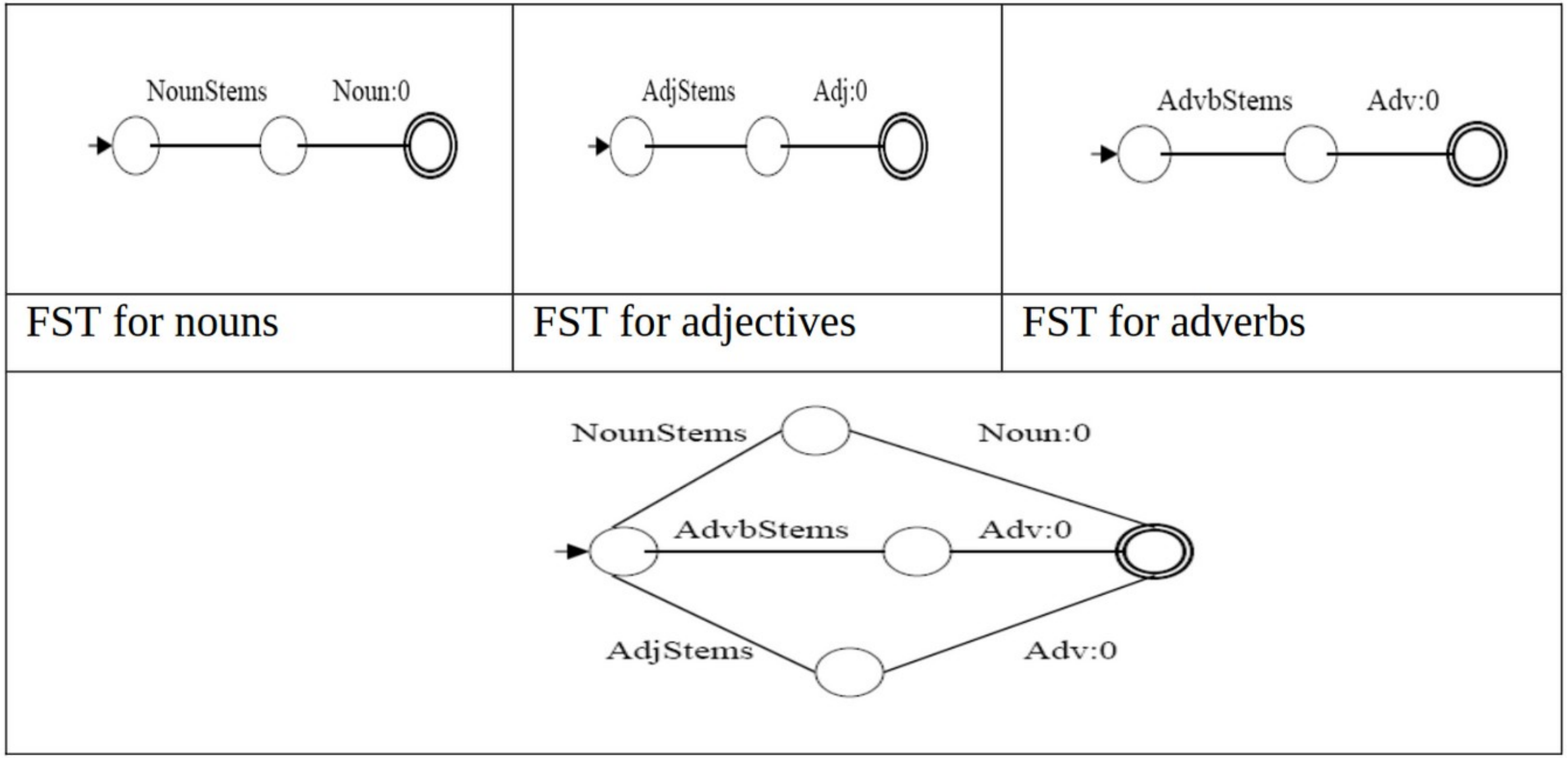


Figure 2.3: FST unioned from three FSTs for nouns, adjectives and adverbs

FST - Concatenation

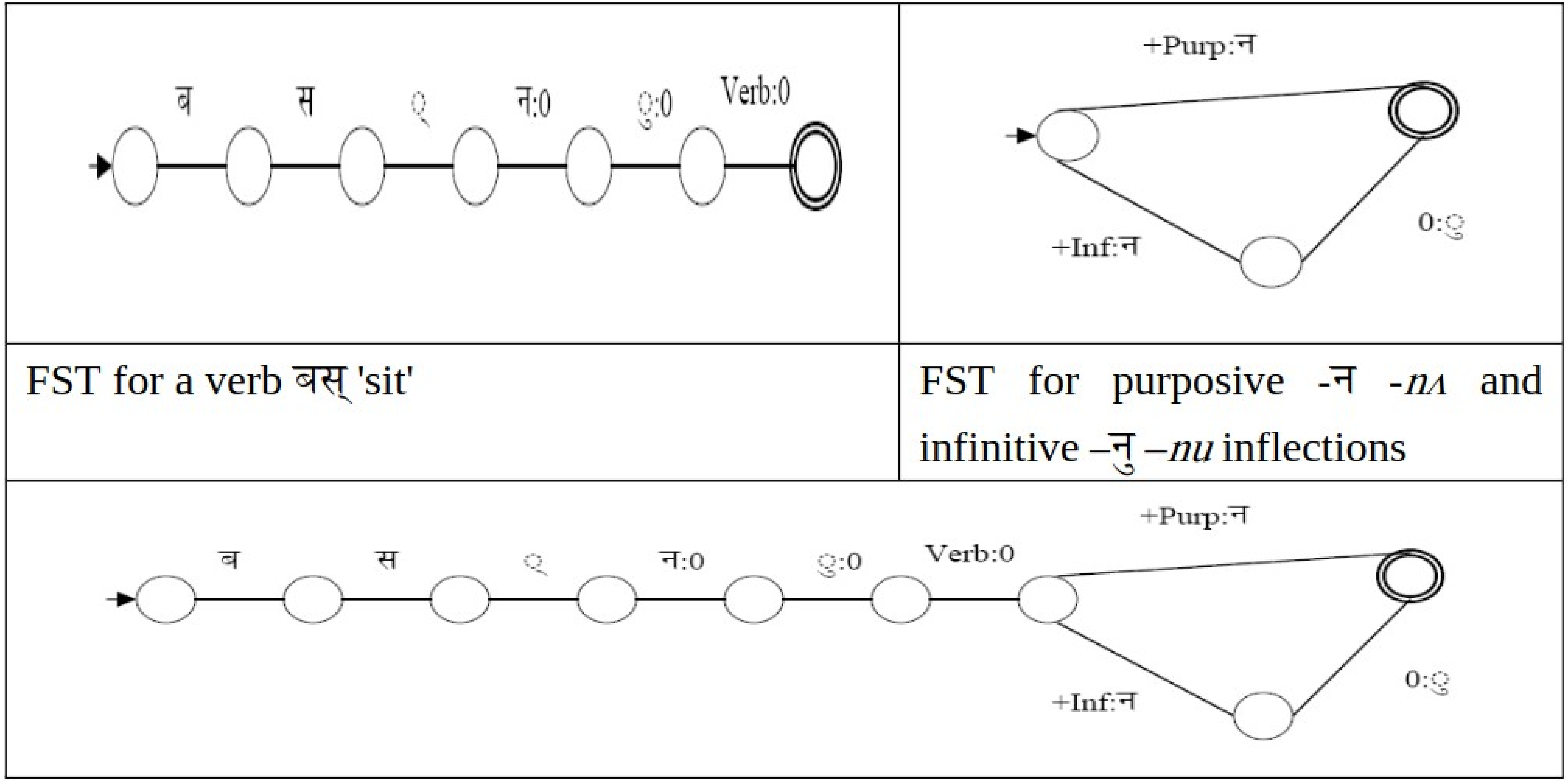


Figure 2.4: A finite state transducer concatenated from two FSTs above

FST - Concatenation

- In Figure 2.4, there are two FSTs in the upper part of the Figure 2.4, one for a Nepali verb बस् bʌs 'sit' and another for purposive - न - nʌ 'PURP' and infinitive - नु – nu 'INF' suffixes.
- And in the lower part of the Figure 2.4, there is an FST resulted from concatenating two FSTs, which can analyze and generate purposive and infinitive forms of the verb बस् bʌs 'sit'.
- This concatenation operation is useful in handling the verb stems and inflectional and derivational suffixes.

FST - Composition

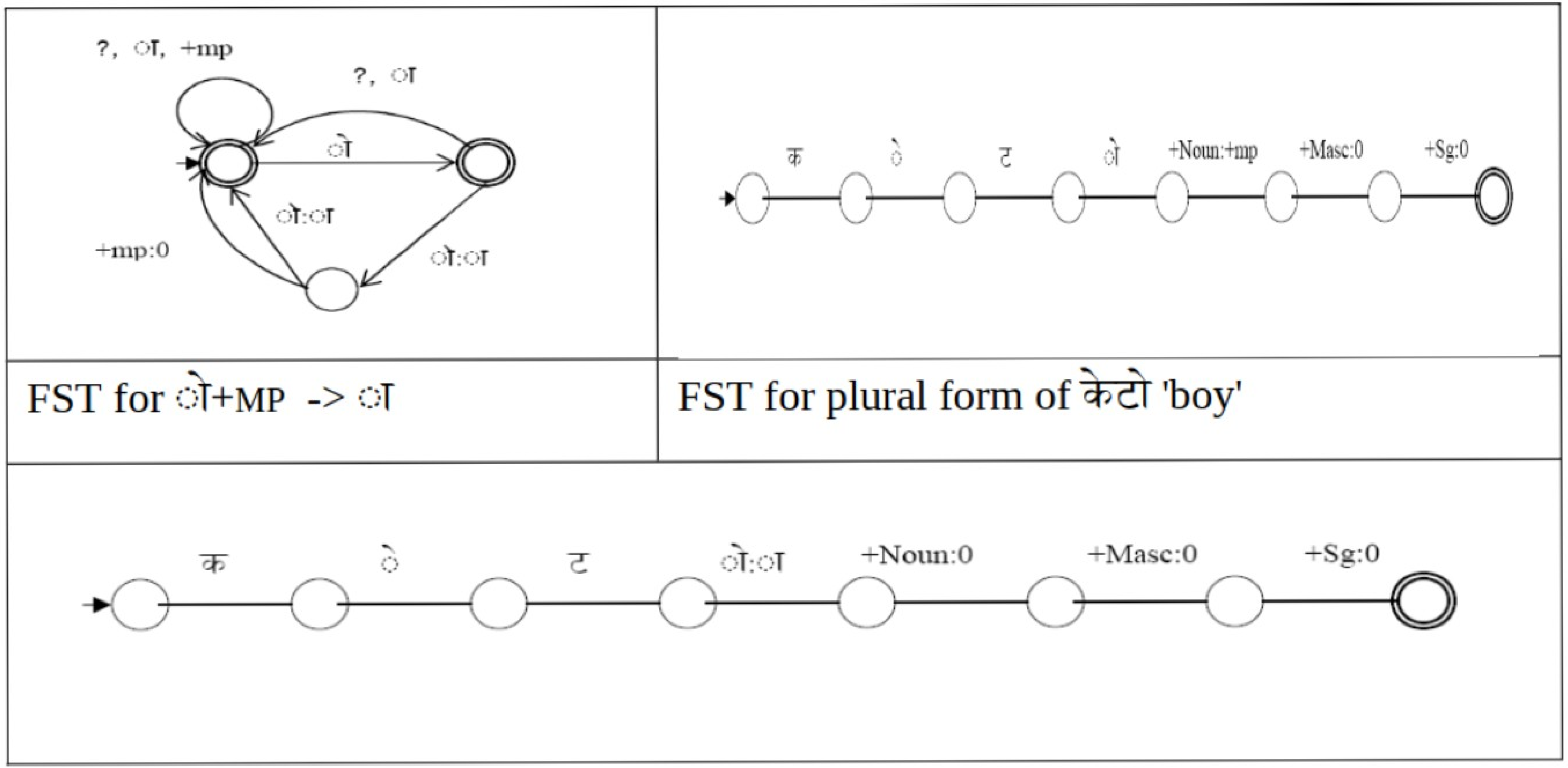


Figure 2.5: A finite state transducer from composing two FSTs above

FST - Composition

- There is a rule FST at the left top in Figure 2.5 which changes ो o into ा a for plural feature. An arbitrary symbol + MP is used for creating the environment so that the rule can be applied to specific group of nouns.
- At the right top of the Figure 2.5, there is an FST for केटो 'boy' with +mp symbol.
  - When these FSTs are composed, it results into a single FST in lower part of the Figure 2.5 which is capable of changing ो o into ा a for plural feature and also removes the arbitray symbol +mp without any intermediate FSTs.

FST - Composition

- In fact, composition operation forms a sequence of transducers.
  - It builds a cascade of FSTs into a single one by eliminating the common intermediate outputs, so, it allows working for a modular structure.
  - Because of this feature of composition, it has been very much useful for composing rules with lexicon to obtain the correct surface forms.

Study of Nepali Morphology

- COMPUTATIONAL ANALYSIS OF NEPALI MORPHOLOGY: A MODEL FOR NATURAL LANGUAGE PROCESSING
- https://ojs.ub.uni-konstanz.de/jsal/dissertations/diss-balaram.pdf
- Nepali Grammer Structure
  - https://www.researchgate.net/publication/237261579_Structure_of_Nepali_Grammar

Morphology

- **Morphology** is the study of words, how they are formed, and their relationship to other words in the same language.
- Internal structure of the word
- It analyzes the structure of words and parts of words such as stems, root words, prefixes, and suffixes.

Morphology - vocabulary

- Morphology is the study of word structure
  - morpheme: a minimal information carrying unit
  - affix: morpheme which only occurs in conjunction with other morphemes (affixes are bound morphemes)
  - words made up of stem and zero or more affixes.

    e.g. dog+s
  - compounds have more than one stem.
    - e.g. book+shop+s
  - stems are usually free morphemes (meaning they can exist alone)
    - Note that slither, slide, slip etc have somewhat similar meanings, but sl- not a morpheme

Affixes

- suffix: dog+s, truth+ful
- prefix: un+wise
- infix: (maybe) abso-bloody-lutely
- circumfix: not in English

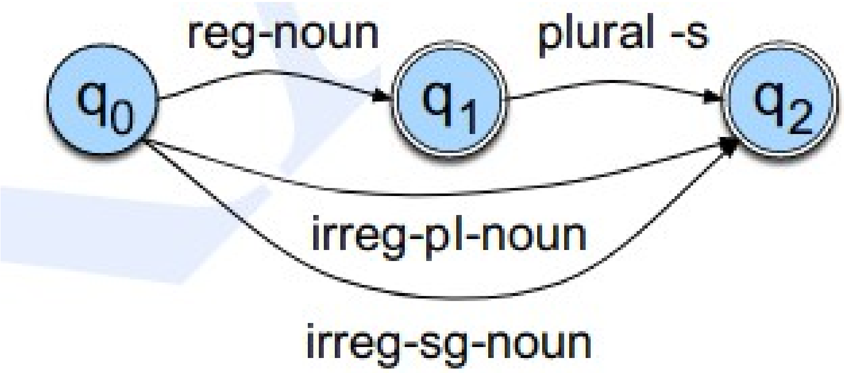
  German ge+kauf+t (stem kauf, affix ge_t)

Inflectional morphemes

- Inflectional morphemes carry grammatical information
- Inflectional morphemes can tell us about tense, aspect, number, person, gender, case...
  - e.g., plural suffix +s, past participle +ed

Inflectional morphemes

- 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	

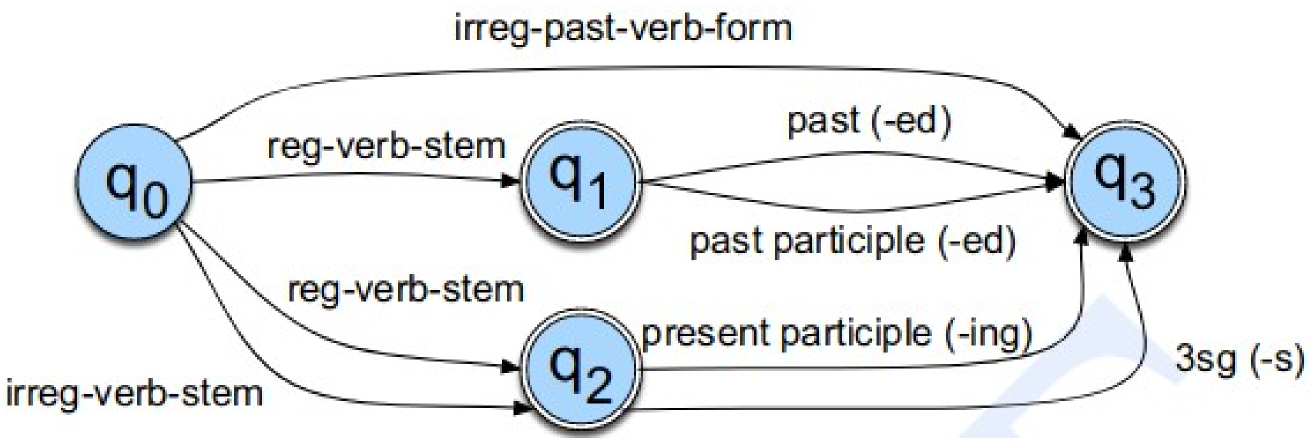
- regular nouns (reg-noun)
- Irreg – irregular
- sg – singular

  pl - plural

Inflectional morphemes

- A finite-state automaton for English nominal inflection

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



Derivational morphemes

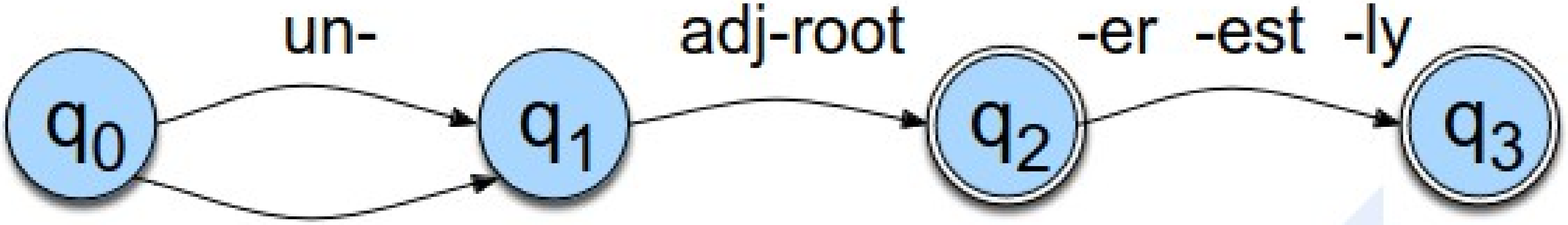
- Derivational morphemes change the meaning
  - e.g., un-, re-, anti-, -ism, -ist ...
  - broad range of semantic possibilities
  - may change part of speech: help → helper
- indefinite combinations:
    - antiantidisestablishmentarianism
    - anti-anti-dis-establish-ment-arian-ism

Derivational morphemes

- Adjectives become opposites, comparatives, adverbs

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

- FSA

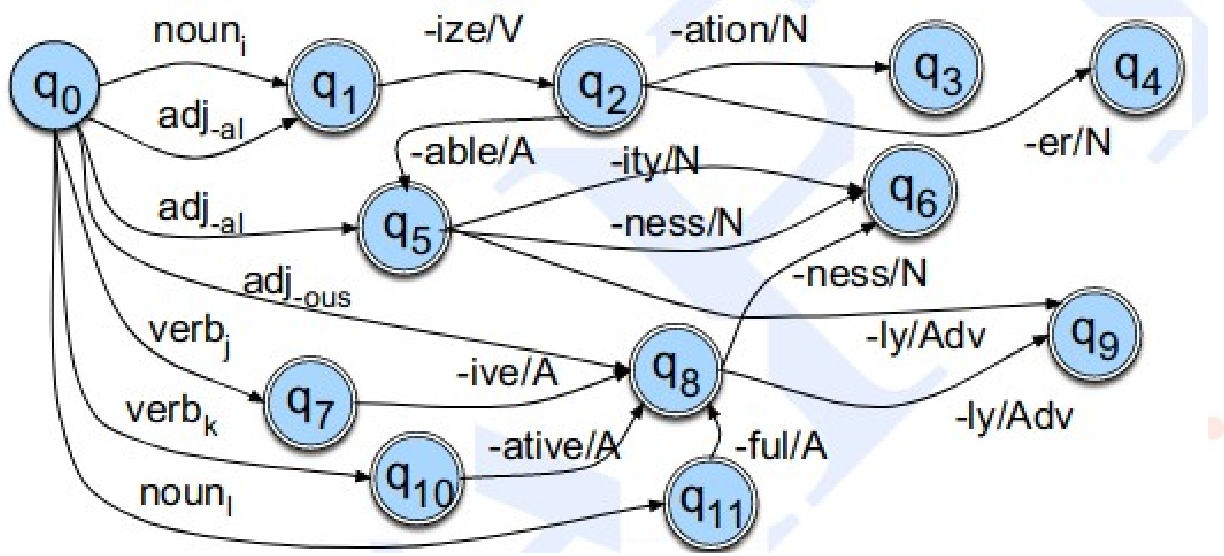


Derivational morphemes

- FSA for fragment of English derivational morphology
  - This FSA models a number of derivational facts
  - Such as the well known **generalization** that any verb ending in -ize can be followed by the nominalizing suffix -ation (Bauer, 1983; Sproat, 1993)
  - Fossilize → fossilization :
    - q0, q1, and q2
  - **adjectives** ending in -al or -able

    at q5 (equal, formal, realizable)

    can take the suffix -ity



Cliticization

- clitic is a unit whose status lies in between that of an affix and a word
  - The phonological behavior of clitics is like affixes; they tend to be short and unaccented
  - Their syntactic behavior is more like words, often acting as pronouns, articles, conjunctions, or verbs.
    - clitics in English are ambiguous
    - she's can mean she is or she has

Full Form	Clitic	Full Form	Clitic
am	'm	have	've
are	're	has	's
is	's	had	'd
will	'll	would	'd

Recognition vs Parsing

- Morphological recognition
  - is_past_tense_verb(loved) --> TRUE
  - Finite State Automata can do this
- Morphological parsing: what is its breakdown?
  - parse(loved) --> take/VERB -n/PAST-TENSE
  - Finite State Transducers can do this

FST - Parsing

- An FST T = Lin × Lout defines a relation between two regular languages Lin and Lout:

  Lin = {cat, cats, fox, foxes, ...}

  Lout = {cat+N+sg, cat+N+pl, fox+N+sg, fox+N+PL ...}

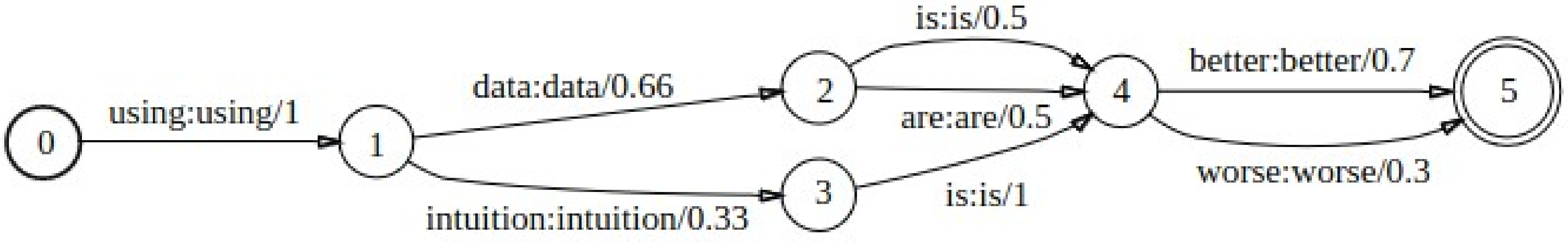
  T = { <cat, cat+N+sg>,
<cats, cat+N+pl>,
<fox, fox+N+sg>,
<foxes, fox+N+pl> }

Using FST on Speech Recognition

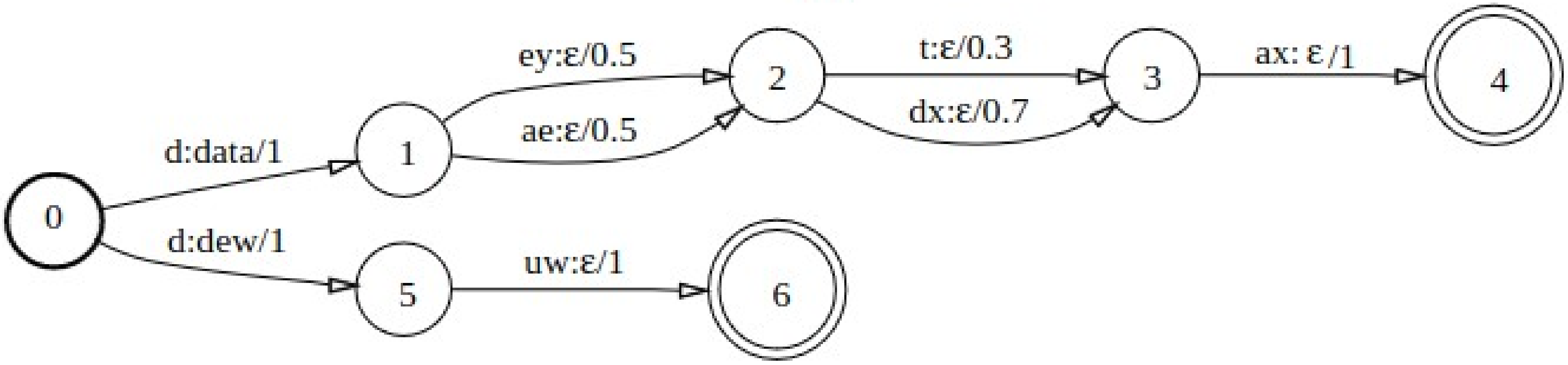
- Weighted Finite-State Transducers
- The weights used in speech recognition often represent probabilities; the corresponding semiring is then the probability semiring
  - $(R ; + ; . ; 0 ; 1)$
- Ref:
  - https://www.openfst.org
  - https://www.openfst.org/twiki/pub/FST/FstBackground/csl01.pdf
  - https://www.openfst.org/twiki/pub/FST/FstBackground/hbka.pdf

Weighted FSTs in Speech Recognition

- Weighted finite state transducer examples



(a)



(b)

Morphological Analysis with Finite State Transducers

- “wizard”, consists of only one morpheme, namely wizard,
- “wizards” consists of two morphemes, namely wizard and s where s contributes the plural.
- “kissed” also consists of two morphemes, namely kiss and the past tense ed.

Morphological Analysis with Finite State Transducers

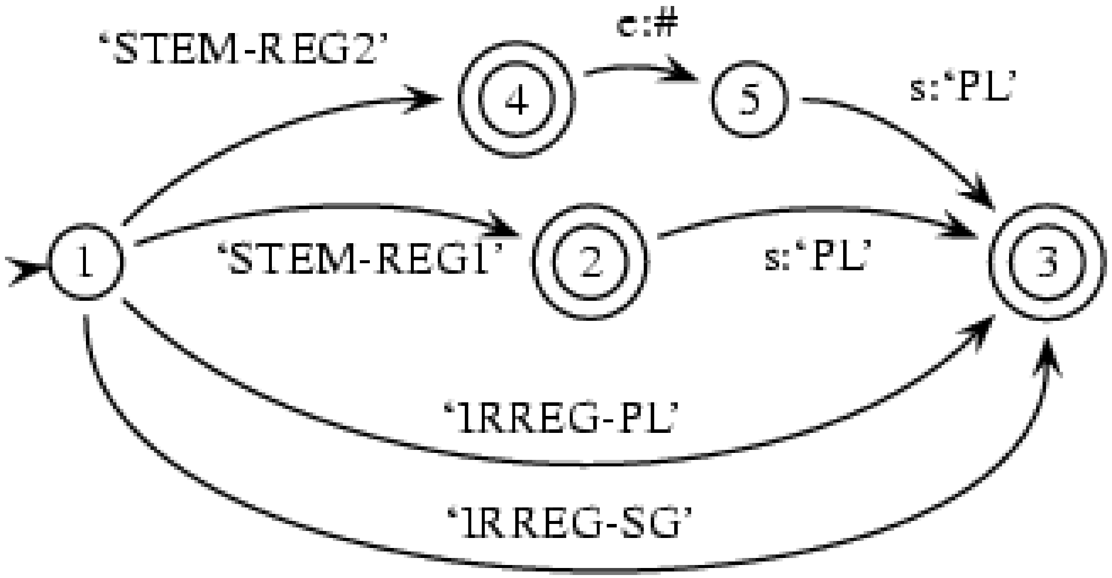
- Morphology is an area of computational linguistics where finite state technology has been found to be particularly useful
  - For many languages the rules after which morphemes can be combined to build words can be caputered by finite state automata.
  - It is possible to write finite state transducers that map the surface form of a word to a description of the morphemes that constitute that word or vice versa.
- They map, for instance, **wizard+s** to **wizard+PL** or **kiss+ed** to **kiss+PAST.**

Morphology – Plural Noun

- Plural nouns in English.
  - The default rule is of course to just add an s as in wizard+s.
  - There are some stems which take es to form the plural, like witch e.g.
    - This can be explained by morpho-phonological rules that insert an e whenever the morpheme preceding the s ends in s, x, ch or another fricative.
  - For simplicity, we will assume here that there are two types of regular stems: those that take an s to form the plural and those that take an es.
  - Finally there are clearly irregular forms like mouse and mice or automaton and automata.

FST - Plural Noun

- Transducer that translates
  - wizard+s into wizard+PL
  - witch+es into witch+PL,
  - mice, into mouse+PL
  - automata into automaton+PL.
- Lexicon
  - `lex(wizard:wizard,`STEM-REG1').`
  - `lex(witch:witch,`STEM-REG2').`
  - `lex(automaton:automaton,`IRREG-SG').`
  - `lex(automata:`automaton-PL',`IRREG-PL').`
  - `lex(mouse:mouse,`IRREG-SG').`
  - `lex(mice:`mouse-PL',`IRREG-PL').`



Orthographic Rules

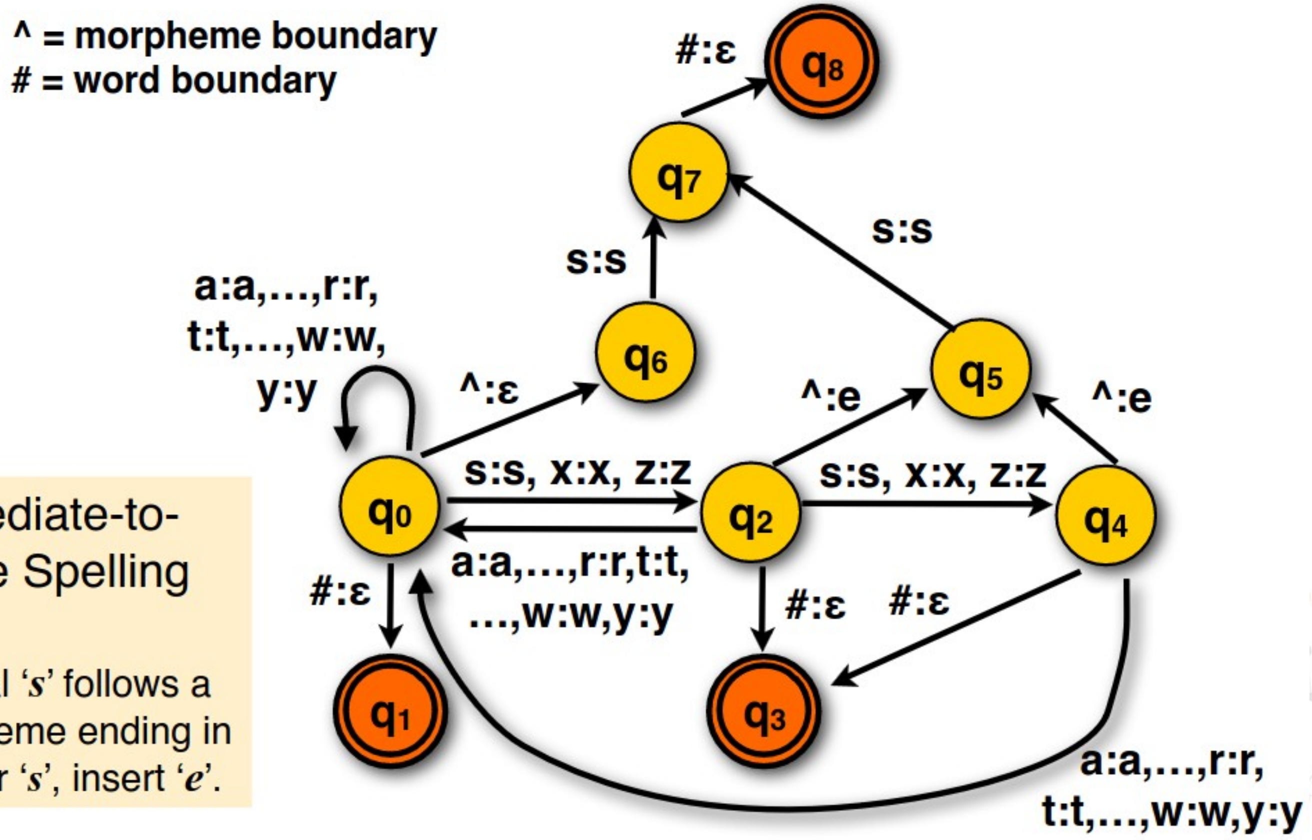
- Concatenating the morphemes won't work for cases where there is a spelling change
  - FSA would incorrectly reject an input like foxes and accept an input like foxs
- We need to deal with the fact that English often requires spelling changes at morpheme boundaries by introducing spelling rules (or orthographic rules)

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

Orthographic Rules

- **es** : the transducer for the E-insertion rule before s to make plural



Intermediate-to-Surface Spelling Rule:

If plural '*s*' follows a morpheme ending in '*x*','*z*' or '*s*', insert '*e*'.

Lexicon

- A lexicon refers to the vocabulary or dictionary of a language.
  - It is a collection of words, phrases, and other linguistic units along with their meanings, pronunciations, and grammatical properties.
  - The lexicon is a fundamental component of a language, serving as a repository of the building blocks used for communication.

Lexicon

- In linguistics and natural language processing, the lexicon includes not only individual words but also
  - various multi-word expressions,
  - Idioms
  - grammatical morphemes (prefixes, suffixes, etc.),
  - information about how these elements are used in context.
- It's important to note that a lexicon is not just a static list of words; it also encompasses information about the
  - relationships between words, such as synonyms, antonyms, homonyms
  - various semantic associations

Lexicon

- For example, consider the word "run."
  - In a lexicon, you would find information about its
  - meaning (to move swiftly on foot),
  - grammatical properties (a verb),
  - various forms (running, ran),
  - its pronunciation.
- Additionally,
  - the lexicon might also include information about related words like "runner" (a person who runs) and "running shoes" (footwear designed for running)

Uses of Lexicon

- In NLP, lexicons are crucial for tasks like
  - part-of-speech tagging
  - word sense disambiguation
  - sentiment analysis
- Lexical resources play a vital role in training machine learning models to understand and generate human language

Further reading

- Book “ Speech and Language Processing – Jurafky and Martin“
  - Chapter 2 and 3 of
- https://brilliant.org/wiki/finite-state-machines/
- https://nepalishabdakosh.com/
- Nepali Examples are taken from: A COMPUTATIONAL ANALYSIS OF NEPALI MORPHOLOGY: A MODEL FOR NATURAL LANGUAGE PROCESSING https://ojs.ub.uni-konstanz.de/jsal/dissertations/diss-balaram.pdf
- https://cs.union.edu/~striegnk/courses/nlp-with-prolog/html/index.html
- Lexicon
  - Blog article of Lexicon: https://mohamedbakrey094.medium.com/all-about-lexicons-in-nlp-12ada00c2821
  - The Role of Lexicon in NLP: https://dl.acm.org/doi/pdf/10.1145/234173.234204

Thank you