Morphology: Word Formation, FSAs and FSTs

COMP-599

Sept 7, 2016

Textbook

An e-book of Jurafsky and Martin 1e is available through the McGill library.

One copy of Jurafsky and Martin 2e is available for 24h reserve loan.

Draft chapters of Jurafsky and Martin 3e are freely available online.

I'll assign readings and practice problems from 2e, and 1e if I can (though not guaranteed). Any assignment that requires a reading from a text will have that section made available.

This Week

Install Python 2.7 if you don't already have it

Install NLTK and scikit-learn packages

- Course outline has more links

Class on Sept 21 will include a tutorial on Python basics

Review

Match the following terms to their object of study

Semantics	Sound patterns
Pragmatics	Passage structure
Discourse	Word structure
Syntax	Implied meaning
Phonology	Speech sounds
Phonetics	Sentence structure
Morphology	Literal meaning

Today's Topics

English morphology

- Inflectional and derivational morphology

Lemmatization vs. stemming

Formalization as FSA, FST

Starting Small

We begin by starting from the smallest level of grammatical unit in language, the **morpheme**.

anti- dis- establish -ment -arian -ism

Six morphemes in one word

cat -s

Two morphemes in one word

of

One morpheme in one word

Types of Morphemes

Free morphemes

- May occur on their own as words (*happy, the, robot*)

Bound morphemes

- Must occur with other morphemes as parts of words
- Most bound morphemes are **affixes**, which attach to other morphemes to form new words.
- **Prefixes** come before the **stem**: *un-*, as in *<u>un</u>happy*
- **Suffixes** come after the stem: *-s*, as in *robot<u>s</u>*
- **Infixes** go inside: *-f**king-*, as in *abso<u>-f**king-</u>lutely*
  - (Not really an infix, but as close as we get in English)
- **Circumfixes** go around: *em- -en*, as in *<u>em</u>bold<u>en</u>*

Derivation vs. Inflection

Inflectional morphology is used to express some kind of grammatical function required by the language

go -> goes *think -> thought*

Derivational morphology is used to derive a new word, possibly of a different part of speech

happy -> happily *establish -> establishment*

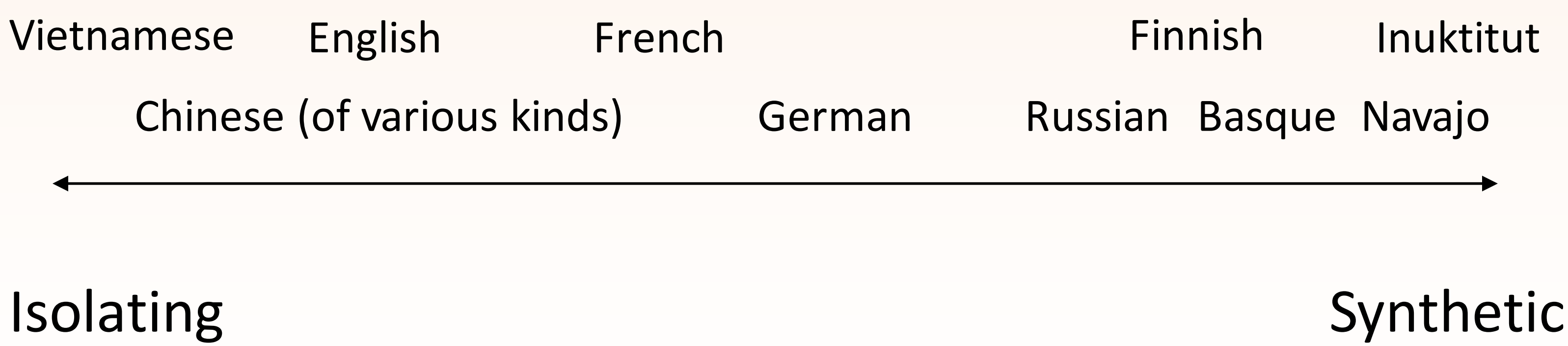
Exercise: come up with three prefixes and suffixes in English. Make sure to include at least one derivational and one inflectional affix.

Cross-linguistic Variation

Languages across the world vary by their morpheme-to-word ratio.

Isolating languages: low morpheme-to-word ratio

Synthetic languages: high morpheme-to-word ratio



Note: this chart is only a rough guide, not a precise ranking!

Compare

English

I ca-n't hear very well.   6 morphemes/5 (or 6) words = 1.2

Cantonese

我 聽 得 唔 係 好 好   7 / 7 = 1.0

ngo5 teng1 dak1 m4 hai6 hou2 hou2

I hear able NEG be very good

French

Je ne peux pas entend-re très bien.   9 / 7 = 1.29

I NEG can-1SG NEG hear-INF very well

Inuktitut

ᑐᓵᑦᓯᐊᕈᓐᓇᖖᒋᑦᑐᐊᓘᔪᖕᒐ   8 / 1 = 8.0

tusaa-tsia-runna-nngit-tu-alu-u-junga

hear-able-NEG-NOM-very-be-1SG

In Other Words…

English morphology is relatively boring!

(And this is why we’re only spending one class on it.)

But It Still Matters!

Recognize whether a word is actually English

foxes vs. **foxs*

Abstract away details that don't matter for an application

The campers saw a bear.

The campers see a bear.

The camper saw a bear.

- In all cases, a bear was seen!

Generate the correct form of a word

see +PRESENT +3SG -> sees

see +PAST +2PL -> saw

Computational Tasks

Morphological recognition

Is this a well formed word?

Stemming

Cut affixes off to find the stem

- *airliner -> airlin*

Morphological analysis

Lemmatization – remove inflectional morphology and recover lemma (the form you'd look up in a dictionary)

- *foxes -> fox*

Full morphological analysis – recover full structure

- *foxes -> fox* +N +PL

Morphological Recognition

Are these valid English words?

friendship, unship, defriender, friendes

Relevant issues:

What prefixes and suffixes can go with a word?

- *-ship, un-, de-, -s*

Different forms of an affix

- *fox -> foxes*
- *friend -> friends*
- *fly -> flies*

Exceptions

- *goose -> geese*

Lexicon

A list of all words, affixes and their behaviours. Entries are often called **lexical items** (a.k.a., lexical entries, lexical units).

- e.g., Noun declensions (Jurafksy and Martin, p. 54)

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

Morphotactics

Tells us the sequence in which morphemes may be combined.

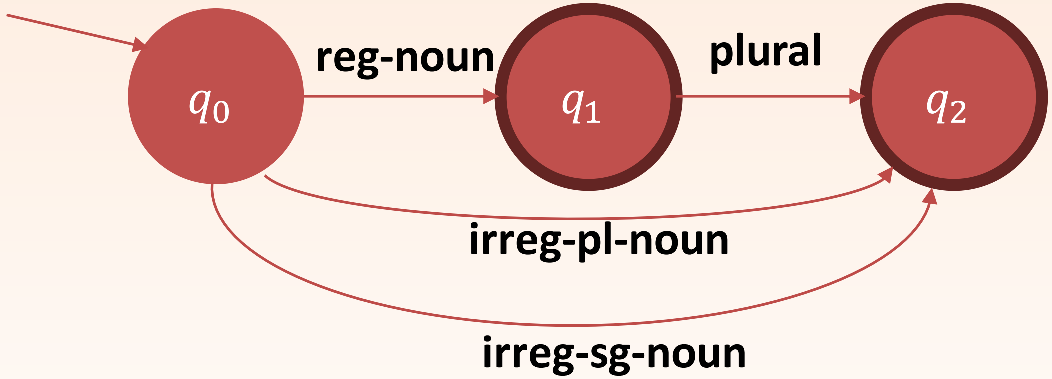
- e.g., English nouns:

  reg-noun

  reg-noun + -s

  irreg-sg-noun

  irreg-pl-noun



Nodes with outline represent an **accepting state**. (This is a word)

This is a representation of a **finite state automaton** (**FSA**).

Finite State Automata

A model of computation that takes in some input string, processes them one symbol at a time, and either **accepts** or **rejects** the string.

- e.g., we write a FSA to accept only valid English words.

A particular FSA defines a **language** (a set of strings that it would accept).

- e.g., the language in the FSA we are writing is the set of strings that are valid English words.

Regular languages are languages that can be described by an FSA (i.e., the FSA accepts exactly those strings that are in the language)

Definition of FSA

A FSA consists of:

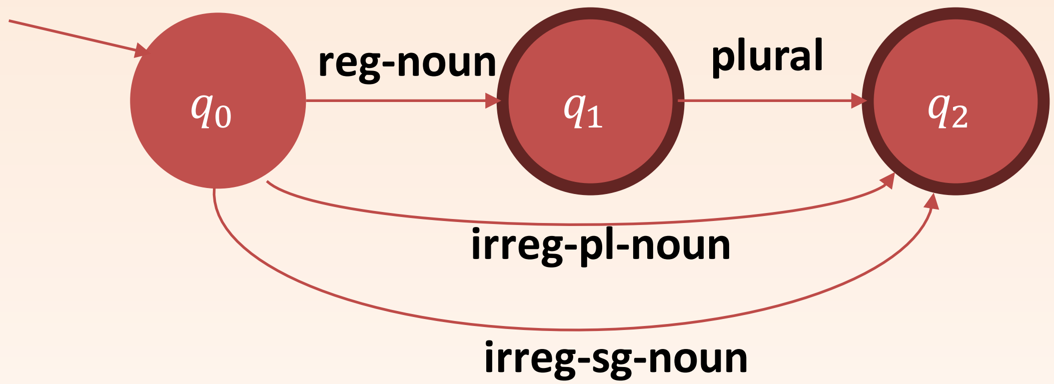
- Q finite set of states
- Σ set of input symbols
- $q_0 \in Q$ starting state
- $\delta : Q \times \Sigma \rightarrow P(Q)$

  transition function from current state and input symbol to possible next states

  - $P(Q)$ is the power set of Q.
- $F \subseteq Q$ set of accepting, final states

Exercises

1. Identify the components of an FSA in:



2. Use lexicon to expand the morphotactic FSA into a character-level FSA

Exercise

Extend the previous FSA to account for *regular* orthographic variations of the plural suffix.

- Ends with consonant + *y*: replace *y* with *ies*
  - e.g., *pony, sky* but not *boy*
- Ends with *-s*, *-z*, *-x*, *-ch*, *-sh* -> add *-es*
  - e.g., *kiss*, *dish*, *witch*

Check your FSA by seeing whether it correctly accepts English words that you model and rejects those that are not

Stemming – Porter Stemmer

An ordered list of rewrite rules to approximately recover the stem of a word (Porter, 1980)

- Basic idea: chop stuff off and glue some endings back on
- Not perfect, but sometimes results in a slight improvement in downstream tasks
- Advantage: no need for lexicon

Examples of Porter Stemmer Rules

ies -> i

- *ponies -> poni*

ational -> ate

- *relational -> relate*

If word is long enough (# of syllables, roughly speaking),

al -> ε

- *revival -> reviv*

Morphological Parsing

Recover an analysis of the word structure

- *foxes -> fox +N +PL*
- *foxes -> fox +V +3SG.PR*

In fact, we will add an intermediate layer for convenience:

Surface	*foxes*	*cats*
Intermediate	*fox^s#*	*cat^s#*
Underlying	*fox +N +PL*	*cat +N + PL*

- Lets us not have to deal with intricacies in the orthographic rules at the same time as the rest
- Irregular nouns handled by intermediate->underlying step

Expanded Lexicon

Basic idea: add more annotations to the lexicon

Map surface to intermediate level:

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

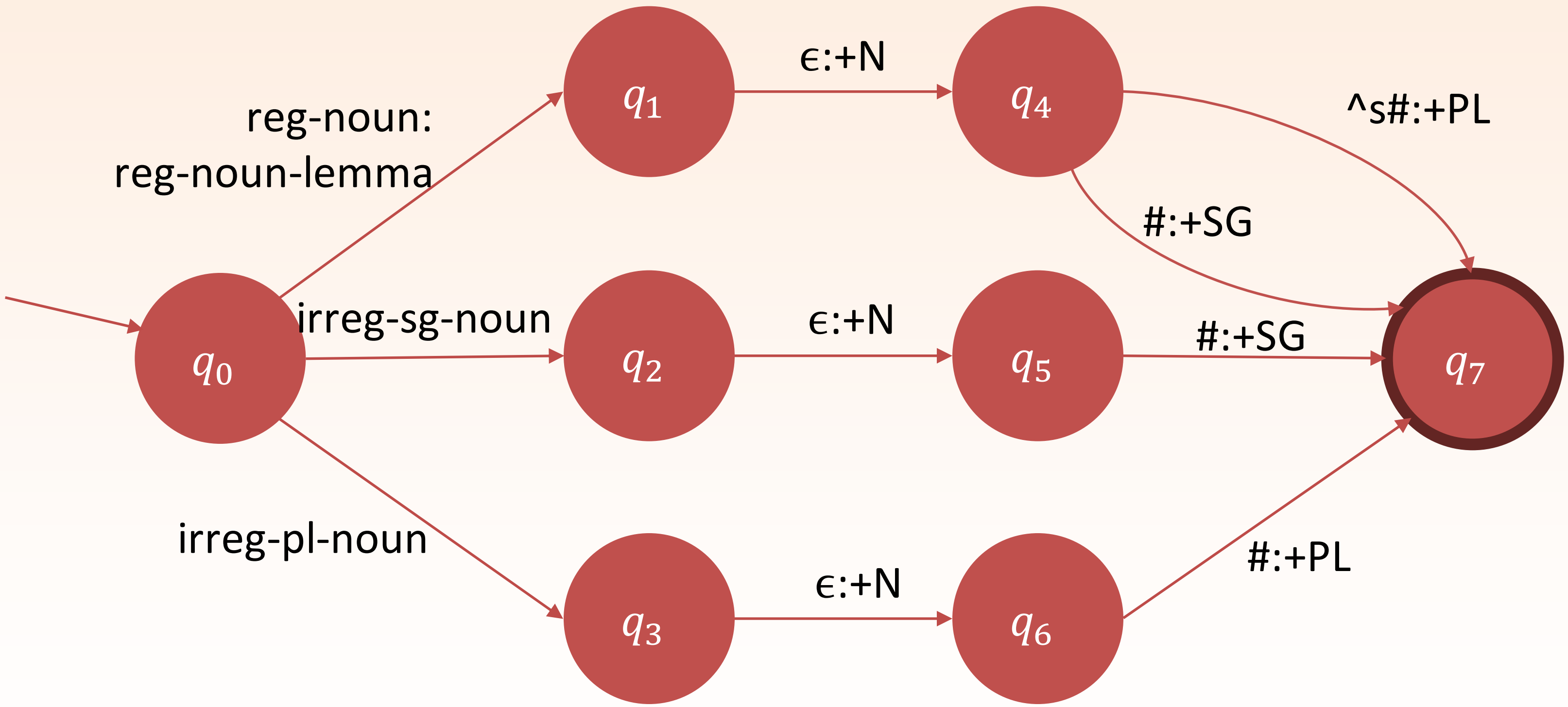
Notation:

- Single letter: map a letter to itself
- Implicit ϵ*:#* transition at ends of words
- Note: in J&M p. 62, they wrote the table for generation, so the letters are flipped

Finite State Transducers

Next step: Intermediate to underlying level

- Need to expand parts like “reg-noun” below with lexicon



Question: what happens with *sheep*?

Exercise

Change our previous character-level FSA:

- add outputs
- add states for the necessary adjustments as necessary
- i.e., this should map from the surface to the intermediate level

Now that we have added outputs, the machine is no longer a FSA. It is a **Finite State Transducer**.

Definition of FST

A FST consists of:

- Q finite set of states
- Σ, Δ sets of input symbols, output symbols
- $q_0 \in Q$ starting state
- $\delta \subseteq Q \times (\Sigma \cup \{\varepsilon\}) \times (\Delta \cup \{\varepsilon\}) \times Q$

  transition relation that specifies, for current state and input symbol, the possible pairs of output symbol and next state
- $F \subseteq Q$ set of accepting, final states

Identify the above components in the previous FST

Composing FSTs

We have two FSTs:

1. Surface to intermediate FST1 *fox -> fox#*
2. Intermediate to underlying FST2 *fox# -> fox +N +SG*

Compose them to make full morphological parser

- surface -> FST1 -> intermediate -> FST2 -> underlying

The composed machine is also a FST.

Inverting FSTs

We now have a FST for morphological parsing. What about morphological generation?

- Simply flip input and output symbol!

  ^s#:+PL becomes +PL:^s#

- underlying -> $FST^{-1}2$ -> intermediate -> $FST^{-1}1$ -> surface

Overall Picture

Build a lexicon of the words you care about

- Handle regular orthographic variations using this intermediate representation – write some rules or FSTs to describe them
- Handle irregular words by building exception lists

The multiple FSTs that you write will be combined in various ways to produce the final morphological analyzer/generator:

- Composition, intersection, …

In general, FSAs and FSTs are very useful models that pop up in many areas of NLP!

Exercise

Write a (surface to intermediate) transducer to segment monosyllabic verbs. Deal with the *-ed* and *-ing* suffixes.

- e.g., *jump -> jump#* *jumped -> jump^ed#*
  jumping -> jump^ing#
- Include some irregular verbs (e.g., *see*, *hit*)
- Deal with verbs that end in *e* (e.g., *hope*, *hate*)
- Deal with consonant doubling – when in a CVC pattern
  - e.g., *chat -> chatted, chatting* *bat -> batted, batting*
  [just handle the case of *t*]

Then, write the template of the intermediate to underlying transducer as in slide 24.