Introdução a NLP e IR

Morphology and Finite State Transducers

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Morphology and Phonology

- Morphology is the study of decomposing words
  - *Kim sleep-s.*
  - *Kim is sleep-ing.*
- Phonology is the study of sound realization based on **environment**
- Morphology and Phonology are complex fields
- For our purposes, we will look at their simplified versions (mostly just Morphology)
- ...in the space of regular languages and FSM

Morphology

- Lexicon (stems)
- affixes:
  - prefix **un**-*cover*
  - suffix *cover*-**ed**
  - infix *v***in***co* (Latin, "I win", basic root "vic")
  - circumfix **ge**-*berg*-**te** (Dutch, "mountain range", from "berg", mountain)
- Templatic morphology
- Isolating languages
- Fusion
- Agglutinating

Morphological classes

Morphological Class	Regularly Inflected Verbs			
stem	walk	merge	try	map
-*s* form	walks	merges	tries	maps
-*ing* participle	walking	merging	trying	mapping
Past form or -*ed* participle	walked	merged	tried	mapped

Morphological Class	Irregularly Inflected Verbs		
stem	eat	catch	cut
-*s* form	eats	catches	cuts
-*ing* participle	eating	catching	cutting
preterite	ate	caught	cut
past participle	eaten	caught	cut

Morphologically rich languages: Agglutination

Turkish	English
muvaffak	successful
muvaffak-iyet	success
muvaffak-iyet-siz	unsuccessful (without success)
muvaffak-iyet-siz-les	to become unsuccessful
muvaffak-iyet-siz-les-tir	to make one unsuccessful
muvaffak-iyet-siz-les-tiri-ci	maker of unsuccessful ones
muvaffak-iyet-siz-les-tiri-ci-les	to become a maker of unsuccessful ones
muvaffak-iyet-siz-les-tiri-ci-les-tir	to make one a maker of unsuccessful ones
...	...

muvaffakiyetsizlestiricilestiriveremeyebileceklerimizdenmissinizcesine

like you would be from those we can not easily make a maker of unsuccessful ones

https://www.rabiaergin.com/turkish-morphology.html

Morphologically rich languages: Fusion

Russian	English
zl**o**	evil (noun:neut, nom, sg)
zl**a**	evil (noun:neut, gen, sg)
zl**oj**	evil (adj., masc, nom, sg)
zl**aja**	evil (adj., fem, nom, sg)
zl**ogo**	evil (adj., masc, gen, sg)
zl**ost**	anger, malevolence (noun:fem,nom,sg)
zlost**i**	anger, malevolence (noun:fem,gen,sg)
zlost**n-ogo**	evil,malignant (adj, masc, gen, sg)
zlostn**ost**	evil, malignancy (noun:fem, nom, sg)
zlostnost**i**	evil, malignancy (noun:fem, gen, sg)

Fusion vs. Agglutination

Fusion:

- one affix can combine several features (e.g. Case, Number, Gender)
- affixes tend to *fuse* with each other and with the base, forming a new base
- once the affix fuses, it "no longer means what it used to"
- common in Indo-European languages

Agglutination

- one affix typically "means" one feature
- affixes maintain their "meaning" in long words
- common in Turkic languages

Derivational morphology

- e.g., *un-*, *re-*, *anti-*, *-ism*, *-ist* etc
- broad range of semantic possibilities, may change part of speech
- indefinite combinations
  e.g., *antiantidisestablishmentarianism*
  anti-anti-dis-establish-ment-arian-ism
- generally semi-productive: e.g., *escapee*, *textee*, *?dropee*, *?snoree*, **cricketee* (* and ?)
- zero-derivation: e.g. *tango*, *waltz*

Internal structure and ambiguity

Morpheme ambiguity stems and affixes may be individually ambiguous: e.g. *dog* (noun or verb), $+s$ (plural or 3persg-verb)

Structural ambiguity: e.g., *shorts* or *short -s*
unionised could be *union -ise -ed* or *un- ion -ise -ed*

Bracketing: *un- ion -ise -ed*

- *un- ion* is not a possible form, so not *((un- ion) -ise) -ed*
- *un-* is ambiguous:
  - with verbs: means 'reversal' (e.g., *untie*)
  - with adjectives: means 'not' (e.g., *unwise, unsurprised*)
- therefore *(un- ((ion -ise) -ed))*

Using morphological processing in NLP

- compiling a *full-form* lexicon
- recognizing and normalizing mini-formal languages (e.g. dates)
- *stemming* for IR (not linguistic stem)
- *lemmatization* (often inflections only): finding stems and affixes as a precursor to parsing. *morphosyntax*: interaction between morphology and syntax

Spelling rules

- English morphology is essentially concatenative
- irregular morphology — inflectional forms have to be listed
- regular phonological and spelling changes associated with affixation, e.g.
  - *-s* is pronounced differently with stem ending in *s*, *x* or *z*
  - spelling reflects this with the addition of an *e* (*boxes* etc)

  morphophonology
- in English, description is independent of particular stems/affixes

Lexical requirements for morphological processing

- affixes, plus the associated information conveyed by the affix

```
ed PAST_VERB
ed PSP_VERB
s PLURAL_NOUN
```

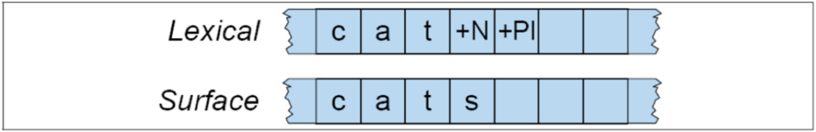
- irregular forms, with associated information similar to that for affixes

```
began PAST_VERB begin
begun PSP_VERB begin
```

- stems with syntactic categories (plus more)

Morphological parsing

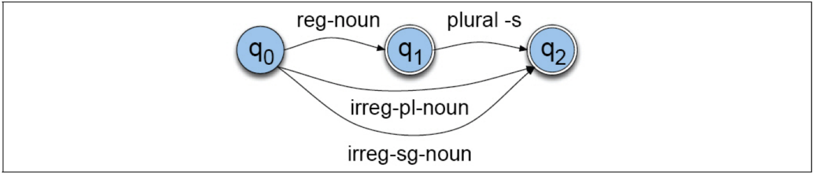
- Accept/reject strings consisting of morphemes
  - E.g. for spell-checking
  - What about just encoding the lexicon as a list of words?
- Map strings to bundles/sequences of linguistic features
- Morphological analysis for research support
  - A parser as a *hypothesis*
  - Build a parser based on your current understanding of what the language does
  - Then run it over a corpus of words, see how much it actually parsed and where and why it broke



J&M text, Fig 3.12

FSA for morphological parsing

- Create FSAs for classes of word stems (word lists).
- Create FSA for affixes using word classes as stand-ins for the stem word lists.
- Concatenate FSAs for stems with FSAs for affixes.

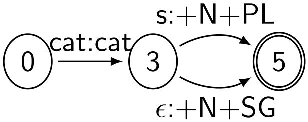


Finite State Transducers

Analyzing (*parsing*) a word morphologically:

cat is *cat [+N, +SG]*,

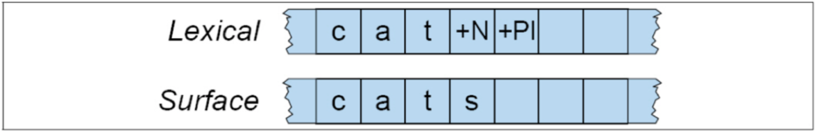
cats is *cat [+N, +PL]*



FST and FSA

- FSA define regular expressions
- FST define **regular relations**
- FST use two alphabet sets
- The **transition** function relates input to states
- the **output** function relates input to output

Visualizing FST



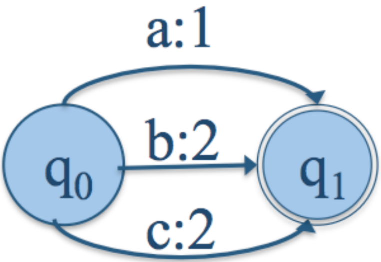
J&M text, Fig 3.12

upper and lower tapes

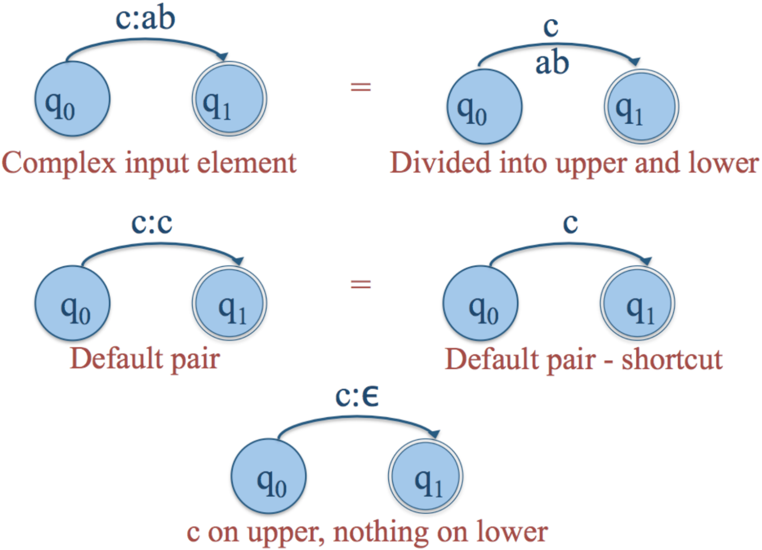
Regular relations

- Regular language: a set of strings
- Regular relation: a set of **pairs** of strings:
  - E.g., Regular relation = {a:1, b:2, c:2}
  - Input $\sum$ = {a,b,c} Output ={1, 2}

FST:

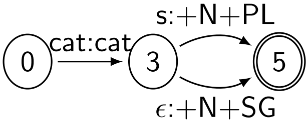


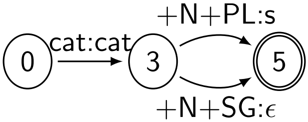
FST conventions



Inversion

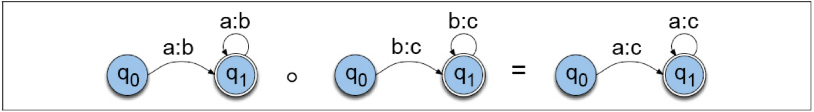
- Inversion of an FST switches input and output labels
- Thus we can turn a *parser* into a *generator*
- Parsing:
  - Input: cat
  - Output: cat+N+SG
- Generating:
  - Input: cat+N+PL
  - Output: cats





Composition

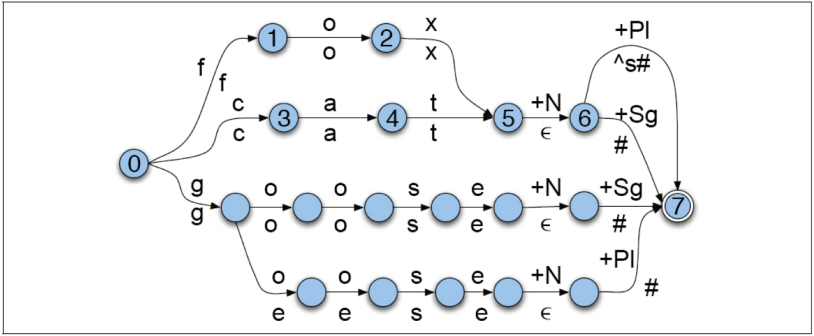
- example:
  - T1 $= \{$a:1$\}$
  - T2 $= \{$1:one$\}$
  - T1$\cdot$ T2 $= \{$a:one$\}$
  - T2(T1(a)) $=$one
- Note that order matters: T1(T2(a)) $\neq$ one
- Take a minute: what is T1(T2(a))?
- Composition is used for complex morphological analysis (e.g. semitic languages)



Morphological parsing with FST

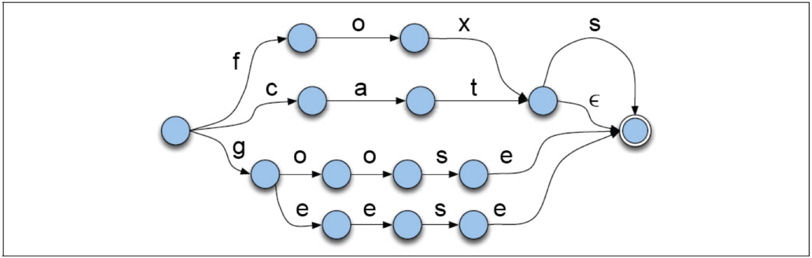
- A very influential approach since Koskenniemi (1983)
- AKA “two-level morphology”
- an example of a *symbolic* approach

Recognizing/analyzing complex words



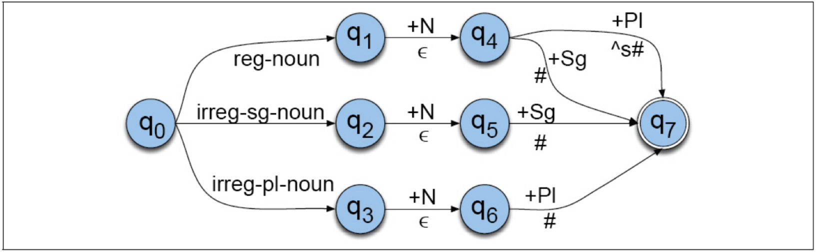
If I only wanted to *recognize*, what would I need?

Recognizing/analyzing complex words



Just an FSA

Identifying word classes



Inflectional classes: Indo-European

LATIN DECLENSIONS

bencrowder.net • Last modified 16 June 2016

1ST DECLENSION

aqua, -ae, F. *water*

	SINGULAR	PLURAL
NOM	aqua	aquae
GEN	aquae	aquārum
DAT	aquae	aquīs
ACC	aquam	aquās
ABL	aquā	aquīs

3RD DECLENSION I-STEM

cīvis, -is, M. *citizen* / mare, -is, N. *sea*

	SINGULAR	PLURAL	SINGULAR	PLURAL
NOM	cīvis	cīvēs	mare	maria
GEN	cīvis	cīvium	maris	marium
DAT	cīvī	cīvibus	marī	maribus
ACC	cīvem	cīvēs	mare	maria
ABL	cīve	cīvibus	marī	maribus

2ND DECLENSION

servus, -ī, M. *slave* / dōnum, -ī, N. *gift*

	SINGULAR	PLURAL	SINGULAR	PLURAL
NOM	servus	servī	dōnum	dōna
GEN	servī	servōrum	dōnī	dōnōrum
DAT	servō	servīs	dōnō	dōnīs
ACC	servum	servōs	dōnum	dōna
ABL	servō	servīs	dōnō	dōnīs

4TH DECLENSION

frūctus, -ūs, M. *fruit* / cornū, -ūs, N. *horn*

	SINGULAR	PLURAL	SINGULAR	PLURAL
NOM	frūctus	frūctūs	cornū	cornua
GEN	frūctūs	frūctuum	cornūs	cornuum
DAT	frūctuī	frūctibus	cornū	cornibus
ACC	frūctum	frūctūs	cornū	cornua
ABL	frūctū	frūctibus	cornū	cornibus

3RD DECLENSION

rēx, rēgis, M. *king* / corpus, corporis, N. *body*

	SINGULAR	PLURAL	SINGULAR	PLURAL
NOM	rēx	rēgēs	corpus	corpora
GEN	rēgis	rēgum	corporis	corporum
DAT	rēgī	rēgibus	corporī	corporibus
ACC	rēgem	rēgēs	corpus	corpora
ABL	rēge	rēgibus	corpore	corporibus

5TH DECLENSION

rēs, reī, F. *thing* / diēs, diēī, M. *day*

	SINGULAR	PLURAL	SINGULAR	PLURAL
NOM	rēs	rēs	diēs	diēs
GEN	reī	rērum	diēī	diērum
DAT	reī	rēbus	diēī	diēbus
ACC	rem	rēs	diem	diēs
ABL	rē	rēbus	diē	diēbus

Inflectional classes: Bigger picture

- Nobody really needs to **look for** inflectional classes in IE languages. . . particularly not in Latin (well-studied) . . .
- But there are many languages in the world for which the exact morphological behavior is not yet fully understood
- Why is it important that we learn about it and describe it?

Example: Abui [abz] (Alor island in Indonesia)

Form	Gloss	Condition
Ø-	stem alone	I
Ca-	patient (PAT)	II
Ce-	location (LOC)	III
Cee-	benefactive (BEN)	III
Co-	recipient (REC)	IV
Coo-	goal (GOAL)	IV

Table 2: Prefix forms and glosses; Condition I i
stem attested bare.

Stem	I	II	III	IV	Class
fil 'pull'	+	+	+	+	A (*1111*)
kaanra 'complete'	+	+	+	+	A (*1111*)
kafia 'scratch'	+	-	+	+	B (*1011*)
yaa 'go'	+	-	+	+	B (*1011*)
mpang 'think'	+	-	-	+	C (*1001*)
bel 'pull out'	-	+	+	+	D (*0111*)
luk 'bend'	-	-	+	+	E (*0011*)

Table 3: Examples of Abui verb classes

Probabilistic morphological parsing

- Train a model on a large training corpus
- E.g. the corpus contains pairs of surface and underlying strings
  - (like that same cats/cat+N+PL pair)
- morpheme boundaries can be inferred statistically
- Neural nets very successful
- Not an option when there is no training data
- Other limitations?

Using FSTs

- FSTs assume *tokenization* (word boundaries) and words split into characters. One character pair per transition!
- Analysis: return character list with affix boundaries, so enabling lexical lookup.
- Generation: input comes from stem and affix lexicons.
- One FST per spelling rule: either compile to big FST or run in parallel.
- FSTs do not allow for internal structure:
  - can't model *un- ion -ize -d* bracketing.
  - can't condition on prior transitions, so potential redundancy

Foma

- https://fomafst.github.io/
- Tutorial 1 (basic)
- Tutorial 2 (more advanced)

Concluding comments

- English is an outlier among the world's languages: very limited inflectional morphology.
- English inflectional morphology hasn't been a practical problem for NLP systems for decades.
- Limited need for probabilities, small number of possible morphological analyses for a word.
- Lots of other applications of finite-state techniques: fast, supported by toolkits, good initial approach for very limited systems.