6.863J Natural Language Processing
Lecture 3: The end of the word

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The Menu Bar

- Administrivia

  Lecture 2 posted; Lab 1b(“component III”) out today
- Finite-state transducer model: the wrapup
- Kimmo & Laboratory 1b: how-to
- Complexity of fst’s – too weak? Too strong? What makes a good computational linguistics representation? A good algorithm?

The Three Ideas of Two-Level Morphology

- Rules are symbol-to-symbol constraints that are applied in parallel, not sequentially like rewrite rules, via sets of <u>transducers</u>
- The constraints can refer to the lexical context, to the surface context or to both contexts at the same time.
- Lexical lookup and morphological analysis are performed in tandem.

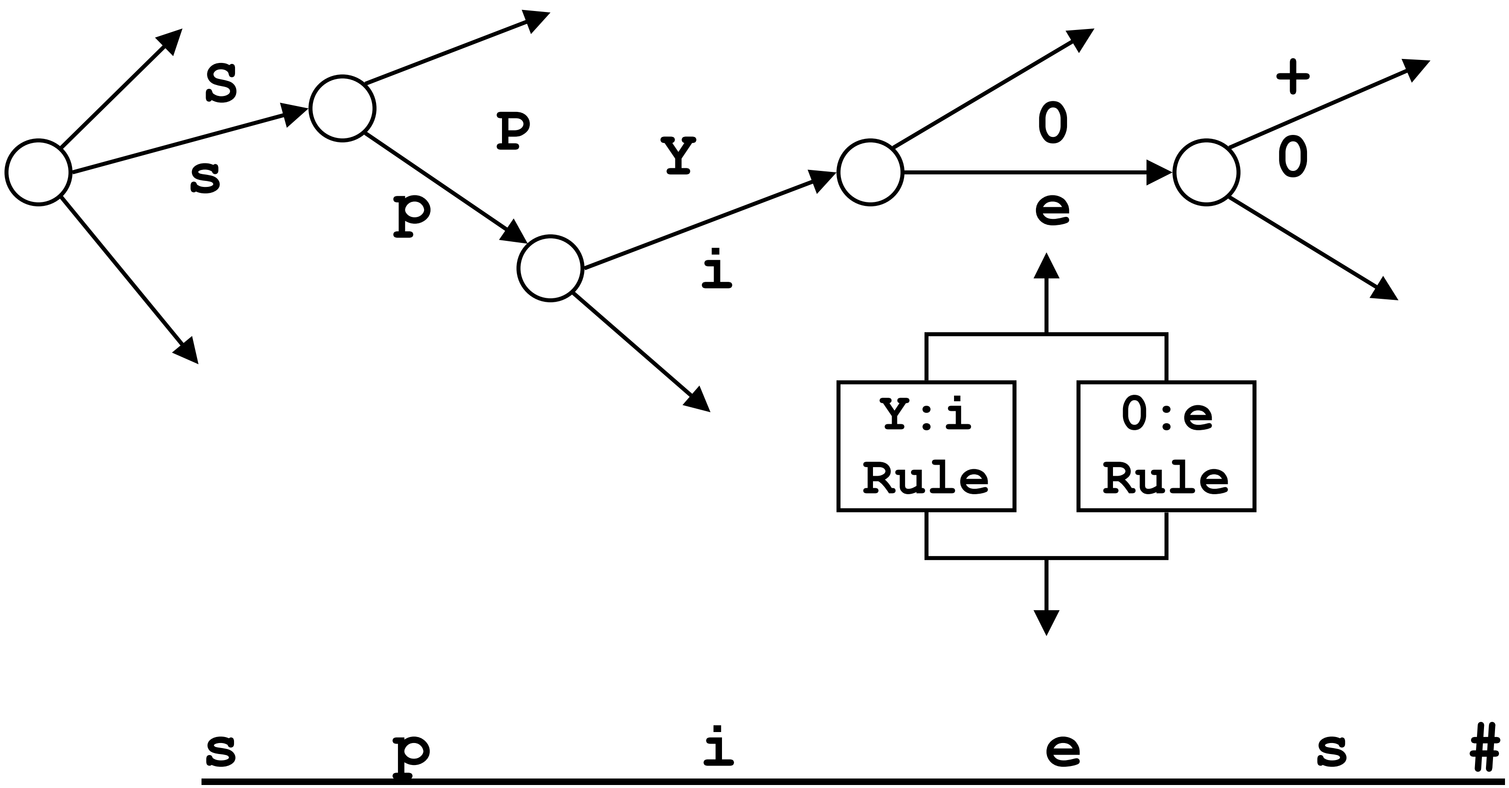
Word of the day

- Turkish word: uygarlas,tiramadiklarimizdanmis,sinizcasina
  =

  uygar+las,+tir+ama+dik+lar+imiz+dan+mis,+siniz+casina

(behaving) as if you are among those whom we could not cause to become civilized

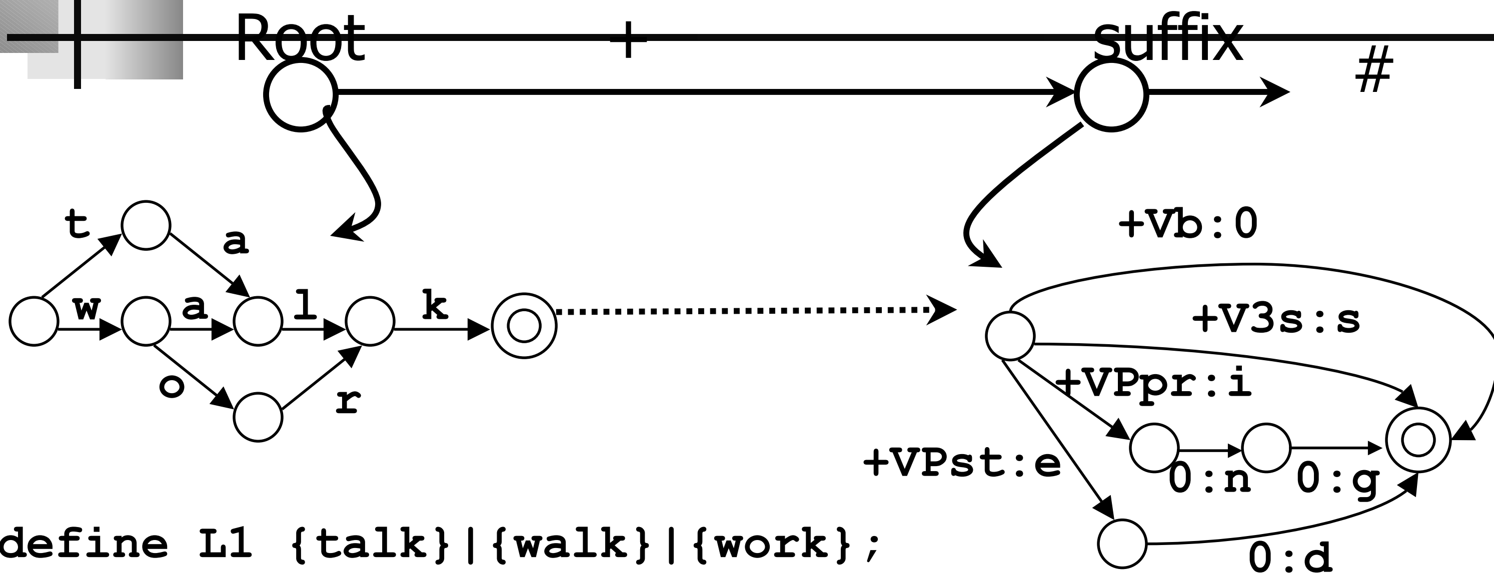
Two fs machines in tandem



Declarative filtering

- ALL possible string pairs come in
- Spelling change fst's only allow valid spelling pairs through the door (doesn't care about what a valid morpheme is): g:g o:o X s:s
- Morpheme tree allows only valid root + affix sequences through the door (doesn't care about spelling): b e e r ↔ X b e + e r
- Combination admits only permissible lexical:surface word forms

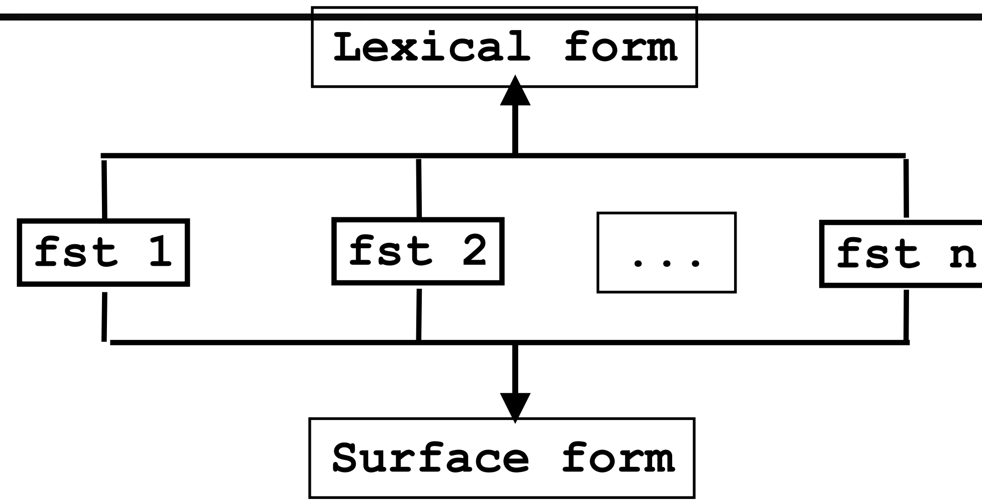
Conceptually:…



define L1 {talk}|{walk}|{work};

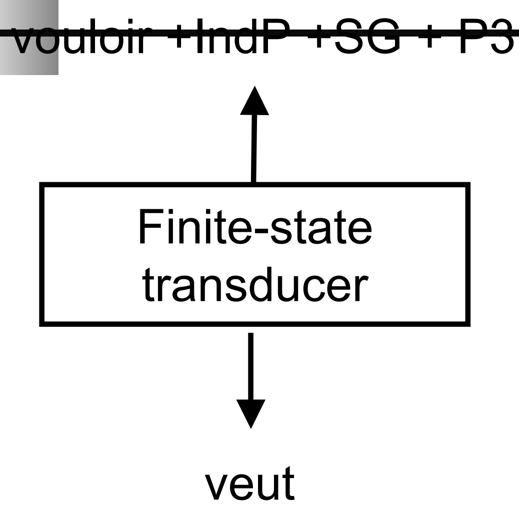
define L2 "+Vb":0 | "+V3s":s | "+Vpr":{ing} | "+Vpst":{ed} ;

Machines

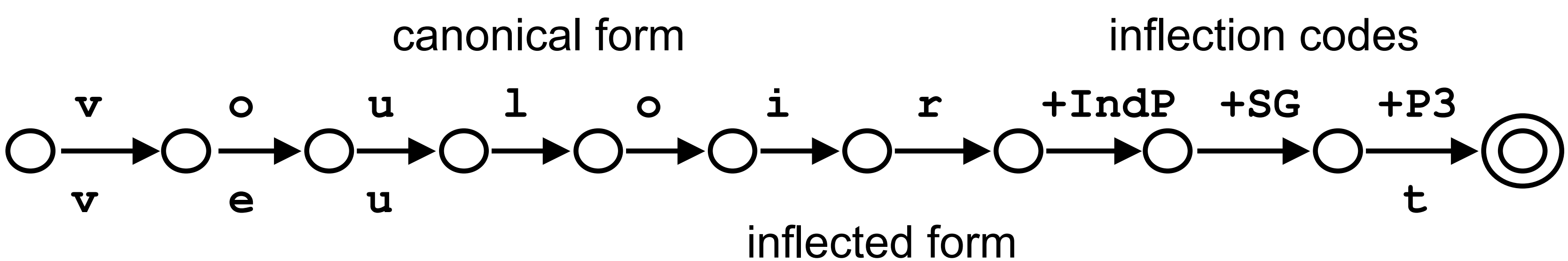


Set of parallel
of two-level rules
compiled into finite-state automata
interpreted as transducers
Koskenniemi '83

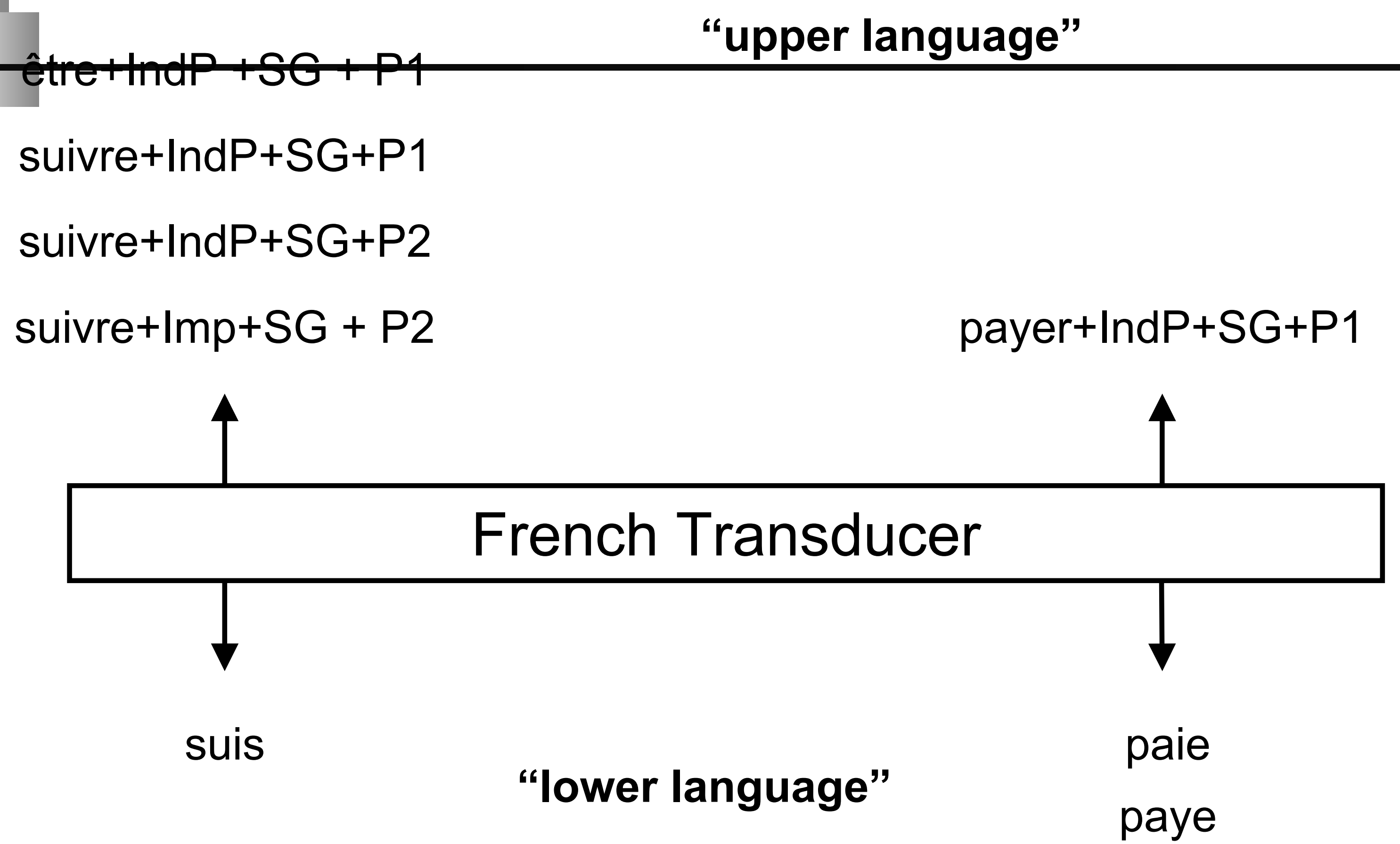
In practice

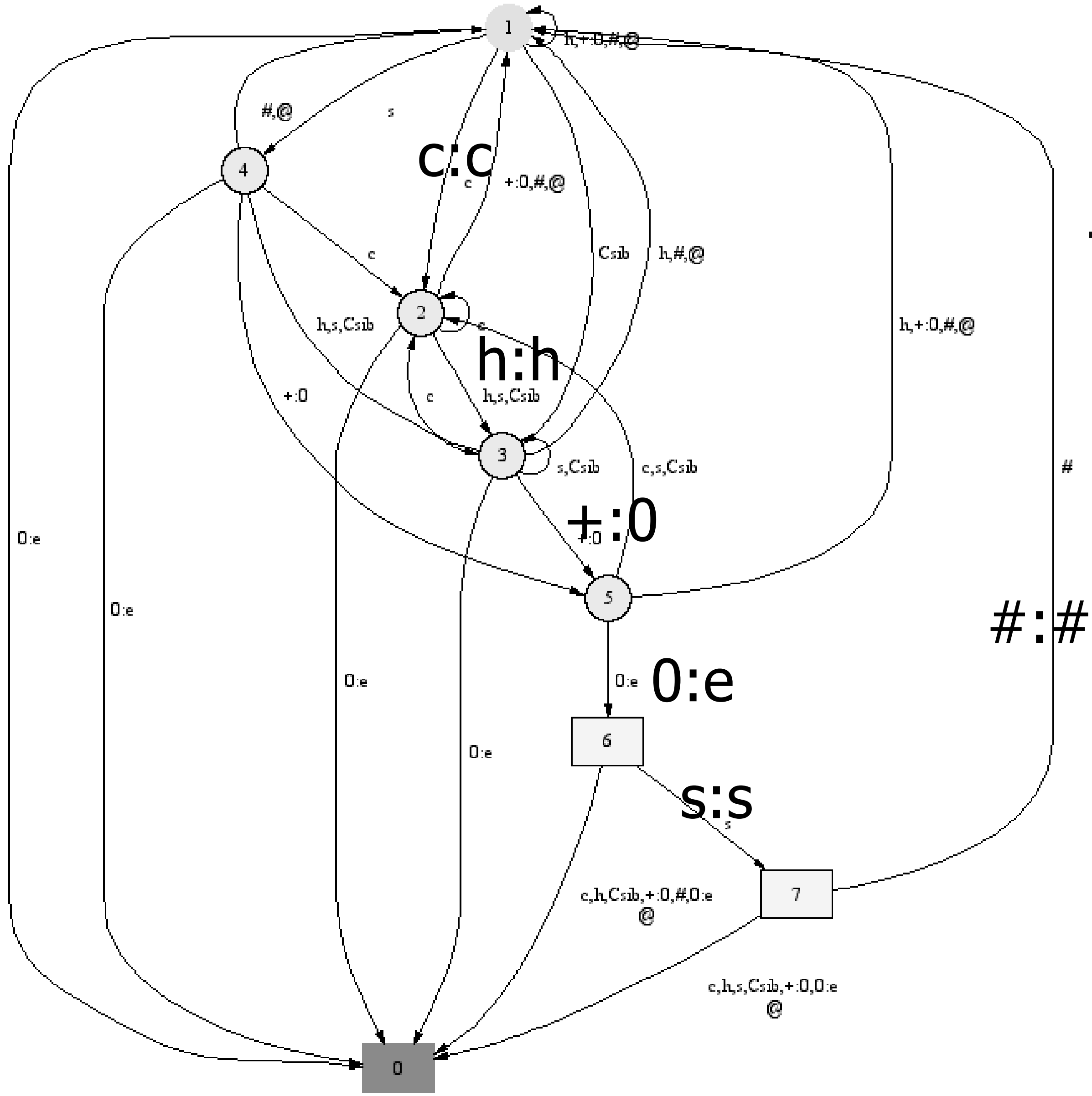


- Bidirectional: generation or analysis
- Compact and fast
- Commercially available for about 20 languges including English, German, Dutch, French, Italian, Spanish, Portuguese, Finnish, Russian, Turkish, Japanese, ...
- Research systems for many other languages, including Arabic, Malay, ...

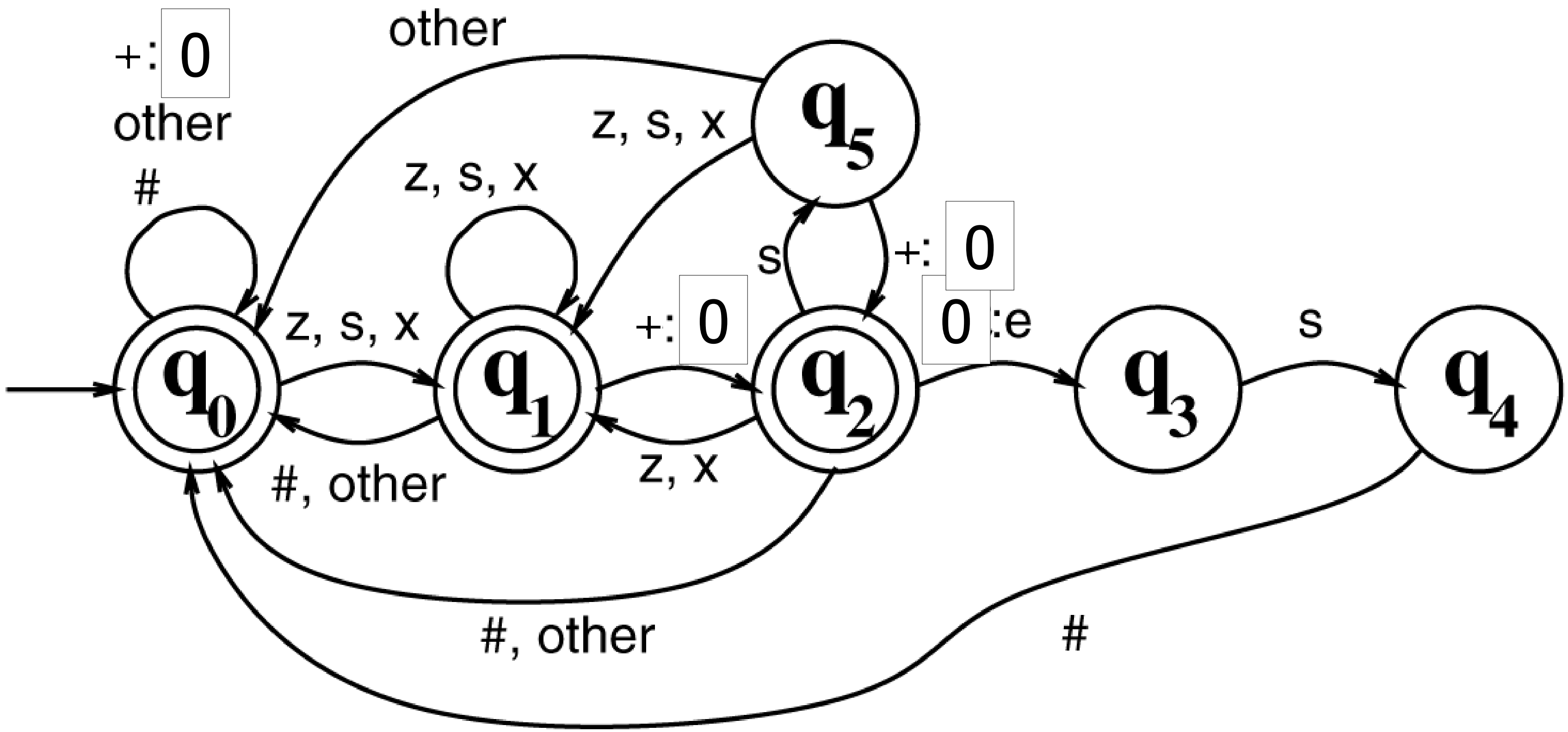


Ambiguities



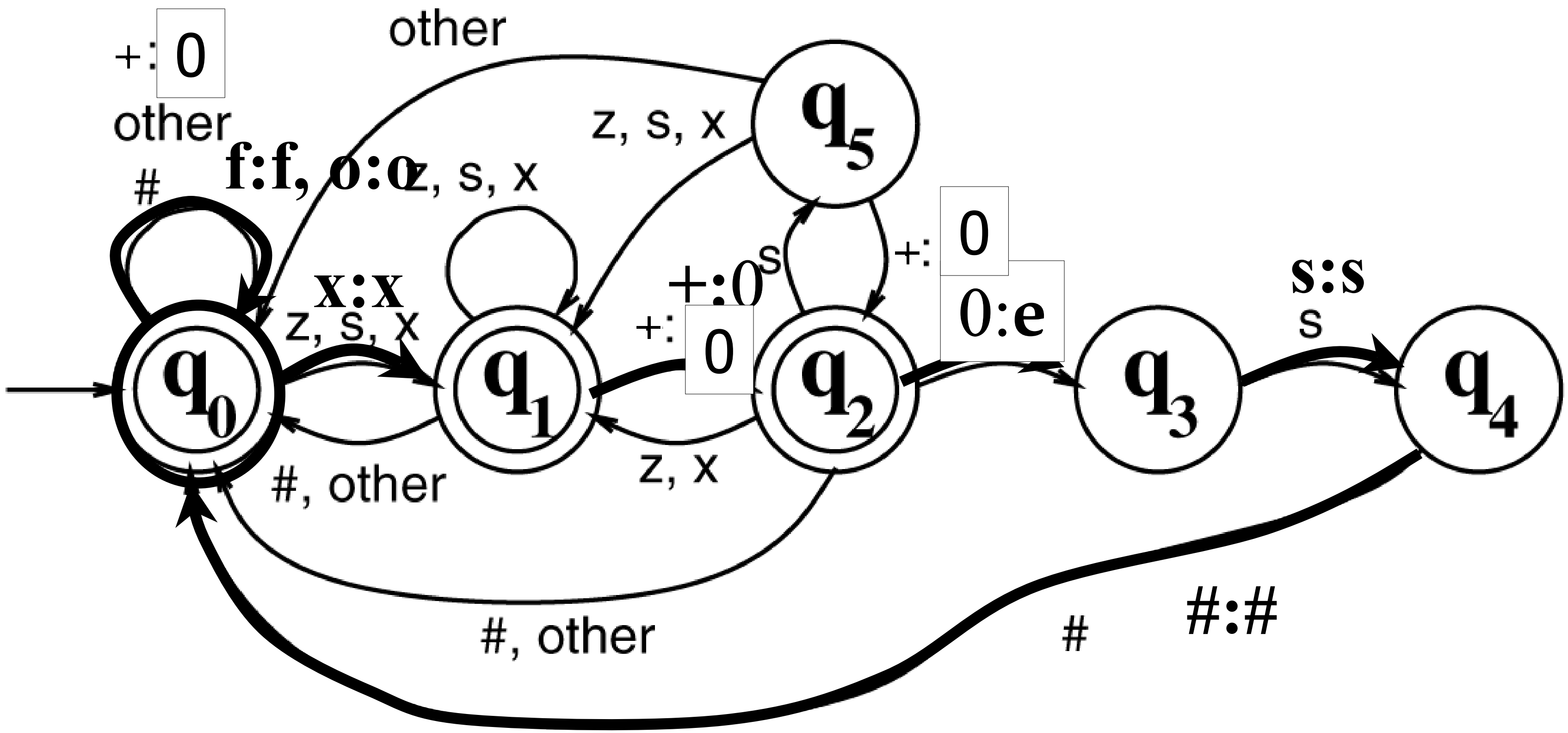

c:c
h:h
+:0
0:e
s:s
#:#
h,+:0,#,@
#,@
s
c
+:0,#,@
Csib
h,#,@
h,+:0,#,@
h,s,Csib
c
+:0
c
h,s,Csib
s,Csib
c,s,Csib
#
+:0
0:e
0:e
0:e
0:e
0:e
c,h,Csib,+:0,#,0:e
@
s
c,h,s,Csib,+:0,0:e
@
1
2
3
4
5
6
7
0

Insert ‘e’ before non-initial z, s, x (“epenthesis”)



f	o	x	0	e	s	#	**surface**
F	**O**	**X**	**+**	**0**	**S**	**#**	**lexical**

Successful pairing of foxes,fox+s



f	o	x	0	e	s	#	**surface**
F	**O**	**X**	**+**	**0**	**S**	**#**	**lexical**

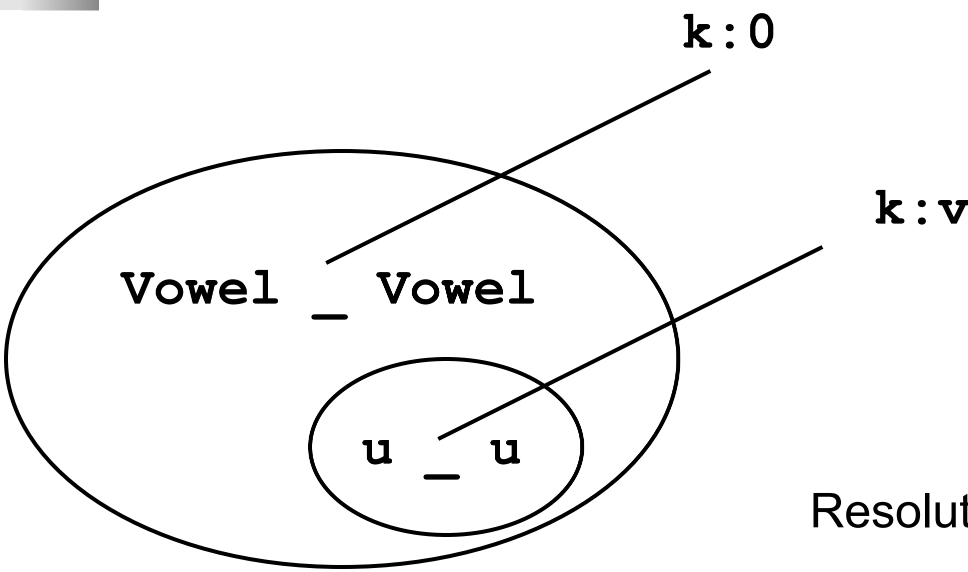
Can a transducer do this?

- igpay atinlay is unfay
- define Cons [b] ;
  define Vowel [a | e | i | o | u] ;
  define Ltr [Cons | Vowel]+ ;
  define Limit [" " | "\t" | .#.] ;

- Suppose just <u>one</u> consonant, e.g, be
- Strategy?

What about rule ordering?

Rule Conflicts



General rule

makun
ma un

Exception

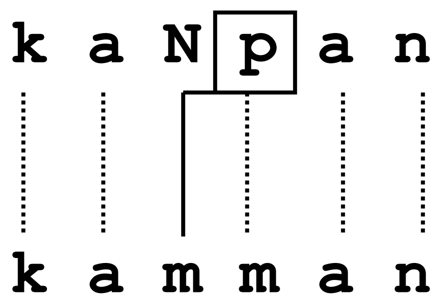
pukun
puvun

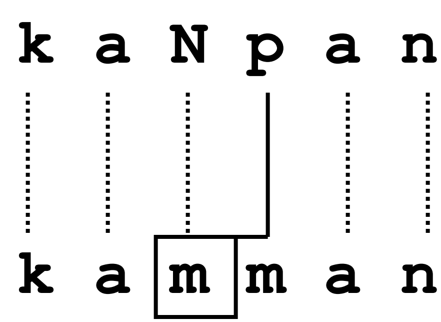
Resolution by underspecification:

```
k:0 | k:v <=> Vowel _ Vowel

  k:v     <=>     u _ u
```

Constraints on both sides





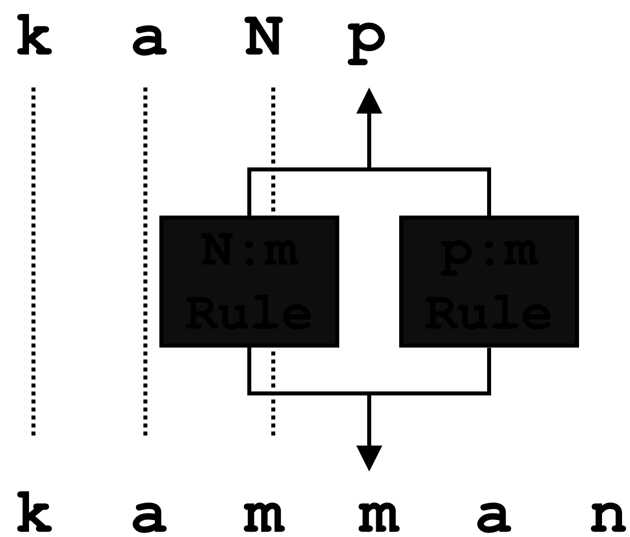
N:m correspondence requires a following p on the lexical side.

In this context, all other possible realization of a lexical N are prohibited.

p:m correspondence requires a preceding m on the surface side.

In this context, all other possible realization of a lexical p are prohibited.

Parallel application – how?

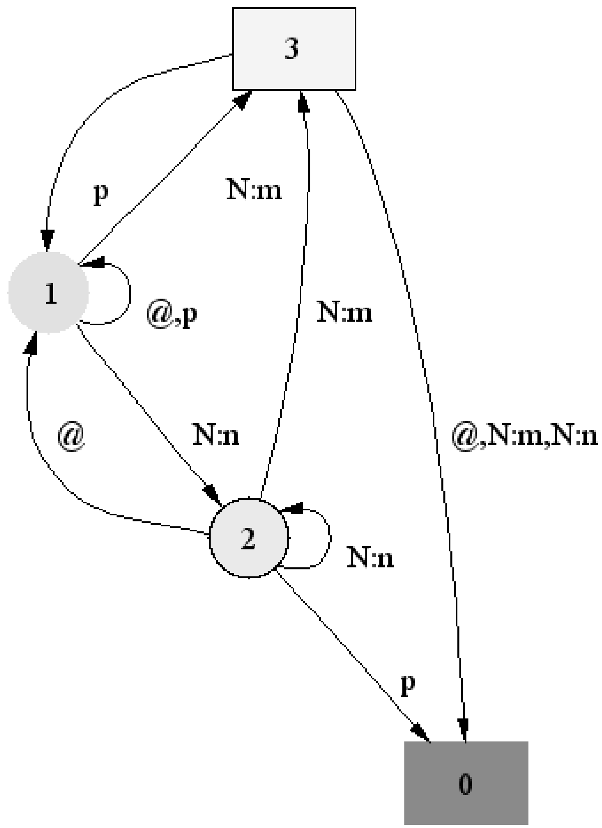


Sequential Application

```
k a N p a n
    ↓               N -> m / _ p
k a m p a n
      ↓             p -> m / m _
k a m m a n
```

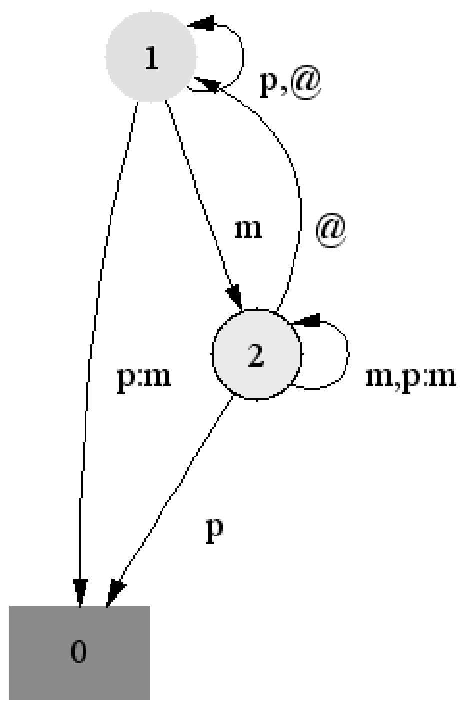
Machine Rule 1 (“N goes to m”)

Rule 1: N→m | __ p



Machine Rule 2 (“p goes to m”)

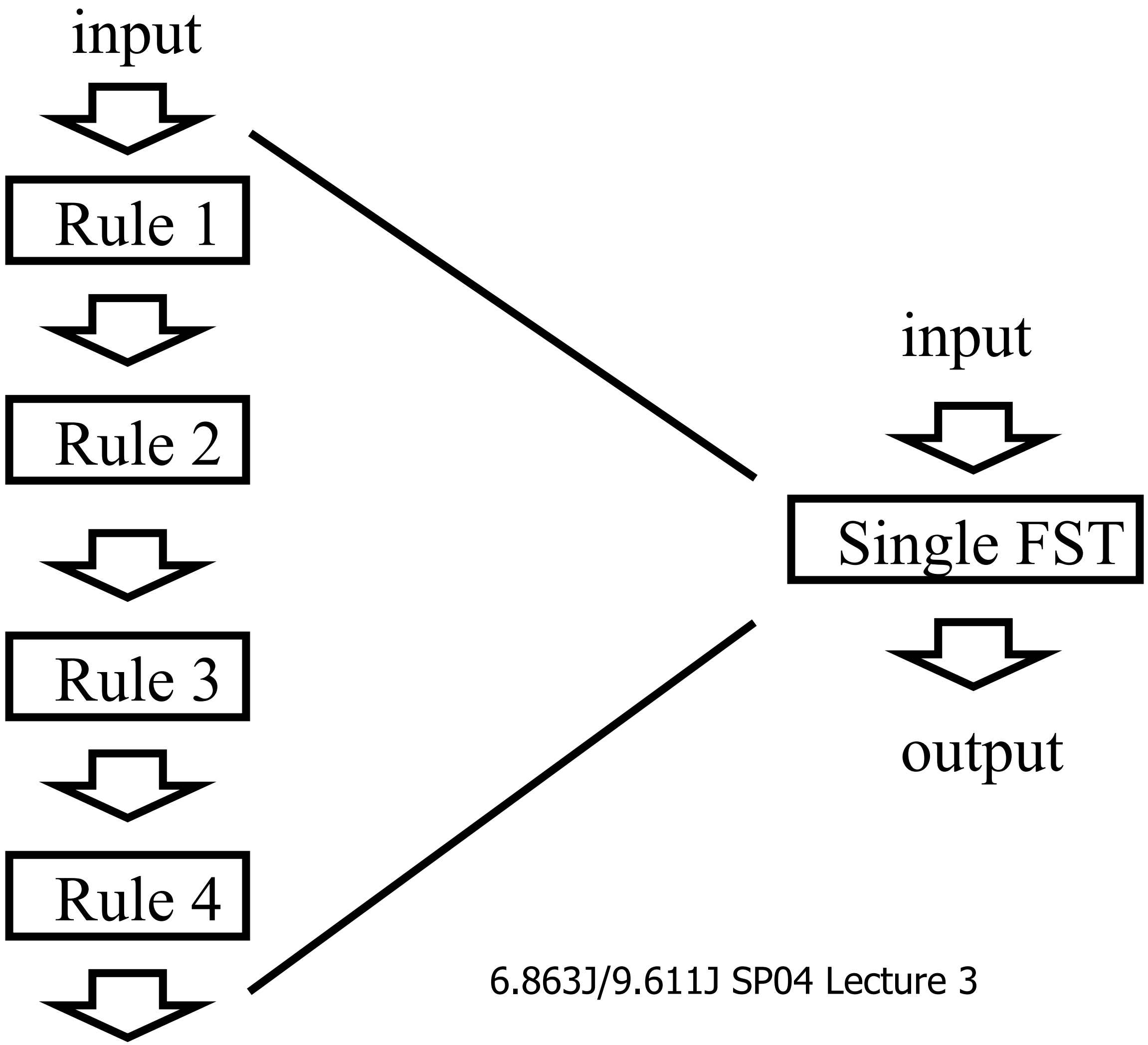
Rule 2: p→ m | m___



Sequential Application in Detail

```
 k a N p a n
0 0 0 2 0 0 0
      ↓
 k a m p a n
0 0 0 1 0 0 0
        ↓
 k a m m a n
```

When is this possible?



OK then…

- To apply all 5 rules at once, we can simply <u>intersect</u> them all, right? (So given character pair has to pass <u>all</u> the spelling checks at each point)

- Right?
- Wrong!

Relations

Ordered Set: members are ordered.

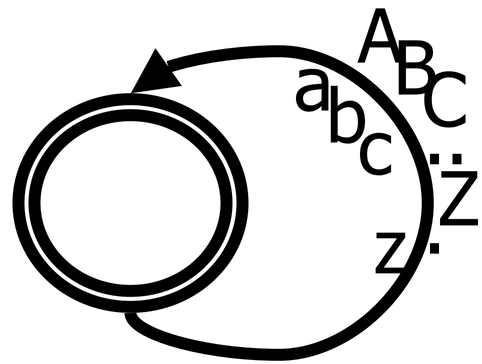
Ordered Pair: <A,B> vs. <B,A>

Relation: set whose members are ordered pairs

- (lexical, surface)

Relations

An Infinite Relation:.



Identity Relation: <"fly", "fly">

What does transducer define?

- Lexical form is a finite-state language (a regular language)
- Surface form is a regular language
- Transducer pairs (lexical form, surface form)= regular relation ("rational relation:")
- What are the properties of rational relations? Is this the same as what Kimmo does?

Closure properties of FSTs not same as FSAs!

- NOT closed under intersection

why? Example: (a:b)*(0:c)* $\cap$ (0:b)*(a:c)*

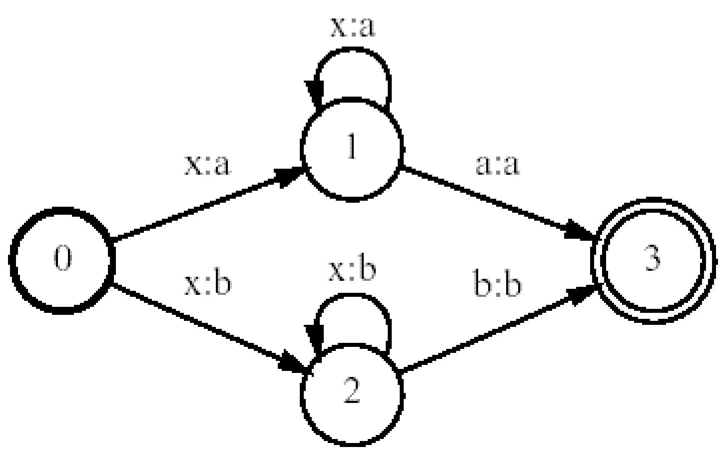
Intuition: 1^{st} makes equal a’s, b’s; 2^{nd}, equal a’s & c’s

So output is: < , >, <a, bc>, <aa, bbcc>, …

- NOT possible to make FTNs deterministic in general either…

why? Consider following FST:

Inherently nondeterministic FTN



Composition

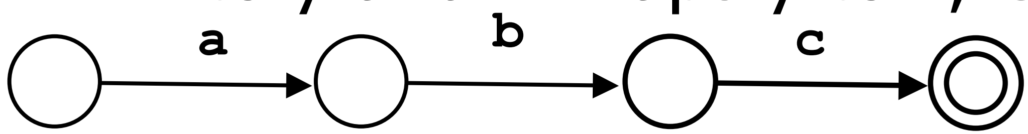
Composition is an operation on two relations.

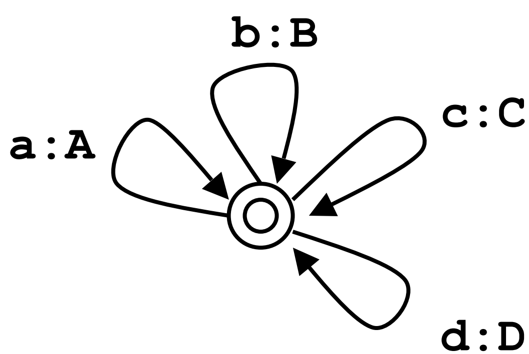
Composition of the two relations <x,y> and <y,z> yields <x, z>

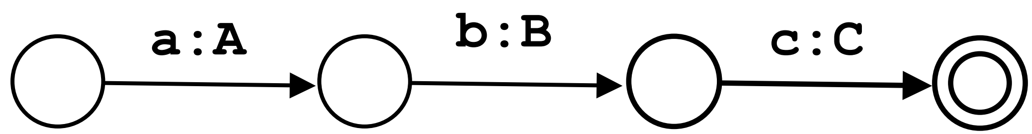
Example: <“cat”, “chat”> with <“chat”, “Katze”> gives <“cat”, “Katze”>

Composition

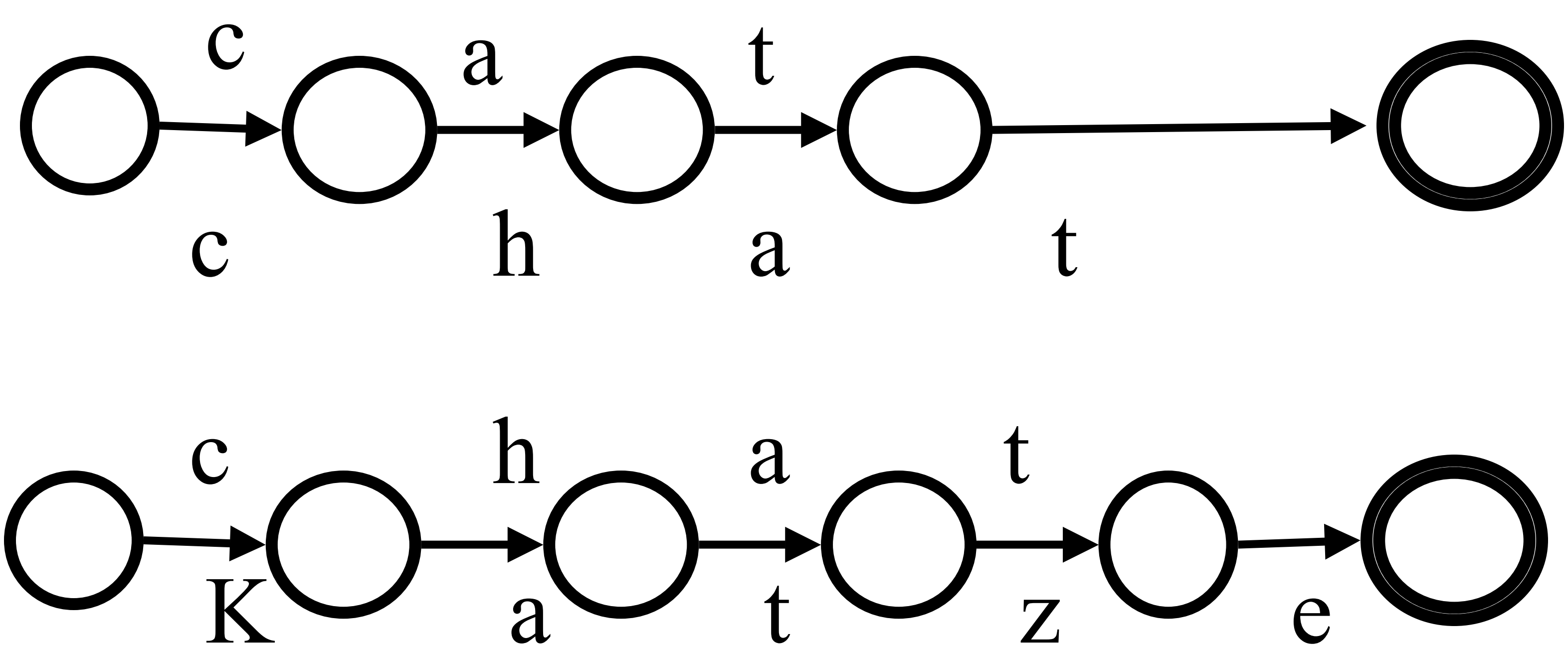
- A *c* B The relation C such that if A maps x to y and B maps y to z, C maps x to z.



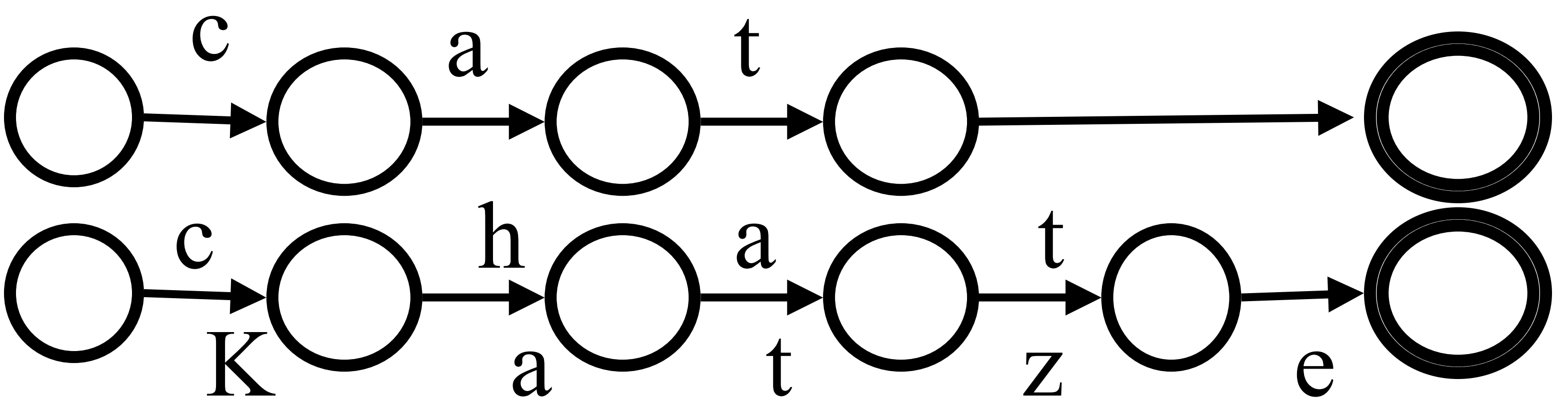




Composition

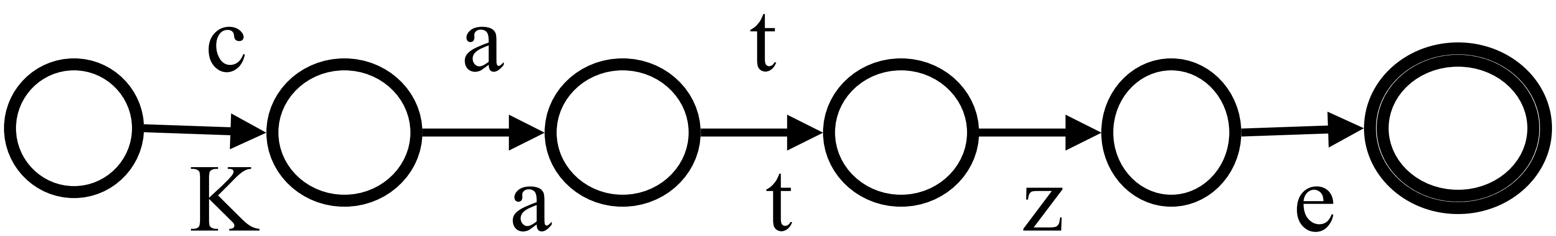


Composition



Merging the two networks

Composition



The Composition of the Networks

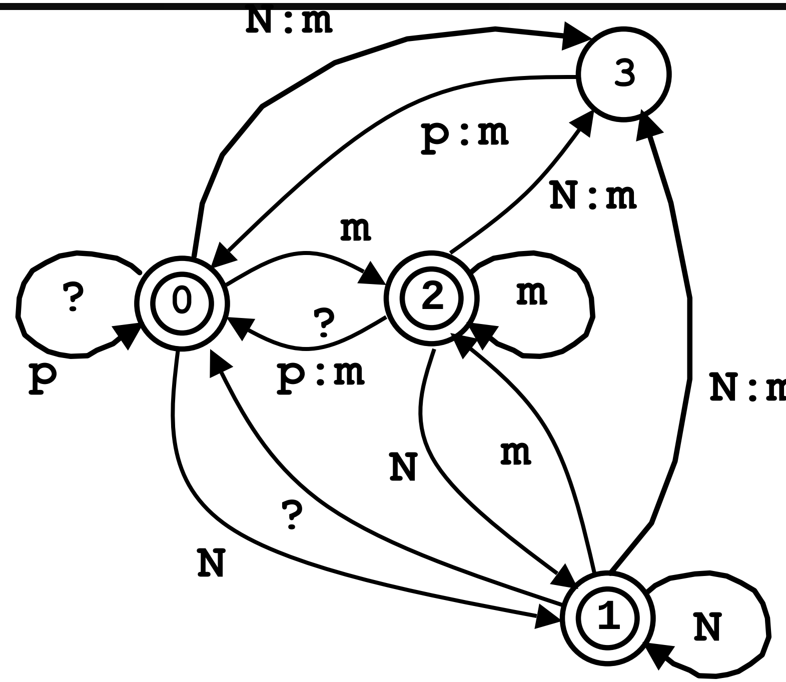
What is this reminiscent of?

Composition

k a N p a n

0 0 0 3 0 0 0

k a m m a n



FTNs <u>ARE</u> closed under composition

What are the implications?

- FTNs inherently require backup if simulated (in the worst case) – Kimmo at least NP-hard (proof later on)
- Empty elements cause computational complexity (unless restricted – equal length condition)
- Composition can save us, but then rule ordering must be watched carefully

Sequential Application in Detail

```
k a N p a n
0 0 0 2 0 0 0
k a m p a n
0 0 0 1 0 0 0
k a m m a n
```

Let’s see an example - English races’

```
Recognizing surface form "races’".
0 (r.r) --> (1 1  1 2 1  1)
               EP G Y EL I

1   (a.a) --> (1 1  4 1 2  1)
                 EP G Y EL I

2     (c.c) --> (1 2 16 2 11 1)

3       (e.0) --> (1 1 16 1 12 1)
                     EP G Y EL I

4         Entry |race| ends --> new lexicon N, config (1 1 16 1 12 1)
                                                       EP G Y EL I
```

- *note* that each of the 5 automata are running “in parallel” (what is the first one?)

Backup search

Problem: e is paired with 0 (null)…!

(which is wrong - it's guessing that the form is "racing" - has stuck in an *empty* (zero) *character* after *c* but before *e*) - *elision* automaton has 2 choices

This is *nondeterminism* in action (or inaction)!

```
5          Entry /0 ends --> new lexicon C1, config (1 1 16 1 12 1)
                                                     EP G Y EL I
6            Entry /0 is word-final --> path rejected (leftover input).
5          (+.0) --> (1 1 16 1 13 1)
                      EP G Y EL I
6            Nothing to do.
5          (+.e) --> automaton Epenthesis blocks from state 1.
4        Entry |race| ends --> new lexicon P3, config (1 1 16 1 12 1)
                                                       EP G Y EL I
```

22 steps later

```
3        (e.e) --> (1 1 16 1 14 1)
                     EP G Y EL I
4         Entry |race| ends --> new lexicon N, (1 1 16 1 14 1)
                                                  E  G Y EL I
5          Entry /0 ends --> new lexicon C1, config (1 1 16 1 14 1)
6           Entry /0 is word-final -->rejected (leftover input)
5            (+.0) --> (1 1 16 1 15 1)
6             (s.s) --> (1 4 16 2 1 1)
7              Entry +/s ends--> new lexicon C2,  (1 4 16 2 1 1)
8               Entry /0 is word-final -->rejected(leftover input)
8                (’.’) --> (1 1 16 1 1 1)
9                 End --> lexical form ("race+s’" (N PL GEN))
```

Laboratory 1b

- Goals:
  - How to use Kimmo to analyze another language (Spanish), as example “front end”
  - Build automata for some simple Spanish morphological/phonemic rules (that interact)
  - Build lexicon
  - Learn what is *hard* and what is *easy* about this
  - Recognize *all* and *only* the words in spanish.rec; Generate all the surface forms
- Resources:
  - Lab1b pdf file link from web page
  - File of all the surface words to parse/reject (covering the phenomena) spanish.rec, also linked from web page
  - Pykimmo, pcimmo & documentation
  - Program to `compile’ rules into automata: fst

What you must turn in (via URL)

1. A description of *how your system operates*
2. URL ptrs to your **`.lex`** and **`.rul`** files

   span.lex

   span.rul
3. A log of a recognition run on the file **`spanish.rec`** which is linked on the web page & also at toplevel on course locker
4. Discussion of what you built/why
5. You must answer 3 questions:

The questions

- What is your name?
- What is your quest?
- What…

The phenomena under study

- You are given the orthography, including some special characters to stand for the accented ones á,é,ó,ü,ñ ; and some underlying characters you may find essential, such as J, C, Z.
- Wise to proceed by *first* building the automata (rul) file; *then* the lexicon(s) - because you can test the rules without any lexicon by *generation* of a surface form
- The automata can be built (roughly) by considering each phenomenon separately
- 3 kinds of phenomena

The phenomena

1. *g-j mutation*
2. *z-c mutation*
3. *pluralization*
4. *Noun endings*
5. *Verb conjugation - 1 form*

Phenomenon 1: g-j mutation

- *g-j* mutation

  g→*j* before a back vowel

  coger (catch, infinitive); *cojo, coges, coge, cogemos, cogen, coja* (NOTE: *coger* is NOT the lexical underlying form!!!)
- But some verbs not subject to this (exceptions!)

  llegar (arrive); *llego, llegan, pagar* (pay); *pago, pagan*
- <u>*Don't acccept*</u> **llejo, *lleja, *cogo, *coga* (the words don't come marked with * on their sleeves, of course!)
- Hint: can use the lexical (underlying) character J to solve (but there are other ways to do it)

How to build Kimmo systems

How to build lexicons using morpheme states and the actual lexical entries

How to build automata for spelling changes

Format for .lex file - 2 parts

1. Lexicon: Morpheme classes – name all the states, some transitions

(1 or more blank lines)

2. Lexicon entries: transitions between the states

(Recall that we consider only the underyling form combinations here – stems + affixes, *not* spelling change rules on the surface)

Example: lexicon design

Phenomena: Nouns and Verbs take different endings

Answer:

Different *morpheme states* for Nouns and Verbs

Example surface (s) underlying (u) pairs tell us what to do

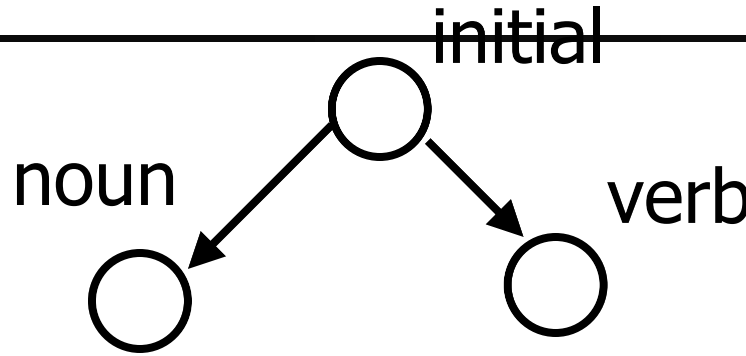
- *ciudad*

  ciudad [N(city)]

- *ciudades*

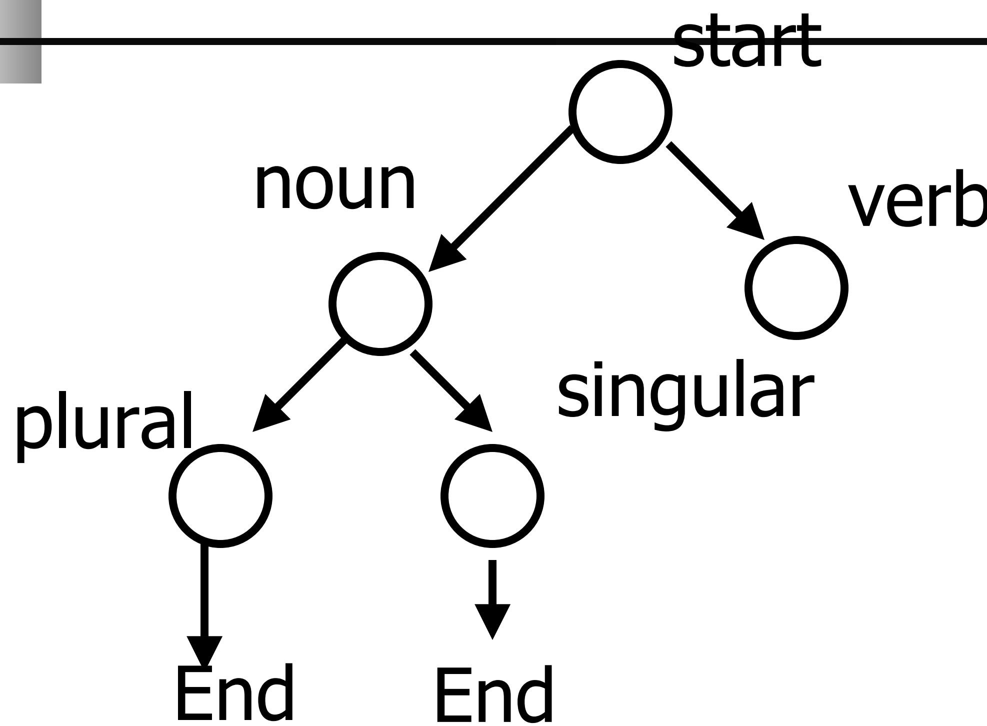
  ciudad+s [N(city)pl]

Automaton design for lexicon



Q: what do we need to add to noun alternation?

Adding plural



How do we build spelling change automata?

Example: look at phenomenon, then see first how to describe

- What is the left and right context of the change?
- Write it as a declarative constraint
- Remember that you can use both the surface and the lexical characters to admit or to rule out a possibility

Phenomenon 2: z-c mutation

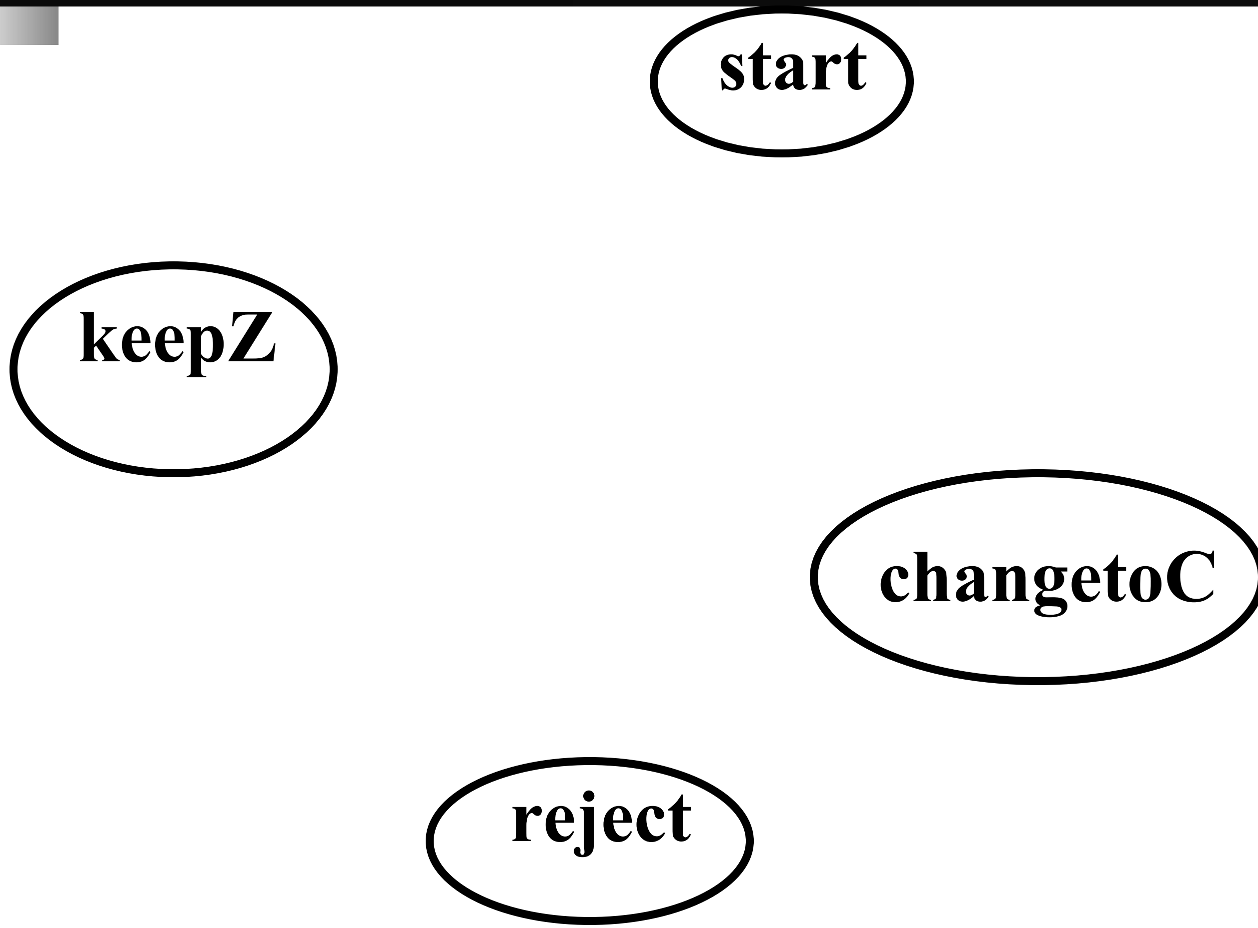
- *z-c mutation*

  z $\rightarrow$ *c* before front vowels, *z* otherwise

  cruzar (to cross); *cruzo, cruzas, cruza, cruzamos, cruzan, cruce*
- If *s* causes a front vowel (e.g., *e*) to surface, then the rule still applies:

  lápiz, lápices (pencil, pencils) [*l^piz, l^pices*]

What's the automaton got to do?



Now add the arcs…

Phenomenon 3: pluralization

- Adding *s* to a noun that ends in a consonant forces a surface *e* to appear:

  ciudad (city); *ciudades*
- This can interact with other rules, e.g., *z-c-mutation:*

  lápiz, lápices
- Nouns ending in a vowel are not subject to this rule: *bota, botas*

The lexicon – take 2

- Add a gloss at the very end of the process, so as to return the feature list and 'translation', e.g., *venzo* [1p sg pres indic conquer, defeat] (first person, singular, present tense, indicative)
  - We'll show *how* to add this in a moment
- You will deal with two types of 'endings'

1. Noun endings: plural suffix +*s*
2. Verb endings: verb stem + tense markers

Simplest: infinitive marker **`+ar`**, **`+er`**, **`+ir`**

See table in pdf file for details: 5 x 3 table for Present tense; ditto for Subjunctive tense ("*I might....*")

Instead of writing fst tables…

- You can use the program fst
- To run:

  build fst type rules in file spanish.fst, then

```
fst -o ~yourpath/spanish.rul ~yourpath/spanish.fst
```

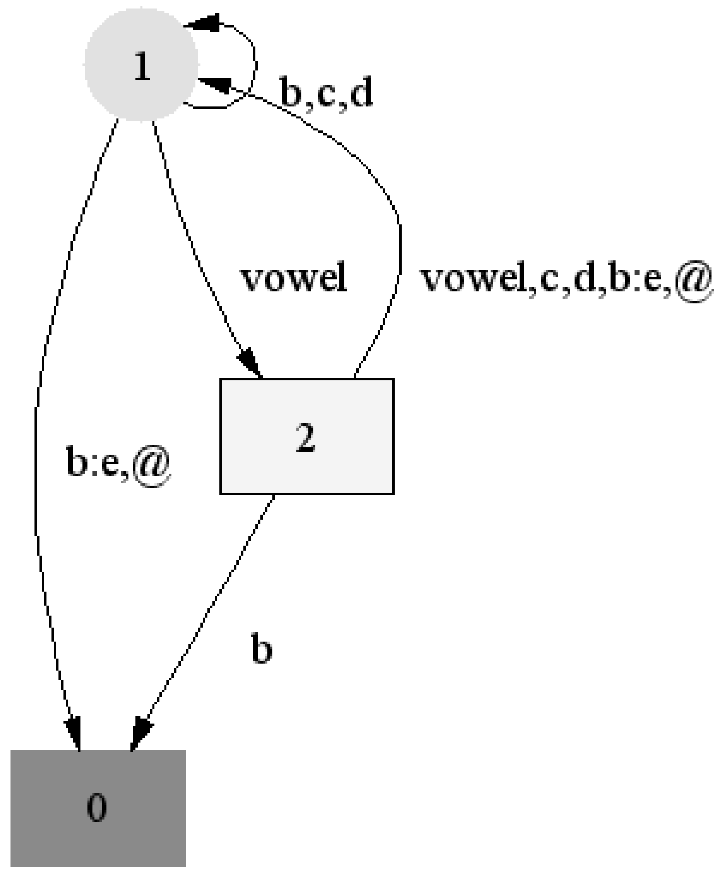
- Also script to print fst files to dot, for ps viewing
- Format for fst rules:

FST rules

- "*b* after a vowel turns to *a*"

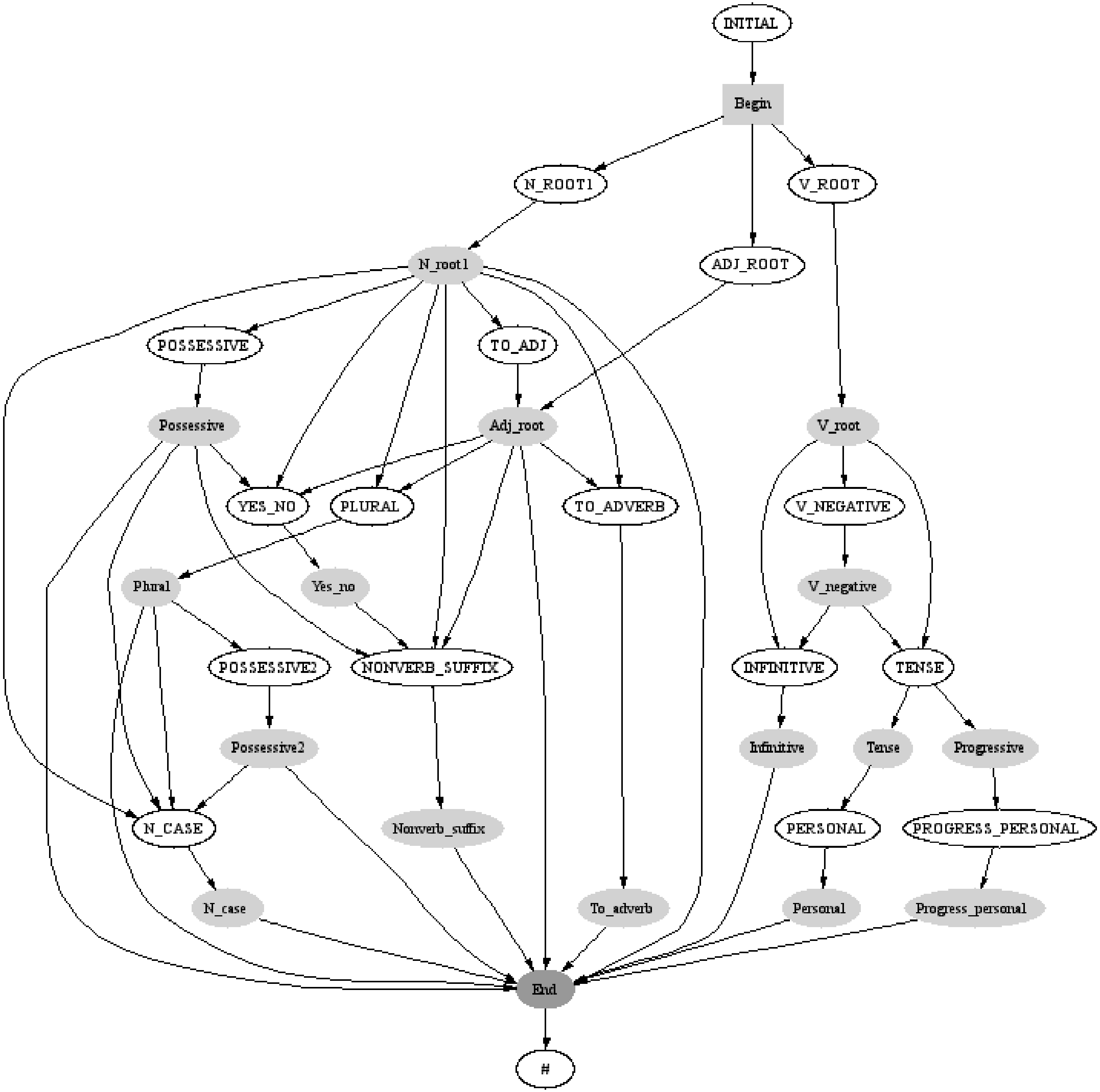
```
subset vowel a e
machine "bintoa"
state foo
vowel:vowel   bar
b:b  foo
c:c  foo
d:d  foo
others reject

rejecting state bar
b:e foo
b:b reject
others foo
```

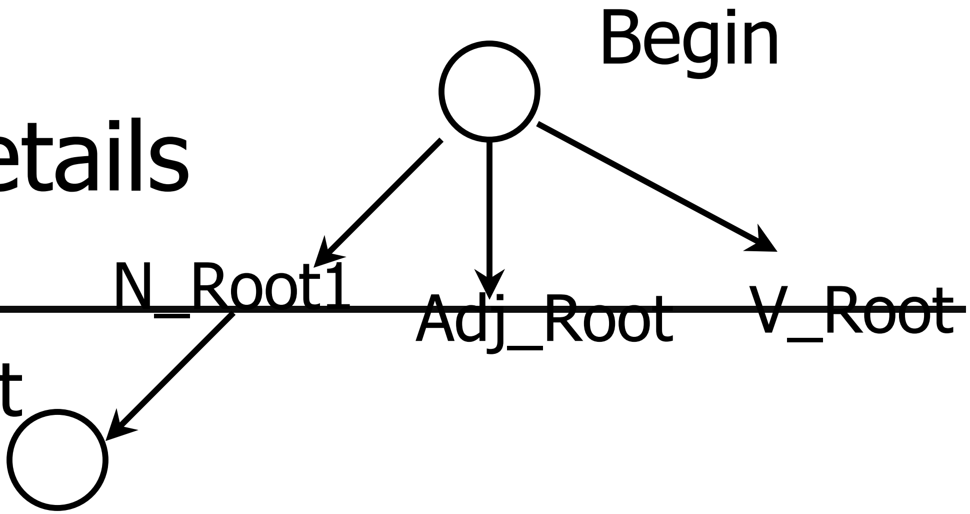

1
b,c,d
vowel
vowel,c,d,b:e,@
b:e,@
2
b
0

Design of morpheme machine

- One big fsa
- Like this…


INITIAL
Begin
N_ROOT1
V_ROOT
N_root1
ADJ_ROOT
POSSESSIVE
TO_ADJ
Possessive
Adj_root
V_root
YES_NO
PLURAL
TO_ADVERB
V_NEGATIVE
Plural
Yes_no
V_negative
POSSESSIVE2
NONVERB_SUFFIX
INFINITIVE
TENSE
Possessive2
Infinitive
Tense
Progressive
N_CASE
Nonverb_suffix
PERSONAL
PROGRESS_PERSONAL
N_case
To_adverb
Personal
Progress_personal
End
#

Specification details



- List states – in cyan – followed by <u>sets</u> of transition labels (possible outgoing arcs)

Begin:	N_Root1	Adj_Root	V_Root
N_root:	Poss	To_adj	

- For each arc: List transitions & next states, and output

N_root1:

Kol	N_root	Noun[‘arm’]
Kitab	N_root	Noun[‘book’]

…

The End

End:

0 # " "