



НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ  
УНИВЕРСИТЕТ

# Morphological modelling

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2 ноября 2018 г.



В 1942—1945 годах профессором [Г. С. Петровым](#) и сотрудниками была разработана серия клеев БФ<sup>[1]</sup>. Советский учёный-химик Петров знаменит также «контактом Петрова» и работами в области химии и технологии [карболита](#) ([бакелита](#), фенолформальдегидных пластмасс)<sup>[2]</sup>.



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- Morphology: What is it? Why should we care?
- Modelling morphology: With finite-state machines
- Development: Some development tips

# Morphology

Morphology is:

« the branch of linguistics that studies patterns of word formation within and across languages, and attempts to formulate rules that model the knowledge of the speakers of those languages. »

This is a big field, here we are interested in practical models.

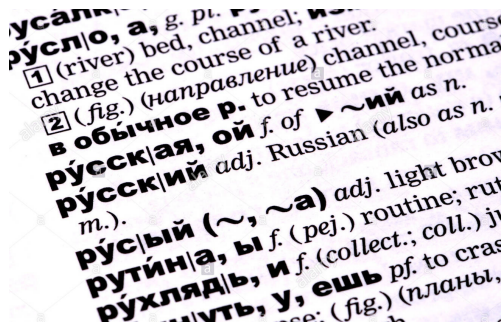
## English or Chinese:

- A full form list is a possibility
- Few or no inflectional forms
  - e.g. 5 forms per English verb {see, sees, saw, seen, seeing}

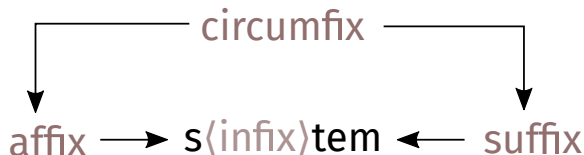
## Other languages:

- Difficult or impossible to enumerate all forms
- Very productive inflection and derivation
  - Russian verbs: over 150 forms (maximally)
  - Turkish verbs: thousands of forms





- Lemma: The citation form of a word (cf. headword)
- Stem: The part of a word affixes attach to
- Paradigm: A description of how the word inflects:



Add additional meaning or change the meaning of a lexical stem:

- **Suffixes:** *hus* 'house' — *huset* 'the house'
- **Prefixes:** *kjent* 'known' — *ukjent* 'unknown'
- **Infixes:** *opstaan* 'stand' — *opgestaan* 'stood'
- **Circumfixes:** *nagy* 'big' — *legnagyobb* 'biggest'

- **Inflection:** Inflectional morphemes carry grammatical information, such as number, case, tense, etc., but do not change the word category
- **Derivation:** Derivational morphemes change the basic semantic meaning of a word, and can also change word category.
- **Compounding:** A process where two or more words are joined together to form one, typically of the same category or supertype.
- **Clitics:** Syntactically independent word that functions phonologically as an affix of another word.
- **Incorporation:** Where a nominal (e.g. direct object) or adverbial is included into a verb form.

Examples of inflection categories:

- **Case:**

*дом-у* 'house-LOC', *ev-de* 'house-LOC', *talo-ssa* 'house-INE'

- **Possession:**

*ev-im* 'house-1SG', *talo-ni* 'house-1SG'

- **Number:**

*дом-а* 'house-PL', *ev-ler* 'house-PL', *talo-t* 'house-PL'

- **Tense, aspect, mood:**

*говори-ла* 'say-PAST.F', *söyle-di* 'say-PAST', *puhu-i* 'say-PAST'

- **Comparison:**

*больш-е* 'big-COMP', *нысăк-рах* 'big-COMP', *iso-mpi* 'big-COMP'

In general: Change in meaning is regular.

Examples of derivational affixes:

- **Actor:** *diş-çi* /tooth-er/ 'dentist'
- **State:** *boş-luk* 'emptiness', *nyctm-oma* 'emptiness'
- **Diminutive:** *dog-gie*, *kedi-cik* /cat-DIM/ 'kitten'

Can often be stacked:

- *temizlikçi* /temiz-lik-çi/ clean-ness-er = cleaner
- *поверхностный* /по-верх-ность-ный/ on-surface-ness-ly = superficial

Change in meaning may be irregular, compare:

- *cooker* /cook-er/ 'machine that cooks'
- *cleaner* /clean-er/ 'person who cleans'
- *looker* /look-er/ 'person that looks good'

May be limited to particular stems.

New words are formed from morphologically/syntactically independent words:

- This may be indicated in the writing system or not.
  - infrastruktuurontwikkelingsplan, or
  - infrastructure development plan
- tri-noun compounds, but different orthographical treatment

**Note:** a given compound word may be split different ways, or a given word may appear as a compound, but not be one:

- Freitag = Friday (not “Frei” + “tag” = free day)
- kulturforskeren = the ethnographer, and not
  - kultur+forskeren = “culture researcher”
  - kultur+forske+ren = “culture research clean”

Clitics are syntactically separate words that are phonologically conditioned by another unit (word, phrase).

- **Pronominal:**

- Spanish: *me lo das* me it you.give 'You give it to me'
- Spanish: *dámelo!* give-me-it 'Give it to me!'

- **Verb forms:**

- Serbo-Croatian: *govorit ću* vs. *govoriću* 'I will speak'
- English: *I'm* 'I am', *gonna* 'going to'

- **Other:**

- Question words (e.g. Finnish *onko?* is-QST? 'Is there?')
- Tense markers (e.g. Kurdish *-ê*)

- **Consider:**

- *нравиться* and *собирать, собираться*

Should these be tokenised prior to analysis?

*Гақорапэнратлэн Сыкwaңақай рэмкык*  
“Cikwaṇaqaj chased after the reindeer in the other encampment.”

га-қора-пэнр-ат-лэн	Сыкwaңақай	рэмк-ык
PERF-reindeer-chase-s3SG	Cikwaṇaqaj	folk-LOC

- Syntactically/pragmatically determined (not lexically!)
- Can be valency changing, e.g.
  - DOBJ + V.TR → V.INTR





- Analytic—Synthetic:
  - Morphemes per word
- Agglutinative—Fusional:
  - Meanings per morpheme / ease of segmentation

# Modelling

## Analysis:

студента  $\rightarrow$  {студент<n><m><aa><sg><gen>,  
студент<n><m><aa><sg><acc> }

## Generation:

студент<n><m><aa><sg><gen>  $\rightarrow$  студента

How morphemes can be combined:

- студентом, играющийся, played, evlerde
- \*омстудент, \*ющийсяигра, \*edplay, \*deevler

We'll be using the `lexc` formalism for modelling this.

The changes that happen when morphemes are combined:

- **Deletion:** работа + ы → работы
- **Epenthesis:** fox + s → foxes
- **Fleeting vowel:** огонёк + ом → огоньком
- **Assimilation:** baş + da → başta
- ...

Several changes can take place at once:

- $\theta\Gamma + \Upsilon \rightarrow \theta\theta$  'house.3SG'
- Deletion of 'r' and assimilation of 'Y'

We'll be using the  $\text{twol}$  formalism for modelling this.

Let's take the Turkish words *ev* 'house', *kız* 'girl':

	<b>Singular</b>	<b>Plural</b>
<b>Nominative</b>	ev, kız	ev-ler, kız-lar
<b>Accusative</b>	ev-i, kız-ı	ev-ler-i, kız-lar-ı
<b>Genitive</b>	ev-in, kız-ın	ev-ler-in, kız-lar-ın
<b>Dative</b>	ev-e, kız-a	ev-ler-e, kız-lar-a
<b>Locative</b>	ev-de, kız-da	ev-ler-de, kız-lar-da
<b>Ablative</b>	ev-den, kız-dan	ev-ler-den, kız-lar-dan

Suffixes are different according to **front** and **back** vowels.

We can represent these as a finite-state automaton:



Where the labels would mean:

- **front-stem**: the front stems (e.g. *ev*)
- **back-stem**: the back stems (e.g. *kız*)
- **front-suffix**: the front suffixes (e.g. *-de*)
- **back-suffix**: the back suffixes (e.g. *-da*)

Multichar\_Symbols

%<n%> %<nom%> %<loc%> %>

LEXICON Root

front-stem ;

back-stem ;

LEXICON front-suffix

%<n%>%<nom%>: # ;

%<n%>%<loc%>:%>de # ;

LEXICON back-suffix

%<n%>%<nom%>: # ;

%<n%>%<loc%>:%>da # ;

LEXICON front-stem

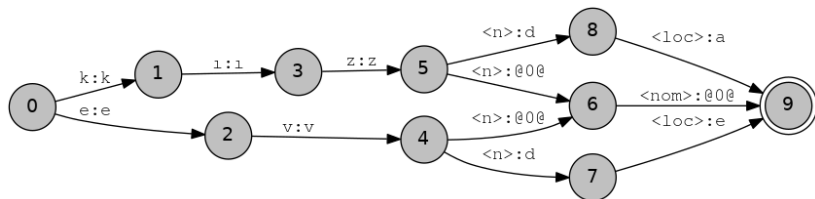
ev:ev front-suffix ; ! "house"

LEXICON back-stem

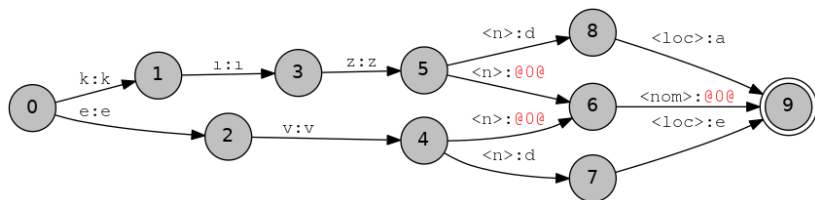
kız:kız back-suffix ; ! "girl"

- **Tags:** Symbols that show grammatical information
- **Continuation class:** Sets of morphemes
- **Next continuation:** Shows where to go next
- **#:** End of string
- **Comment string:** Indicated with !
- **%>:** Morpheme boundary





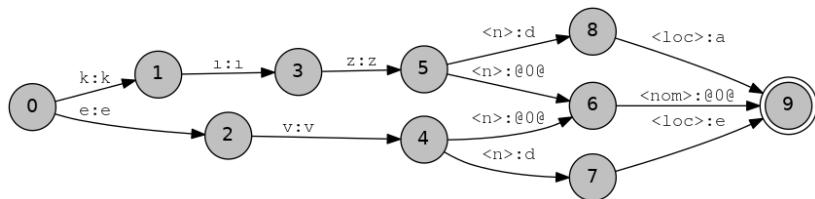
- $Q$  = Set of  $N$  states =  $\{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$
- $\Sigma$  = Input alphabet =  $\{a, d, e, k, l, v, z, \epsilon\}$
- $\Delta$  = Output alphabet =  $\{e, k, l, v, z, \langle n \rangle, \langle nom \rangle, \langle loc \rangle\}$
- $q_0 \in Q$  = A single start state = 0
- $F \subseteq Q$  = A set of final states =  $\{9\}$
- $\delta(q, w)$  = A transition function from a state  $q \in Q$  and a string  $w \in \Sigma^*$  to a set of states in  $Q$



Sometimes we need to input or output a symbol without reading or writing an actual symbol.

- e.g. the  $\epsilon \rightarrow \langle n \rangle$  transition.
- This is commonly encoded as @0@ and written as  $\epsilon$ .

**Epsilon closure:** Finding all states that can be found without reading any input.



	Cur. state(s)	In. sym.	Out. state(s)	Out. sym	Out. string(s)
c	0	ε	0	–	–
s	0	k	1	k	k
c	1	ε	1	–	k
s	1	l	3	l	kl
c	3	ε	3	–	kl
s	3	z	5	z	kız
c	5	ε	6	<n>	kız<n>
c	6	ε	9	<nom>	kız<n><nom>

We can simplify the morphotactics by using **archiphonemes**:

- Archiphonemes stand in for underspecified surface symbols
- e.g. underlying **%{A%}** can be surface *a* or *e*

## Example:

Multichar\_Symbols

```
%<n%> %<nom%> %<loc%> %{A%}
```

LEXICON Root

```
stems ;
```

LEXICON suffix

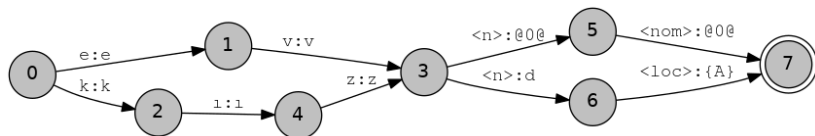
```
%<n%>%<nom%>: # ;
```

```
%<n%>%<loc%>:%>d%{A%} # ;
```

LEXICON stems

```
ev:ev suffix ; ! "house"
```

```
kız:kız suffix ; ! "girl"
```



- 50% reduction in code length (15 lines → 10 lines)
- 20% reduction in number of states (9 states → 7 states)

It is helpful to think about the transducer as a number of tapes:

<b>Lexical</b>	k	1	z	0	<n>	<nom>
<b>Morphotactic</b>	k	1	z	>	d	{A}
<b>Surface</b>	k	1	z	0	d	a

**Objective:** Produce a mapping between these tapes

evd{A}:evde		
evd{A}:evda	[apply rules]	evd{A}:evde
k1zd{A}:k1zde	→	k1zd{A}:k1zda
k1zd{A}:k1zda		

- First expand all possible forms on the morphotactic tape
- Rules are constraints on possible symbol pairs
- Each rule is an automaton which accepts or rejects a string

## Alphabet

```
a b c d e f g h i j k l m n o p q r s t u v  
w x y z ü ö ş ç ı %{A%}:a %{A%}:e ;
```

## Sets

```
Back = a ı o u ;
```

```
Cns = b c d f g h j k l m n p q r s t v w x y z ş ç ;
```

## Rules

### Three main sections:

- **Alphabet:** Valid symbol pairs, n.b.  $a = a : a$ , etc.
- **Sets:** Groups of symbols to be used in rules
- **Rules:** Constraints



```
"Vowel harmony for archiphoneme {A}"  
%{A%}:a <=> :Back [ Cns: | :Back | %>: ]* _ ;
```

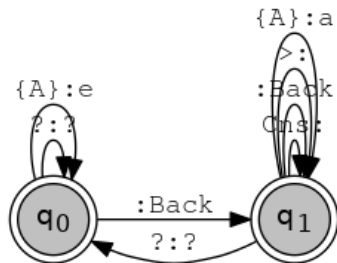
- **Symbol pair**: The symbol pair to constrain
- **Rule operator**: The type of constraint
- **Rule context**: The context where the rule should apply
- **Rule centre**: Where the symbol pair is found in the context

# Rule example: Vowel harmony



"Vowel harmony for archiphoneme {A}"

$\% \{A\} : a \iff : \text{Back} [ \text{Cns} : | : \text{Back} | \% > : ]^* \_ ;$



k	ɪ	z	d	{A}
k	ɪ	z	d	a
k	ɪ	z	d	<b>{A}</b>
k	ɪ	z	d	<b>e</b>
				↑ <b>FAIL</b>

	<i>Positive Reading</i>	<i>Negative Reading</i>
$a:b \Leftrightarrow l\_r ;$	<ol style="list-style-type: none"> <li>1. If the symbol pair <math>a:b</math> appears, it must be in the context <math>l\_r</math>.</li> <li>2. If lexical <math>a</math> appears in the context <math>l\_r</math>, then it must be realized on the surface as <math>b</math>.</li> </ol>	<ol style="list-style-type: none"> <li>1. If the symbol pair <math>a:b</math> appears outside the context <math>l\_r</math>, FAIL.</li> <li>2. If lexical <math>a</math> appears in the context <math>l\_r</math> and is realized as anything other than <math>b</math>, FAIL.</li> </ol>
$a:b \Rightarrow l\_r ;$	If the symbol pair $a:b$ appears, it must be in the context $l\_r$ .	If the symbol pair $a:b$ appears outside the context $l\_r$ , FAIL.
$a:b \Leftarrow l\_r ;$	If lexical $a$ appears in the context $l\_r$ , it must be realized on the surface as $b$ .	If lexical $a$ appears in the context $l\_r$ and is realized as anything other than $b$ , FAIL.
$a:b / \Leftarrow l\_r ;$	Lexical $a$ is never realized as $b$ in the context $l\_r$ .	If lexical $a$ is realized as $b$ in the context $l\_r$ , FAIL.

Table 1.1: **twolc** Rule Operator Semantics

Sometimes several rules can apply to the same form:

	Singular	Plural
<b>Nominative</b>	ev, kız, baş	evler, kızlar, başlar
<b>Accusative</b>	evi, kızı, başı	evleri, kızları, başları
<b>Genitive</b>	evin, kızın, başın	evlerin, kızların, başların
<b>Dative</b>	eve, kıza, başa	evlere, kızlara, başlara
<b>Locative</b>	evde, kızda, başta	evlerde, kızlarda, başlarda
<b>Ablative</b>	evden, kızdan, baştan	evlerden, kızlardan, başlardan

The suffix *-da* can be *-ta/-te*, e.g. *başta* 'head-LOC' not *\*başda*.

- This calls for another archiphoneme!  $\% \{D\% \} \rightarrow \{d, t\}$

Multichar\_Symbols

%<n%> %<nom%> %<loc%> %{A%} %{D%}

LEXICON Root

stems ;

LEXICON suffix

%<n%>%<nom%>: # ;

%<n%>%<loc%>:%>%{D%}%{A%} # ;

LEXICON stems

ev:ev suffix ; ! "house"

kız:kız suffix ; ! "girl"

baş:baş suffix ; ! "head"

## Input

ev>{D}{A}  
kız>{D}{A}  
baş>{D}{A}

## Expand

ev>{D}{A}:evda  
ev>{D}{A}:evde  
ev>{D}{A}:evta  
ev>{D}{A}:evte  
kız>{D}{A}:kızda  
kız>{D}{A}:kızde  
kız>{D}{A}:kızta  
kız>{D}{A}:kızte  
baş>{D}{A}:başda  
baş>{D}{A}:başde  
baş>{D}{A}:başta  
baş>{D}{A}:başte

## Apply rules

ev>{D}{A}:evde  
kız>{D}{A}:kızda  
baş>{D}{A}:başta

"Vowel harmony for archiphoneme {A}"

`%{A%}:a <=> :Back [ Cns: | :Back | %>: ]* _ ;`

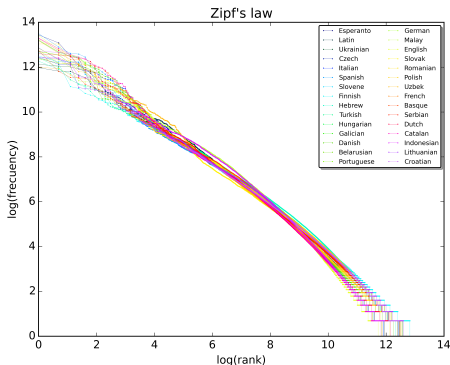
"Devoicing of {D}"

`%{D%}:t <=> :Unvoiced %>: _ ;`

- Rules are applied in parallel
- Every pair must be accepted by all rules

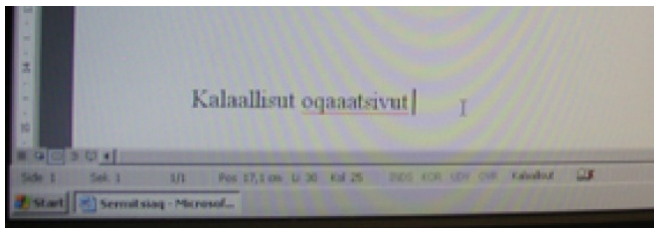
# Development





Take **frequency** into account, in adding:

- Stems
- Morphemes
- Phonological rules



- **Spellcheckers:** For morphologically-rich languages that have little data, FSTs are the only choice.
- **Online dictionaries:** For languages where it is non-trivial to determine the headword from a surface form, an FST can be a real aid
  - for learners and for newly literate speakers
- **Improve parsing:** For languages with limited data for training a parser, an FST can significantly improve performance.

- **Templatic morphology:**

- Semitic languages like Maltese, Hebrew and Arabic use templates to form surface forms, e.g. Maltese *k-t-b* could be *ktieb* 'book' or *kotba* 'books'
- The FSMBook<sup>1</sup> has examples of how to treat these

- **Machine learning approaches:**

- Recent advances in morphological generation (SIGMORPHON)<sup>2</sup>
- Morphological analysis way behind

- **Rewrite rules:**

- Some prefer to write phonological rules as a cascade of rules
- Computationally equivalent
- See FSMBook for further details

- **Weighting:**

- Refer to the practical

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<sup>1</sup>Beesley and Karttunen (2003) *Finite-State Morphology* (Chicago: CLSI)

<sup>2</sup><https://sigmorphon.github.io/sharedtasks/>

Go through the following practical:

[https://ftyers.github.io/2017-КЛ\\_МКЛ/hfst.html](https://ftyers.github.io/2017-КЛ_МКЛ/hfst.html)

This will take you through all of the main steps to build a transducer.