НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ
УНИВЕРСИТЕТ

# Morphological modelling

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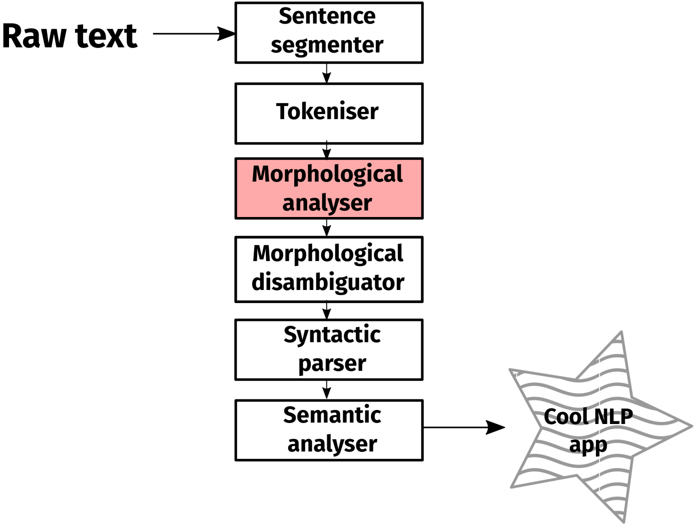
2 ноября 2018 г.

# Pipeline



Raw text

Sentence segmenter

Tokeniser

Morphological analyser

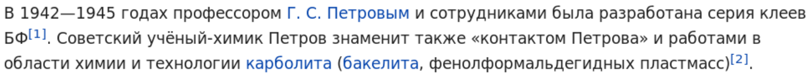
Morphological disambiguator

Syntactic parser

Semantic analyser

Cool NLP app

# The story so far



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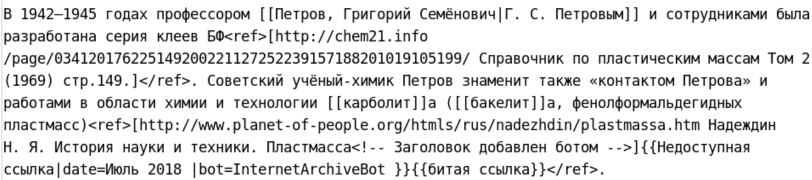

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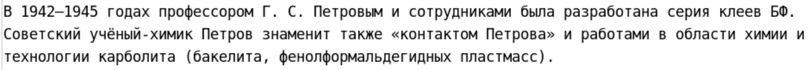

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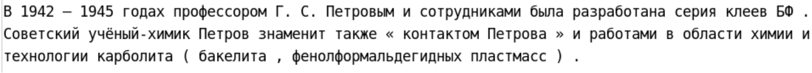

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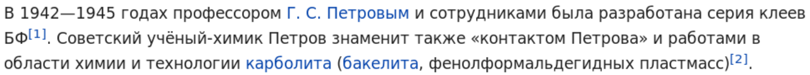

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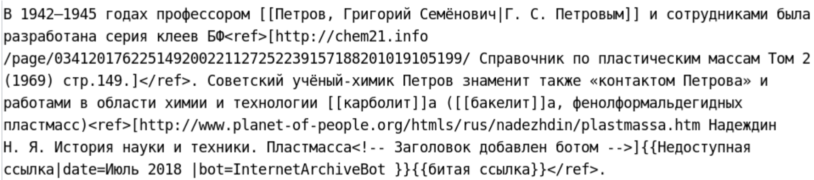

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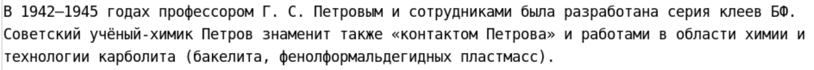

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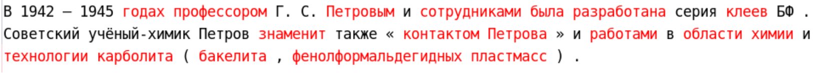

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```

# Overview

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

# Morphology

# What is 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.

# Why produce 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

# Lexicon

усалк|

рýсл|о, а, g. pl. р

① (river) bed, channel; из

change the course of a river.

② (fig.) (направление) channel, cours

в обычное р. to resume the norma

рýсск|ая, ой f. of ▶ ~ий as n.

рýсск|ий adj. Russian (also as n.

m.).

рýс|ый (~, ~а) adj. light brow

рути́н|а, ы f. (pej.) routine; rut

рýхляд|ь, и f. (collect.; coll.) j

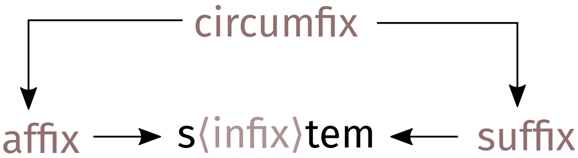
рýх|нуть, у, ешь pf. to cras

(fig.) (планы,

A morphological lexicon consists of entries:

- 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:

# Affixes



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'

# Morphological processes

- **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.

# Inflection

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’, *пысӑк·рах* ‘big-COMP’, *iso·mpi* ‘big-COMP’

In general: Change in meaning is regular.

# Derivation

Examples of derivational affixes:

- Actor: *diş·çi* /tooth-er/ ‘dentist’
- State: *boş·luk* ‘emptiness’, *пуст·ота* ‘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.

# Compounding

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

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*)

Should these be tokenised prior to analysis?

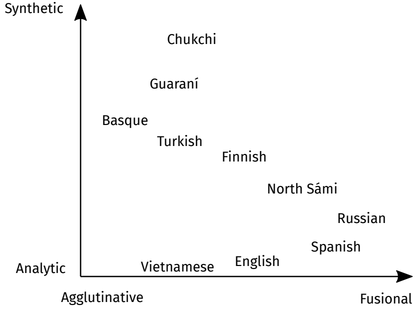
# Incorporation

*Гаӄорапэнратԓэн Сыкваӈаӄай рэмкык*
"Cıkwaŋaqaj chased after the reindeer in the other encampment."

| | | |
|---|---|---|
| га-ӄора-пэнр-ат-ԓэн | Сыкваӈаӄай | рэмк-ык |
| PERF-reindeer-chase-S3SG | Cıkwaŋaqaj | folk-LOC |

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

# Morphological typology



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

# Modelling

# Analysis and generation

**Analysis:**

студента → {`студент<n><m><aa><sg><gen>`,
`студент<n><m><aa><sg><acc>`}

**Generation:**

`студент<n><m><aa><sg><gen>` → студента

# Morphotactics

How morphemes can be combined:

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

# Morphophonology

The changes that happen when morphemes are combined:

- работа + ы → работы
- fox + s → foxes
- огонёк + и → огоньки

# Running example

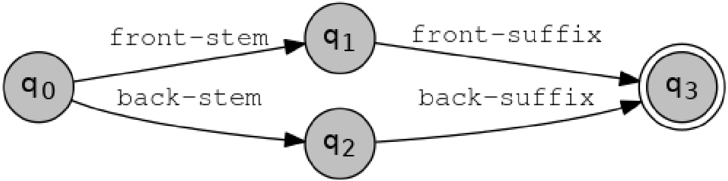
Let's take the Turkish words *ev* 'house', *kız* 'girl':

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

Suffixes are different according to front and back vowels.

# Finite-state morphology

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*)

# Lexicon format: `lexc`

```
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

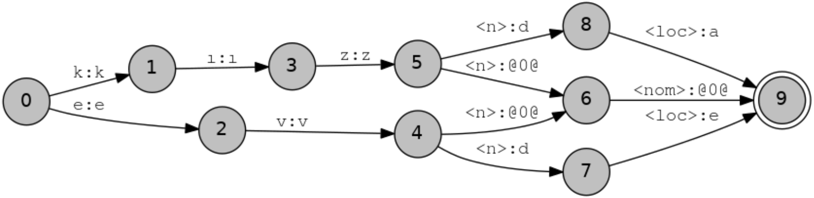
ev:ev front-suffix ; ! “house”

LEXICON back-stem

kız:kız back-suffix ; ! “girl”
```

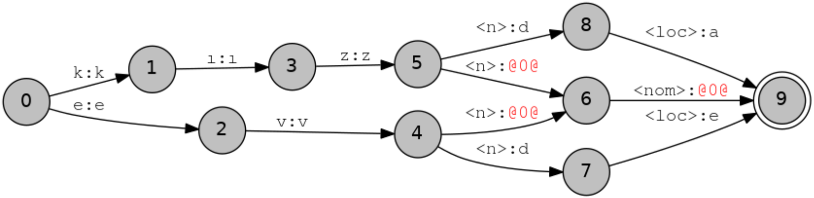
- Tags: Symbols that show grammatical information
- Continuation class: Sets of morphemes
- Next continuation: Shows where to go next
- **#**: End of string
- Comment string: Indicated with **!**

# Representing the lexicon



- $Q$ = Set of N states = $\{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$
- $\Sigma$ = Input alphabet = $\{$a, d, e, k, ı, v, z, $\epsilon\}$
- $\Delta$ = Output alphabet = $\{$e, k, ı, v, z, $<$ n $>$, $<$ nom $>$, $<$ loc $>\}$
- $q_0 \in Q$ = 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 $Q$

# Epsilons

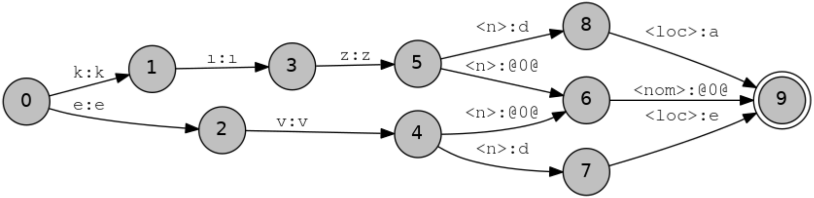


Sometimes we need to input or output a symbol without reading or writing an actual symbol.

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

**Epsilon closure**:

# Lookup



| Cur. state(s) | In. sym. | Out. state(s) | Out. sym | Out. string(s) |
|---|---|---|---|---|
| 0 | $\epsilon$ | 0 | – | – |
| 0 | k | 1 | k | k |
| 1 | $\epsilon$ | 1 | – | k |
| 1 | ı | 3 | ı | kı |
| 3 | $\epsilon$ | 3 | – | kı |
| 3 | z | 5 | z | kız |
| 5 | $\epsilon$ | 6 | <n> | kız<n> |
| 6 | $\epsilon$ | 9 | <nom> | kız<n><nom> |

# Archiphonemes

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 ;

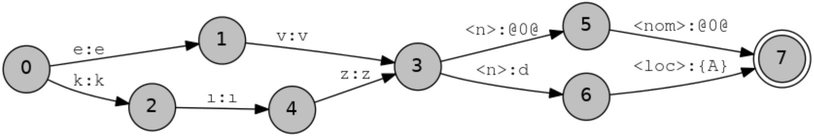
LEXICON suffix

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

LEXICON stems

ev:ev suffix ; ! “house”
kız:kız suffix ; ! “girl”
```

# Archiphonemes/2



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

# Tapes

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

| | | | | | | |
|---|---|---|---|---|---|---|
| **Lexical** | k | ı | z | 0 | <n> | <nom> |
| **Morphotactic** | k | ı | z | > | d | {A} |
| **Surface** | k | ı | z | 0 | d | a |

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

# Two-level rules

```
evd{A}:evde
evd{A}:evda                [apply rules]          evd{A}:evde
kızd{A}:kızde                    →                kızd{A}:kızda
kızd{A}:kızda
```

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

# Schema of a rule file

```
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
```

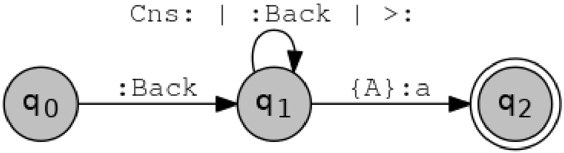
Three main sections:

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

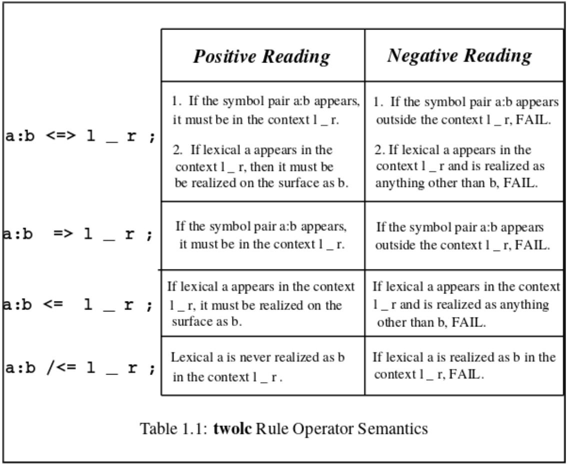
# Rule example: Vowel harmony

```
”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 operators



| | *Positive Reading* | *Negative Reading* |
|---|---|---|
| `a:b <=> l _ r ;` | 1. If the symbol pair a:b appears, it must be in the context l _ r.<br>2. If lexical a appears in the context l _ r, then it must be be realized on the surface as b. | 1. If the symbol pair a:b appears outside the context l _ r, FAIL.<br>2. If lexical a appears in the context l _ r and is realized as anything other than b, FAIL. |
| `a:b  => 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 <=  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 /<= 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

From `twolc.pdf` page 22

# Running example/2

Sometimes several rules can apply to the same form:

| | **Singular** | **Plural** |
|---|---|---|
| **Nominative** | ev, kız, baş | evler, kızlar, başlar |
| **Accusative** | evi, kızı, başı | evleri, kızları, başları |
| **Genitive** | evin, kızın, başın | evlerin, kızların, başların |
| **Dative** | eve, kıza, başa | evlere, kızlara, başlara |
| **Locative** | evde, kızda, başta | evlerde, kızlarda, başlarda |
| **Ablative** | 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%}` → `{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”
```

# Rule application process

### 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
```

# Rule application

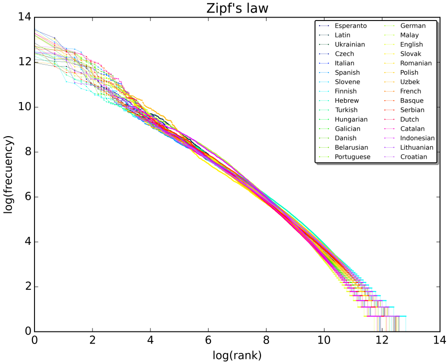
```
"Vowel harmony for archiphoneme {A}"
%{A%}:a <=> :Back [ Cns: | :Back | %>: ]* _ ;
```

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

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

# Development

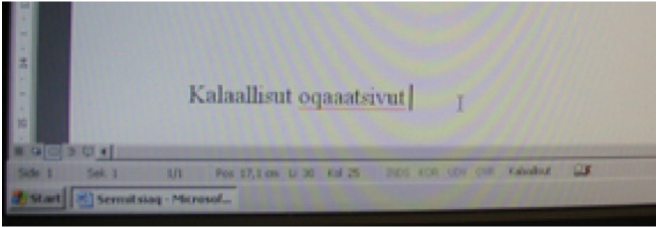
# Development guidelines



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

- Stems
- Morphemes
- Phonological rules

# Applications



Kalaallisut oqaaatsivut

- **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.

# What we have not covered

- **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[1] has examples of how to treat these
- **Machine learning approaches:**
  - Recent advances in morphological generation (SIGMORPHON)[2]
  - 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

[1] Beesley and Karttunen (2003) *Finite-State Morphology* (Chicago: CLSI)

[2] https://sigmorphon.github.io/sharedtasks/

# Practical

Go through the following practical:

https://ftyers.github.io/2017-КЛ_МКЛ/hfst.html

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