# Designing finite-state morphological transducers for Kypchak languages


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- Turkic languages (SOV, agglutinative, vowel harmony)

| | Kyrgyz /qɯrʁɯz/ | Kazakh /qazaq/ | Tatar /tʊtar/ | Kumyk /qumuq/ |
|---|---|---|---|---|
| classification | Eastern | Southern | Northern | Western |
| population of speakers | | | | |
| number | 3M | 8M-12M | 5.4M | 430K |
| primary | Kyrgyzstan | Kazakhstan | Tatarstan | Dagestan |
| secondary | China, etc. | China, Mongolia | Bashqortostan | — |
| external influences | | | | |
| Mongolic | moderate | moderate | light | light |
| Oghuz | — | — | light | moderate |
| Persian | heavy | heavy | heavy | heavy |
| Russian | heavy | heavy | heavy | heavy |

## Morphological transducers

- Efficient (in speed & size) models of a language's morphology
- Take a surface form, and produce valid lexical form(s)
- Take a lexical form, and produce valid surface form(s)

  алдым ↔ ал<v><tv><ifi><p1><sg>, алд<n><px1sg><nom>

## Transducers for Turkic languages

- Turkish (Çöltekin, 2010 & 2014; Oflazer, 1994)
- Crimean Tatar (Altuntaş, 2001)
- Turkmen (Tantuğ et al., 2006)
- Kazakh (Бекманова & Махимов, 2013)
- our Kyrgyz, Kazakh, Tatar, Kumyk: all GPL (=free and open)!

## Framework: HFST

- Reimplements Xerox FST formalisms (`lexc` & `twol`)
- Also provides a wrapper around popular free/open-source FST toolkits: SFST, OpenFST, and Foma

## Approach

- morphotactics implemented in `lexc`
- morphophonology implemented in `twol`
- compiled separately; compose-intersected to single transducer

  алдым ↔ ал>{D}{I}>м ↔ ал<v><tv><ifi><p1><sg>

  алдым ↔ алд>{I}м ↔ алд<n><px1sg><nom>

- Part of **Apertium Turkic** project:
  `http://wiki.apertium.org/wiki/Apertium_Turkic`
- Transducers available **live** at `turkic.apertium.org`
- **Source code** available from Apertium's svn repo
- Turkic RBMT **mailing list** (>25 subscribers):
  `apertium-turkic@lists.sourceforge.net`
  Feel free to post in any language!
- See our papers in LREC proceedings (2012: Kyrgyz, 2014: Kazakh, Tatar, Kumyk)
- And feel free to contact the authors any time!

## Gloss

(1)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Кудай | Өзү | жаратканынын | баарына | карап, | өтө | жакшы | экенин | көрдү. |
| Құдай | Өзінің | жаратқандарының | бәріне | қарап, | өте | жақсы | екенін | көрді. |
| Аллаһ | Үзе | яраткан | нәрсәләргә | карап, | аларның | бик | яхшы | икәнен | күрде. |
| Аллағь | Оьзю | яратғьан | затлагьа | къарап, | олар | бек | яхшы | экенин | гёрген. |
| God | own-his | created | [everything/thing-s]-to | looked.at, | they/their | very | good | being | saw. |

'*God looked at everything he had created and saw that it was very good.*' (Bible, Genesis 1:31)

## Output

| Kyrgyz (kir) | Kazakh (kaz) | Tatar (tat) | Kumyk (kum) |
|---|---|---|---|
| Кудай өзү жаратканынын баарына карап, өтө жакшы экенин көрдү. | Құдай Өзінің жаратқандарының бәріне қарап, өте жақсы екенін көрді. | Аллаһ Үзе яраткан нәрсәләргә карап, аларның бик яхшы икәнен күрде. | Аллағь Оьзю яратғьан затлагьа къарап, олар бек яхшы экенин гёрген. |
| Кудай<n><nom><br>Өз>prn><ref><px3sp><nom><br>жарат<v><tv><ger_past><px3sp><gen><br>бары<prn><qnt><px3sp><dat><br>кара<v><tv><gna_perf><br>,<cm><br>—<br>өтө<adv><br>жакшы<adj><br>э<cop><ger_past><px3sp><acc><br>көр<v><tv><ifi><p3><sg><br>.<sent> | Құдай<n><nom><br>Өз>prn><ref><px3sp><gen><br>жарат<v><tv><ger_past><pl><px3sp><gen><br>бәрі<prn><qnt><px3sp><dat><br>қара<v><tv><gna_perf><br>,<cm><br>—<br>өте<adv><br>жақсы<adj><br>е<cop><ger_past><px3sp><acc><br>көр<v><tv><ifi><p3><sg><br>.<sent> | Аллаһ<n><nom><br>Үз>prn><ref><px3sp><nom><br>ярат<v><tv><ger_past><br>нәрсә<n><pl><dat><br>кара<v><tv><gna_perf><br>,<cm><br>әлар<prn><pers><p3><pl><gen><br>бик<adv><br>яхшы<adj><br>и<cop><ger_past><px3sp><acc><br>күр<v><tv><past><p3><sg><br>.<sent> | Аллағь<n><nom><br>Оьз>prn><ref><px3sp><nom><br>ярат<v><tv><ger_past><br>зат<n><pl><dat><br>къара<v><tv><gna_perf><br>,<cm><br>олар<prn><pers><p3><pl><nom><br>бек<adv><br>яхшы<adj><br>э<cop><ger_past><px3sp><acc><br>гёр<v><tv><past><p3><sg><br>.<sent> |

## Tagset

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| `<n>` | Noun | `<iv>` | Intransitive | `<nom>` | 'Nominative' | `<sent>` | Sentence |
| `<v>` | Verb | `<tv>` | Transitive | `<gen>` | Genitive | `<past>` | Past (General) |
| `<prn>` | Pronoun | `<p3>` | Third person | `<acc>` | Accusative | `<ifi>` | Past (Eyewitness/Recent) |
| `<det>` | Determiner | `<pl>` | Plural | `<dat>` | Dative | `<px3sp>` | 3rd person poss. (Singular/Plural) |
| `<adj>` | Adjective | `<ref>` | Reflexive | `<qnt>` | Quantifier | `<gna_perf>` | Verbal noun (Past) |
| `<adv>` | Adverb | `<pers>` | Personal | `<cm>` | Comma | `<gna_perf>` | Verbal adverb (Perfect) |
| | | | | | | `<gpr_past>` | Verbal adjective (Past) |

## Desonorisation (kaz & kir)

- {N} desonorises to д after a consonant

  алма-{N}{I} → алманы '*apple*–ACC'

  сыр-{N}{I} → сырды '*secret*–ACC'
- {L} desonorises to д after cons. of sonority ≤ /l/

  сыр-{L}{A}р → сырлар '*secret*–PL'

  кыз-{L}{A}р → кыздар '*girl*–PL'

```
"L Desonorisation"
%{L%}:д <=> :VoicedLowSonCns %>: __ ;

"N Desonorisation"
%{N%}:д <=> :VoicedCns %>: __ ;
```

## Epenthesis

- Turn {y} into a harmonised high vowel when a vowel doesn't follow the following consonant:

  мур{y}н → мурун '*nose*'

  мур{y}н+{I}м → мурдум '*my nose*'

```
%{y%}:Vy <=> [ :LastVowel :Cns* :Cns ]/[:0] _
             [ :Cns [ .#. | :Cns ] ]/[ :0 | %>:] ;
 where Vy in ( и ү и и ү ы ы у у ы у у )
LastVowel in ( и ү е э ө я а ё о ы ю у )
             matched ;
```

- HFST transducers are trivially converted to **spell checkers**
- Segmenter, e.g. көрүшкөндөрүмдөнсүнбү :

  көр>{I}ш>{G}{A}н>{L}{A}р>{I}м>{D}{A}н>с{I}ң>{B}{I}

## Morphological & orthographical words

- өнүктүрөбүзбү ? *'will we develop [it]?'*

  өнүк<v><tv><caus><aor><p1><pl>+бы<qst>
- келатсаң '*if you come*'

  кел<v><iv><prc_impf>+жат<vaux><gna_cnd><p2><sg>

## Irregular [noun + possessive + case] forms

- Some combinations of possessive + case morphemes are unpredicted (i.e., not formed simply by concatenation and application of phonology):

| case | form | 1SG | 2SG | 3SP |
|---|---|---|---|---|
| nominative | — | -(I)м | -(I)ң | -(с)I |
| accusative | -NI | -(I)мдI | -(I)ндI | **-(с)Iн** |
| genitive | -NIн | -(I)мдIн | -(I)ндIн | -(с)IнIн |
| locative | -DA | -(I)мдA | -(I)ндA | **-(с)IндA** |
| ablative | -DAн | -(I)мдAн, **-(I)мAн** | -(I)ндAн, **-(I)ңAн** | **-(с)IнAн** |
| dative | -GA | **-(I)мA** | **-(I)ңA** | **-(с)IнA** |

A,I,N,D,G have various allophones; (I) null after vowels; (с) null after cons.

- underlying `<px3sp>` form used: {s}{I}{n}
- {s} and {n} default to с and н; rules map to null by context
- morphophonology more complicated, morphotactics simpler

## Noun-noun compounds

- a N-N compund type: N2 has `<px3>` and related morphology e.g., аба ырайы`<n><loc>`: аба ырайында, *аба ырайыда

```
LEXICON N-INFL-3PX-COMPOUND
%<n%>:%>%{S%}%{I%}%{n%} GEN-POS ;

LEXICON Nouns
аба% ырайы:аба% ырай N-INFL-3PX-COMPOUND ;
                                    ! "weather"
чакыруу% кагазы:чакыруу% кагаз N-INFL-3PX-COMPOUND
                                    ; ! "invitation"
```

## Ambiguous characters

- Have front- and back-vowel readings in native words

| | letters | values | examples |
|---|---|---|---|
| **kaz** | и, у, ю | /ǝj, ǝw, jǝw/<br>/ǝj, ɔw, jɔw/ | киюда '*chopping down*'<br>киюде '*getting dressed*' |
| **tat** | е | ə / C _<br>/j/+ы<br>/j/+ə | дәреслəр '*lessons*'<br>еллар '*years*'<br>егетлəр '*boys*' |
| **kum** | ё, ю | /ø, y/ / C _<br>/jø, jy/<br>/jo, ju/ | гюнлер '*days*'<br>гёзлер '*eyes*'<br>юреклер '*hearts*'<br>ёнкюлер '*darlings*'<br>юлдузлар '*stars*'<br>ёллар '*roads*' |

- solution: hairy `twol` rules cover majority of examples
- unaccounted-for words get a harmony-forcing character
- adjust rules for harmony-forcing characters

## Loanwords

- Letters that represent front vowels in native words may represent "back" vowels in Russian words

| | native word example | Russian word example |
|---|---|---|
| **kaz** | елдің '*country's*' | Назарбаевтың '*Nazarbayev's*' |
| **tat** | галимнәр '*scientists*' | артистлар '*artists*' |
| **kum** | сёзлер '*words*' | самолётлар '*airplanes*' |

- solution: separate continuation lexicon (messy rules)

```
LEXICON N1-RUS
:%{а%} N1 ;

LEXICON Nouns
артист:артист N1-RUS ; ! "artist"
галим:галим N1 ; ! "scientist"
```

## Acronyms and numerals

- `twol` rules handle phonology for spelt-out words

  отыздан '*from thirty*', бестен '*from five*'
- no phonological triggers available in numerals (incorrect phonological triggers in acronyms)

  30-дан '*from 30*', 5-тен '*from 5*'
- solution: phonology-triggering characters
- simplified: e.g., {c} for all voiceless ostruents

```
4:4%{э%}%{с%} NUM-DIGIT ; ! "төрт"
5:5%{э%}%{с%} NUM-DIGIT ; ! "бес"
3%0:3%0%{а%}%{э%} NUM-DIGIT ; ! "отыз"
```

## й + vowel letters

- [ а о у ] become [ я ё ю ] after й and й deletes
- й incorporated into the context of many rules
- additional rules to change the characters and delete original й

```
"Deletion of й before yoticised vowels"
й:0 <=> __ [ :YotVow ]/[ :0 | %>: ] ;
```

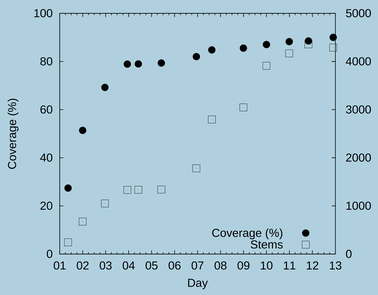
## A resulting messy `twol` rule

```
RdYotVow = ё ю Ё Ю ;
AbstractVow = %{а%} %{э%} %{у%} %{о%} ;

"A front unrounded harmony"
%{А%}:е <=>                [ [ :FrontVow | [ :Vow :ь ] ] :Cns :Cns* ]/:0 _ ;
                           [ [ :RdVow :ь ] :Cns :Cns* ]/:0 _ ;
                  [ [ [ \[ .#. | :Vow ] ] :RdYotVow ] :Cns :Cns* ]/:0 _ ;
                  [ :RdYotVow й:0 :RdYotVow :Cns :Cns* ]/[ :0 - й:0 ] _ ;
          [[%{э%}:0|%{у%}:0] :Cns* ]/[[ :0 - AbstractVow: ]  | %>: ]  ;
        except
                  [ :RdYotVow :Cns* %{а%}:0 :Cns* ]/[ :0 - %{а%}:0 ] _ ;
                                          [ :Cns :р %{а%}:  %>:  :Cns* ]/:0 _ ;
                    [ [ :Vow - :RdYotVow ] :RdYotVow :Cns :Cns* ]/:0 _ ;
                                          [ :Vow ]/[ [ :0 - й:0 ] | %>: ]  _ ;
```

| | Kyrgyz | Kazakh | Tatar | Kumyk |
|---|---|---|---|---|
| begun | Apr. 2011 | Dec. 2010 | Dec. 2011 | Oct. 2013 |
| 80% cov. | Aug.? 2011 | Aug. 2012 | Aug. 2012 | Oct. 2013 |
| time | 4 months | 19 months | 7 months | 1 week |

- Kazakh transducer based on Kyrgyz transducer
- Kumyk transducer based on Kazakh, Tatar transducers
- ~1 week to reach 80% coverage, +1 week to reach 90%




## Adjectives

- morphologically distinct adjective classes
- most sources: adjectives can be used substantively and adverbially
- Other Turkic transducers: `0`-derivation (overgenerates)
- but not all adjectives have all of the following: comparative forms, substantive readings, adverbial readings
- Our approach: categorisation
- if properly categorised, only correct forms are analysed and generated

| Type | Gloss | `<adj>(<comp>)` | `<adj>(<comp>)<subst>` | `<adj>(<comp>)<advl>` |
|---|---|---|---|---|
| **A1** | '*good*' | яхшы (яхшырак) | яхшы (яхшырак) | яхшы (яхшырак) |
| **A2** | '*old*' | иске (искерәк) | иске (искерәк) | — (—) |
| **A3** | '*dead*' | үле (—) | үле (—) | — (—) |
| **A4** | '*basic*' | төп (—) | — (—) | — (—) |

## Adverbs

- Certain time adverbs have special attributive and genetive forms

  бүгүн, быйыл, кече, жана,

## Number of stems

| Part of speech | Number of stems | | | |
|---|---|---|---|---|
| | Kyrgyz | Kazakh | Tatar | Kumyk |
| Noun | 4582 | 2640 | 2795 | 2568 |
| Verb | 1193 | 1470 | 1143 | 386 |
| Adjective | 1211 | 754 | 816 | 219 |
| Proper noun | 5887 | 5701 | 5361 | 1443 |
| Adverb | 312 | 171 | 177 | 63 |
| Numeral | 66 | 63 | 63 | 44 |
| Conjunction | 77 | 46 | 45 | 13 |
| Postposition | 50 | 50 | 43 | 12 |
| Pronoun | 51 | 32 | 28 | 17 |
| Determiner | 64 | 39 | 34 | 9 |
| Total: | 13749 | 11224 | 10737 | 4845 |

## Test corpora

| | Wikipedia | News | Religion |
|---|---|---|---|
| **Kyrgyz** | Wikipedia | azattyk.org | Bible |
| **Kazakh** | Wikipedia | azattyq.org | Quran + Bible |
| **Tatar** | Wikipedia | tat.tatar-inform.ru | Quran + New Testament |
| **Kumyk** | — | yoldash.etnosmi.ru | Genesis + New Testament |

## Evaluation measures

- **Naïve coverage** - percentage of surface forms in a given corpus receiving ≥ 1 analysis
- **Mean ambiguity** - average number of analyses for each surface form found in analysed corpus
- **Precision** - probability that a provided analysis is valid
- **Recall** - probability that a certain valid analysis is among those provided by the transducer

## Evaluation results

| | Corpus | Tokens | Coverage (%) | Amb. |
|---|---|---|---|---|
| **Kyrgyz** | Wikipedia | 5.3M | 84.51 ± 2.27 | 3.56 |
| | News | 4.1M | 91.43 ± 0.51 | 4.19 |
| | Religion | 215K | 91.66 ± 1.81 | 3.99 |
| (r54474) | Average | | 89.20 ± 3.48 | 3.91 |
| **Kazakh** | Wikipedia | 25.6M | 85.61 ± 1.37 | 2.43 |
| | News | 3.8M | 92.12 ± 2.72 | 2.88 |
| | Religion | 851K | 92.49 ± 1.66 | 2.63 |
| (r50547) | Average | | 90.07 ± 1.91 | 2.64 |
| **Tatar** | Wikipedia | 159K | 86.35 ± 2.17 | 2.24 |
| | News | 5.2M | 89.75 ± 0.07 | 2.30 |
| | Religion | 382K | 91.25 ± 2.55 | 2.24 |
| (r50260) | Average | | 89.12 ± 1.60 | 2.26 |
| **Kumyk** | News | 286K | 91.10 ± 0.86 | 1.53 |
| | Religion | 227K | 92.47 ± 1.03 | 1.53 |
| (r50300) | Average | | 91.78 ± 0.94 | 1.53 |

- selected & proofed unique random surface forms from news corpora

| Language | Forms | Precision (%) | Recall (%) |
|---|---|---|---|
| Kyrgyz | 500 | | |
| Kazakh | 1000 | 98.61 | 57.98 |
| Tatar | 1000 | 95.03 | 85.65 |
| Kumyk | 500 | 96.57 | 69.11 |

- Disambiguation, more stems, clean up transducers
- Machine translation between these languages
- Bring other Kypchak transducers to comparable performance: Qaraqalpaq, Bashqort, Nogay, Crimean Tatar
- Other Turkic lgs: Uzbek, Uyghur, Chuvash, Yakut, Tuvan, etc.