A Finite-State Morphological Analyser for Tuvan

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Abstract
This paper describes the development of free/open-source finite-state morphological transducers for Tuvan, a Turkic language spoken in and around the Tuvan Republic in Russia. The finite-state toolkit used for the work is the Helsinki Finite-State Toolkit (HFST), we use the lexc formalism for modelling the morphotactics and twol formalism for modelling morphophonological alternations. We present a novel description of the morphological combinatorics of pseudo-derivational morphemes in Tuvan. An evaluation is presented which shows that the transducer has a reasonable coverage—around 93%—on freely-available corpora of the languages, and high precision—over 99%—on a manually verified test set.

Keywords: morphological analysis, finite-state transducers, Tuvan

1. Introduction
This paper describes the development of a morphological transducer for Tuvan. The paper is laid out as follows: §2. gives a short introduction to Tuvan and §3. describes some prior work on computational linguistics for Tuvan. Then §4. documents how a number of issues related to mor-photactics (§4.2.) and morphophonology (§4.3.) were dealt with. An evaluation of the transducer is provided in §5., and §6. outlines future work related to the transducer.

2. Language
Tuvan (demonym tɯβɑ) is the largest member of the Sayan branch of Turkic languages. It is an official language of the Tuva Republic (in Southern Siberia, within the Russian Federation, see figure 1), and is also spoken in the surrounding areas. Russia’s 2010 census (Poccrar, 2011) recorded over 250,000 Tuvan speakers, and Lewis et al. (2015) report about 27,000 speakers in Mongolia and about 2,400 in China. Many Tuvan speakers also know Russian, Mongolian, or Chinese, depending on which country they are from.

Like other Turkic languages, Tuvan exhibits a rich system of agglutinating morphology, replete with productive and idiosyncratic morphotactics and morphophonology. There have been a number of grammars written for Tuvan, including a large academy grammar in Russian (Нсхаакоф и Пальмбах, 1961), and a grammar sketch in English (Anderson and Harrison, 1999).

3. Prior work
Very little work has been done on computational linguistics for Tuvan, even basic resources are lacking. Of the two publications on computational linguistics, we find one paper on proposing a tagset for the Tuvan National Corpus (Bayyr-ool and Voinov, 2012), and one Bachelor’s thesis on Tuvan–English statistical machine translation (Killackey, 2013). The analyser presented in this paper does not follow the tagset designed by Bayyr-ool and Voinov (2012), and instead uses a pan-Turkic tagset being adopted by the Aper-tium project. It is worth noting however that our tagset is a superset of the tagset of Bayyr-ool and Voinov (2012), that is it makes more distinctions rather than fewer distinctions, and as such conversion from our tagset to theirs would be feasible.

4. Development
4.1. Background
The transducer is designed based on the Helsinki Finite State Toolkit (Linden et al., 2011) which is popular in the field of morphological analysis. It implements both the lexc formalism for defining lexicons, and the twol and xfst formalisms for modelling morphophonological rules. This toolkit has been chosen as it has been widely used for other Turkic languages, such as Turkish (Cöltekin, 2010), Kyrgyz (Washington et al., 2012), Kazakh, Tatar, and Kumyk (Washington et al., 2014), and is available under a free/open-source licence.

4.2. Morphotactics
Tuvan morphotactics, like that of other Turkic languages is characterised by a concatenative suffixing morphology, with a large number of inflectional and derivational morphemes.

1http://www.apertium.org
4.2.1. Nominal

The nominal morphotactics, used for modelling the inflection of nouns and substantivised adjectives, is essentially identical to that in use in previous transducers for Turkic languages (Washington et al., 2014, 2012). One difference in Tuvan compared to Kypchak Turkic is the presence of two allative morphemes, -же and -ДИвА. These were added in the case lexicon alongside the other case morphemes.

4.2.2. Verbal

While a substantial amount of the nominal morphotactics used in the Tuvan transducer were able to be copied from Kypchak transducers, Tuvan verbal morphology is quite different from that of Kypchak, so the verbal morphotactics for the Tuvan transducer had to be written entirely from scratch. We based the verbal morphotactics on the system described in Anderson and Harrison (1999). This grammar describes the use of many morphemes, but does not include a description of their combinatorics; to our knowledge there is no existing description of the combinatorics of Tuvan verbal pseudo-derivation and inflectional morphemes. So, we developed a model using field-work techniques. We learned that a series of pseudo-derivation morphemes can immediately follow the verb stem, in turn followed by inflectional suffixes. Figure 2 describes a preliminary model of how the pseudo-derivation morphemes can be combined. The inflectional suffixes which follow each “group” of pseudo-derivation morphemes are summarised later in Table 1.

Figure 2: Preliminary verb morphotactics for inflectional and pseudo-derivation affixes. The inflectional affix groups are described in Table 1.

The pseudo-derivation morphemes identified in Tuvan are not true derivational morphemes. They appear to be almost entirely productive, and do not form new parts of speech. However, the types of verbal morphology that may follow are not the same for each group. The affixes presented in Figure 2 are outlined below:

-ЖИГА: Iterative, expressing “to do something a little bit.”

-БА: Negative, expressing one way to negate verbs. Мен ол номну номчудукым. ‘I did not read that book.’

-ИВУТ: Perfective, having a number of different uses, for example “to do something for a short while” and “to do something to completion”.

There are two basic types of inflectional affix used with verbs in Tuvan: ones that create finite verb forms and ones that create non-finite verb forms. Traditional grammars of Tuvan concede that there is some overlap between these classes (i.e., some morphemes can create both finite and non-finite forms). The traditional classification of non-finite forms centres around two Russian terms: “причастие” (often translated as participle) and “деепричастие” (often translated as adverbial participle, converb or gerund). Translations for these terms vary, but they refer to verb forms that are attributive, and subordinate, respectively.

Non-finite forms may be further divided based on a more nuanced understanding of their syntactic function. The non-finite verbal morphemes create verb forms that can function substantivally, attributively, adverbially, and as dependent on an auxiliary. We refer to these forms, respectively, as verbal nouns, verbal adjectives, verbal adverbs, and participles.

Finite: Finite verb forms function as independent clauses, and are hence the only form of verbs that can form their own predicate [without depending on a copula or another verb form]. All finite forms in Tuvan take person and number agreement with the subject, but are not the only verb forms that may.

Non-finite: Non-finite forms form dependent clauses; that is, they rely on another word form to be integrated into an independent clause.

Participle: These are verb forms that act as a single predicate when combined with an auxiliary verb. Participles form the root of a verb phrase, and are used in the creation of “compound verb tenses”. Participles in Tuvan almost never take person/number agreement. Съм иштин тур мен ‘I am drinking milk.’

Substantive (verbal noun): Verbal nouns are forms of verbs that allow a verb phrase to be used as a noun phrase, e.g., as a complement clause or subject of another verb. They may take person/number agreement in the form of nominal

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2Another level of pseudo-derivation morphemes exists, which for the purposes of this paper simply form new stems: passive, causative, and cooperative. These affixes are not nearly as productive as the ones described here, but they still probably do not constitute true derivation.

3While we understand that these terms may be unconventional, they represent a convenient, principled way to sub-divide non-finite forms. Note that while they are termed e.g. verbal nouns, we do not consider them to be e.g. nouns, but e.g. substantivised verbs.

4These are also referred to as “auxiliary verb constructions.”
rules in the transducer, totaling nearly 400 lines of code (not counting commented or empty lines).

The morphophonology of Tuvan is in many ways quite similar to that of other Turkic languages, with phenomena such as voicing assimilation across morpheme boundaries, front/back vowel harmony, phonologically conditioned alternations between certain allomorphs that cannot be explained purely by the phonology of the language, phonologically conditioned epenthesis, and consonant desonoration. There are a number of alternations that are purely due to orthographic convention (such as ⟨я⟩ standing in for what would otherwise be ⟨й⟩) and complications due to the presence of many Russian borrowings, which are quite frequently left in their original orthography. Because of the similarities of these issues to those encountered in the development of transducers for other Turkic languages (especially those with Cyrillic orthographies), the specific strategies used in previous Turkic transducers to deal with these issues were largely able to be applied in the development of the Tuvan transducer.

A number of challenges specific to Tuvan were dealt with, including the specific treatment of certain types of Russian loanwords in terms of vowel harmony, a nuanced process (or set of processes) of velar deletion, and a range of phonological changes that occur during epenthesis. In Tuvan, there are processes of both front-back vowel harmony and rounding vowel harmony, whereby the backness and/or roundedness of an affix vowel is determined by that of the previous vowel. While harmonising high vowels (represented by the archiphoneme (I)) acquire their backness and roundedness from the previous vowel, low affix vowels that undergo vowel harmony (represented by the archiphoneme (A)) are always unrounded, and only acquire their backness from the previous vowel. In some Russian loanwords in Tuvan, however, affix vowels harmonise as front and unrounded, despite the previous vowel being back and sometimes rounded. Specifically, harmonising affixes

4.3. Morphophonology

Using HFST, morphophonology is mostly dealt with by assigning special segments in the morphotactics (lexc) which are used as the source, target, and/or part of the conditioning environment for two rules. Currently there are 61 two rules in the transducer, totaling nearly 400 lines of code (not counting commented or empty lines).

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5For a more detailed account of Tuvan vowel harmony, see Anderson and Harrison (1999, pp. 4–6).

| Affix | Trad. class | Group I | Group II | Group III | Group IV | Group V | Group VI | Group VII | Type
|-------|-------------|---------|----------|-----------|----------|---------|----------|-----------|--------|
| -DI   | fin.        | +       | +        | +         | +        | +       | +        | +         | FIN    |
| -Jk   | fin.        | +       | +        | +         | +        | +       | +        | +         | SUBS   |
| -ZA   | fin.        | +       | +        | +         | +        | +       | +        | +         | ATTR   |
| -GIde | fin.        | +       | +        | +         | +        | +       | +        | +         | ADVL   |
| -GAй  | fin.        | +       | +        | +         | +        | +       | +        | +         | PRC    |
| -Глэц | fin.        | +       | +        | +         | +        | +       | +        | +         |        |
| -Ап   | pri., fin.  | +       | +        | +         | +        | +       | +        | +         |        |
| -ГАн  | pri., fin.  | +       | +        | +         | +        | +       | +        | +         |        |
| -ГАЛак| pri., fin.  | +       | +        | +         | +        | +       | +        | +         |        |
| -Blac | deep.       | +       | +        | +         | +        | +       | +        | +         | FIN    |
| -GAй  | deep.       | +       | +        | +         | +        | +       | +        | +         | SUBS   |
| -In   | deep.       | +       | +        | +         | +        | +       | +        | +         | ATTR   |
| -E    | deep.       | +       | +        | +         | +        | +       | +        | +         | ADVL   |
| -ГАЛА | since       | +       | +        | +         | +        | +       | +        | +         | PRC    |

Table 1: Inflectional affix possibilities after given combinations of pseudo-derivational morphemes. The groups correspond to the inflectional groups after a given combination of pseudo-derivational morpheme (see Figure 2). The type corresponds to the syntactic function of the form in a given group. The traditional classification (trad. class) corresponds to either finite (fin.), ‘deepпричастие’ (deep.), or ‘причастие’ (pri.).

For an example of how to read Figure 2 and Table 1, consider the following word: чурттасанас мен ‘I would not like to live’, the stem is чурттама- ‘live’, this is followed by the pseudo-derivational desiderative morpheme -ксA-, which is in turn followed by the negative morpheme -BA-. After the negative morpheme we look up the inflectional group following the combination -ксA-BA-, which is group v, and find in Table 1 that the next suffix is -c which is the negative allomorph of the aorist, this is then followed by men which is the first person singular finite agreement.

Adjectival (verbal adjective): Verbal adjectives are forms of verbs that allow a verb phrase to be used as an adjectival phrase. They sometimes may further be substantivised, in which case they take a limited set of nominal morphology, but otherwise they do normally have no further morphology. Бир дугаар көрдүм. ‘I saw the person who came one time.’

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immediately following words ending in \( \text{бль} \), such as an-
самъбъ ‘ensemble’ and рубль ‘rouble’, are always front and
unrounded. Table 2 provides an example comparing forms
of медаль ‘medal’ and рубль ‘rouble’ to corresponding
forms of ансамбль ‘ensemble’ and рубль ‘rouble’.

| stem     | V | C | dative | genitive |
|----------|---|---|--------|---------|
| медаль   | а | ль | медальгъа | медальдын |
| ансамбль | а | бль | ансамбльге | ансамбльдън |
| рубль    | у | ль | рубльгъа | рубльдън |
| рубль    | у | бль | рубльдо | рубльдън |

Table 2: A comparison of the result of back and rounding vowel harmony of both (A) (in the dative suffix) and (I) in stems ending in both ль and бль

The fact that the harmonised vowel is always front and unrounded is presumably related to a pronounced—but
unwritten—epenthetic vowel that occurs between бь and
лъ in the bare stem forms. However, since no vowel is
inserted in forms with a following vowel (e.g., ансамбль, рубль), this phenomenon provides an interesting case of
phonological opacity—an analysis of which is beyond the
scope of the present paper. Our implementation of this phe-
omenon in the transducer involved creating a two-rule
specific to stems in бль, as well as exceptions to the nor-
mal vowel harmony rules matching the same environment,
as shown in figure 3. To our knowledge, this aspect of Tu-
van morphophonology has not been documented elsewhere.

"(I) harmony"

\[
\text{\{I\}}: \text{Y} \rightarrow \text{\{VX: :Cns\} \rightarrow :0 \} \mid \text{\{I\}} \}
\]

except

\[
[ \text{\{BackVow: :Cns: \} \rightarrow \text{\{Vow: :Cns\} \rightarrow :0\}} ;
\]

where \text{\{Vow: :Cns\} \rightarrow \text{\{Vow: :Cns\} \rightarrow :0\}} \}

"(I) always front when intervening Cns"

\[
\text{\{I\}}: \text{x} \rightarrow \text{\{BackVow: :Cns: \} \rightarrow \text{\{Vow: :Cns\} \rightarrow :0\}} ;
\]

where \text{\{Vow: :Cns\} \rightarrow \text{\{Vow: :Cns\} \rightarrow :0\}} \}

Figure 3: A general rule for vowel harmony with exceptions for stems ending in бль (emphasised in black), and an additional rule to harmonise as front unrounded. The rules are simplified some-
what from the actual code for purposes of demonstration.

Descriptions of Tuvan morphophonology, including An-
derson and Harrison (1999, pp. 22–23) and Искаков
and Пальмбах (1961, pp. 117–118), have documented a
widespread and productive process of stem-final velar
deletion in Tuvan. In short, this process results in the voicing of
къ intervocalically at the end of monosyllabic stems (e.g.,
\( /\text{ок}:\{I\} / \rightarrow /\text{я}:\{I\} / \)). The deletion of \( /\text{ок}:\{I\} / \) at the
end of multisyllabic stems (e.g., /\text{инек}:\{I\} / \rightarrow /\text{инэ}:\{I\} /),
and the deletion of \( /\text{р}:\{I\} / \) intervocalically at the end of stems of any
length (e.g., /\text{ор}:\{I\} / \rightarrow /\text{о}:\{I\} /). In addition to two rules that
deal with these specific deletion phenomena, rules (along
with exceptions to other rules) had to be implemented to
create the long monophthongs that result from a consonant
being lost between two potentially different vowels. In
addition to these rules, it was found that the velar nasal \( /\text{н}:\) also deletes intervocally in stem-final position in some
(but not most) words in Tuvan (e.g., /\text{сон}:\{I\} / \rightarrow /\text{с}:\{I\} /). To
account for this, the rule for \( /\text{н}:\) deletion was expanded to apply to \( /\text{н}:\). Stems where \( /\text{н}:\) is not deleted were marked
with a special archiphoneme, which is normally used for
loanwords, and an exception to the environment for this ex-
expanded rule was created so that it did not apply to these
stems. The resulting set of rules is provided in figure 4.

"Intervocalic voiced velar deletion"

\[\text{C:0} \rightarrow \text{Vow: :Cns*} \mid \{\text{Vow: :0\}} ; \]

except

\[\text{Vow: :0\}} \mid \{\text{Vow: :0\}} \mid \{\text{Vow: :0\}} ; \]

"Intervocalic voiceless velar deletion"

\[\text{C:0} \rightarrow \text{Vow: :Cns*} \mid \{\text{Vow: :0\}} ; \]

except

\[\text{Vow: :0\}} \mid \{\text{Vow: :0\}} \mid \{\text{Vow: :0\}} ; \]

Figure 4: The rules that deal with intervocalic deletion, with the
exception that blocks deletion in stems where \( /\text{н}:\) does not delete
emphasised in black. The exception in the voiceless deletion rule is
the environment where voicing of \( /\text{н}:\) occurs in monosyllabic
stems. The rules are somewhat simplified from the actual code.

Like most Turkic languages, Tuvan has a small number of
stems which receive an epenthetic vowel between the
last two consonants when a vowel doesn’t follow. The
epenthetic vowel is always high, and harmonises in front-
ness and roundness to the previous vowel of the stem, it-
self becoming the vowel to which following vowels har-
nomise. In addition to the presence of absence of a vowel,
the consonants on either side of it may witness various alter-
ations based on their prosodic position (e.g., syllable-final
versus intervocalic) or proximity to other segments (e.g.,
whether a voiceless consonant precedes it or a voiced con-
sonant or vowel precedes it). Some examples are illustrated
in table 3. Besides simple epenthesis, processes of inter-
volcalic voicing, desonorisation, fortition, and nasal assim-
lilation are all found. Because writing a rule to change an
empty space into a character is dangerous in two�, a place-
holder “archiphoneme” character (и) was used that either
surfaces as zero or as a harmonised epenthetic vowel.
The lexce entries containing this character are shown in the
table. Rules to harmonise the vowel, “combine” it with it to form
и if it was rounded, and deal with the various consonant
issues, were all implemented.

Table 3: Some examples of words with epenthetic vowels. Pre-
sented are the citation form, a proposed underlying representation
(UR), the entry used in the lexicon file (lexc), and a form of the
stem with following vowel-initial morphology. For purposes of
comparison with the citation form and UR, the stems have been
highlighted in bold in the forms with a following vowel.

4.4. Lexicon

The lexicon was compiled semi-automatically. Words were
added to the lexicon by frequency, based on frequency lists
from the corpora described in section 5.1. In order to determine the part of speech, the Russian description in the Tuvan–Russian dictionary by Тенишев (1968) was used.

| Part of speech | Number of stems |
|----------------|-----------------|
| Noun           | 4226            |
| Proper noun    | 4217            |
| Adjective      | 1603            |
| Verb           | 1064            |
| Adverb         | 136             |
| Numeral        | 85              |
| Conjunction    | 70              |
| Postposition   | 28              |
| Pronoun        | 35              |
| Determiner     | 26              |
| Total:         | 11,490          |

Table 4: Number of stems in each of the main categories.

5. Evaluation

We have evaluated the morphological analysers in two ways. The first was by calculating the naïve coverage and mean ambiguity on freely available corpora. Naïve coverage refers to the percentage of surface forms in a given corpus that receive at least one morphological analysis. Forms counted by this measure may have other analyses which are not delivered by the transducer. The mean ambiguity measure was calculated as the average number of analyses returned per token in the corpus.

5.1. Corpora

We have selected corpora from five domains to be used in the evaluation of the morphological analyser. From the encyclopaedic domain we have selected the Tuvan Wikipedia. From the news domain, the archives of the Tuvan daily News. From the religious domain we have used the Tuvan translation of the New Testament. The two additional domains were literature and folklore.

| Domain | Tokens | Coverage (%) |
|--------|--------|--------------|
| News   | 1,539,459 | 95.73       |
| Religion | 746,124   | 93.84       |
| Literature | 297,830  | 91.96       |
| Encyclopaedic | 276,547  | 90.86       |
| Folklore | 27,902    | 91.57       |
| Average |        | 92.79       |

Table 5: Corpora used for naïve coverage tests

5.2. Precision and recall

Precision and recall are measures of the average accuracy of analyses provided by a morphological transducer. Precision represents the number of the analyses given for a form that are correct. Recall is the percentage of analyses that are deemed correct for a form (by comparing against a gold standard) that are provided by the transducer.

To calculate precision and recall, it was necessary to create a hand-verified list of surface forms and their analyses. We extracted 1,500 unique surface forms at random from a Wikipedia corpus, and checked that they were valid words in the languages and correctly spelled. Where a word was incorrectly spelled or deemed not to be a form used in the language, it was discarded. This list of surface forms was then analysed with the most recent version of the analyser, and each analysis was checked. Where an analysis was erroneous, it was removed; where an analysis was missing, it was added. This process gave us a ‘gold standard’ morphologically analysed word list of 1,425 forms. The list is publically available for each language in Apertium’s SVN repository.

We then took the same list of surface forms and ran them through the morphological analyser once more. Precision was calculated as the number of analyses which were found in both the output from the morphological analyser and the gold standard, divided by the total number of analyses output by the morphological analyser.

Recall was calculated as the total number of analyses found in both the output from the morphological analyser and the gold standard, divided by the number of analyses found in the morphological analyser plus the number of analyses found in the gold standard but not in the morphological analyser.

The results for precision and recall are presented in table 6.

Table 6: Precision & recall over all tokens and only known tokens.

5.3. Qualitative

Along with calculating the precision and recall, we also performed a qualitative evaluation using the gold standard data. We looked at each word where an error was found and categorised the error into five types: missing stem, wrong categorisation, bad morphotactics, bad phonology and other. The other category included Russian words not used in Tuvan, spelling mistakes, and tokenisation errors. These errors are summarised in Table 7.

An example of bad phonology would be the word *оюнүн* ‘game.3sg.acc’. The morphotactic representation (before morphophonology is applied) is *оү*({y})\(\overset{(I)}{\rightarrow}\)({N}{I}). which is incorrectly rendered as *оюнүн*. Normally, epenthesis (conversion of \(y\) to an output vowel, instead of resulting in no output) would not occur in this sort of environment.
in Tuvan, but in this particular form it seems to be required. Additionally, because the orthography of Tuvan almost always renders a *тий* sequence as *ти*, the relevant two rules would need specify that epenthesis, in this case, occurs by way of an input *ти* surfacing as *ти*, and the archiphoneme for epenthetic vowels not being output. These problems add an additional layer of complication that has yet to be resolved.

An example of inadequate morphotactics would be the proper noun *а* for ‘this’, which can take possessive suffixes, the current paradigm only allows case suffixes after personal and demonstrative pronouns. Another example would be the derivational suffix -ла, which when applied to proper nouns produces a verb which means ‘to go to X’, e.g. *москвала* ‘go to Moscow’. In terms of categorisation, we found both errors in phonological categorisation. One example would be for proper nouns loaned via Russian, e.g. *Париж* ‘Paris’, we need a special lexicon to ensure that final voiced consonants are treated as unvoiced. The correct dative would be *Парижге* instead of *Парижу*.

Around a third of all missing stems were noun stems, and another third were verb stems; the remaining third were made up of proper nouns and adjectives, with one modal word, one adverb, and two interjections found.

| Error type            | Count | %    |
|-----------------------|-------|------|
| Missing stem          | 364   | 78.8 |
| Other                 | 65    | 14.1 |
| Bad morphotactics     | 19    | 4.1  |
| Bad phonology         | 8     | 1.7  |
| Incorrect categorisation | 6   | 1.3  |
| **Total**             | **462** | **100** |

**Table 7:** Error categorisation from the gold standard.

6. Future work
The analyser we have presented here forms part of a family of computational morphological descriptions for Turkic languages. We are actively working with the Universal Dependency project to express our annotation scheme in a way compatible with their objectives. For an example, see Tyers and Washington (2015).

There is a clear need to increase the size of the lexicon: in the evaluation nearly 80% of all errors were caused by missing stems. The few remaining issues in morphotactics, morphophonology and incorrect categorisation can be fixed relatively easily.

7. Conclusions
We have presented, to our knowledge, the first ever published morphological analyser for Tuvan. The analyser is free and open-source, meaning that it can be used and extended by anyone interested. In the development of the analyser, we have expanded linguistic knowledge about Tuvan, and developed strategies for difficult-to-implement grammatical patterns. The analyser has a high precision, over 99%, and fairly high coverage, over 90% on a range of available corpora. The analyser is currently used to provide morphological analyses for an online corpus of Tuvan, and we intend to use it for annotating the Tuvan National Corpus.

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