An Expanded Finite-State Transducer for Tsuut’ina Verbs

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Abstract

This paper describes the expansion of a finite state transducer (FST) for the transitive verb system of Tsuut’ina (ISO 639-3: srs), a Dene (Athabaskan) language spoken in Alberta, Canada. Tsuut’ina languages have unique templatic morphology, in which lexical, inflectional and derivational tiers are interfaced. Drawing on data from close to 9,000 verbal wordforms, the expanded model can handle a great range of common and rare argument structure types, including ditransitive and uniquely Dene object experiencer verbs. When speed remains a challenge, the expanded FST shows the ability of FST modelling to handle morphology of this type, and the expanded FST shows great promise for community language applications such as a morphologically informed online dictionary and word predictor, and for further FST development.

Keywords: Na-Dene, Indigenous languages, finite state transducers, morphology

1. Introduction

This paper describes the development of a finite state transducer (FST) for the inflectional system of verbs in Tsuut’ina (ISO 639-3: srs), a highly endangered Dene (Athabaskan) language spoken near Calgary, Alberta, Canada. Arppe et al. (2017) outlined the creation of an FST for intransitive verbs in Tsuut’ina, with only a few exemplary lexemes. The current paper describes the expansion of this FST architecture with a larger set of intransitive verbs as well as to encompass transitive verbs of various argument structures, which vastly increases the range and complexity of the morphology that the FST needs to represent. Full verb conjugations are needed for language learning resources, but manually creating paradigm tables would be impractical. The FST automates this and responds to the Tsuut’ina community’s desire for computer-based language tools that are typical FST applications, such as a morphologically enhanced online dictionary, a spellchecker, and predictive word suggestions on mobile devices. Through the integration of this FST with the GiellaLT infrastructure, all of these applications are readily derivable from the FST described in this paper.

FSTs (Beesley and Karttunen, 2003) use bidirectional rule-based mapping between sets of items, e.g. a string of characters as input, and a morphological analysis as output, or vice versa. FSTs are ideal for this work: they have open source implementations of compilers such as Foma (Hulden, 2009) (used in this project); they are compatible with most operating systems; their computational properties and end-user applications are well established (see Moshagen et al. (2013)) and Trosterud (2004, 2006, Arppe et al. (2016), Antonsen et al. (2013), Johnson et al. (2013) for discussions of similar language-learning applications.). As data structures they are efficient for generating rule-based verb paradigms, which is advantageous given the limited data and corpora that are available for Tsuut’ina. However, caution is needed: rule-based paradigm generation is only as accurate as the morphological model used as input. The automatic generation of paradigms of a morphologically complex language can produce thousands of potential forms, but not all such forms are grammatically and pragmatically acceptable to speakers, who cannot verify them all.

1.1. Previous FST Work for Polysynthetic, Indigenous and Non-Concatenative Morphology

FSTs have been used numerous times to generate morphologically complex wordforms in polysynthetic Indigenous languages spoken in Canada and elsewhere in North America, for example Snoek et al. (2014) and Harrigan et al. (2017) for Plains Cree, Kazeminejad et al. (2017) for Arapaho, Kazantseva et al. (2018) for Kanyen’kéha (Mohawk), Lachler et al. (2018) for Northern Haida, Bowers et al. (2017) for Odawa, and Chen and Schwartz (2018) for Yup’ik. Further afield, Antonsen et al. (2013) show that FSTs are well-suited to computer-assisted language learning (CALL) tools for Northern Saami, as does Hurskainen (2009) for Swahili.

While the above projects show that FSTs are extremely promising for developing computational models and end-user applications for First Nations languages, with their varying origins and morphological characteristics, Dene languages pose a particular challenge, as they are virtually unique in having a “templatic” morphological structure, to be described in detail in sections 1.2 and 2. This poses significant and unique challenges to building an FST (see Sections 1.2 and 2 below; see also Hulden and Bischoff (2008) for an early exploration of these questions), some of which were addressed in Arppe et al. (2017) for the intransitive verb model (see section 1.2 below), but many others of which are described in
1.2. Basic FST Architecture for Tsuut’ina

Intransitive Verbs

Arppe et al. (2017) presented the creation of the core architecture of the FST for Tsuut’ina. This subsection will give the briefest review of features of Dene verb template that had to be modelled for the FST. Section provides a more thorough overview of Tsuut’ina inflection and participant marking relevant to the current expansion. Then the core features of the FST architecture are described and the next steps needed for the expansion.

Dene verbs do not use a simple, linear lexical-derivational-inflectional concatenation; rather, the three types of prefixes are interlaced (see Figure 1). The lexical tier or “verb theme” consists of a stem on the right edge, a voice/valence prefix directly to its left, and up to three prefix positions: inner lexical, a middle “areal” slot (the areal prefix is a historical agreement prefix referring to a place or situation, but is lexicalized as part of many verb themes), and an outer lexical position. “Outer”, “middle” and “inner” lexical prefixes are defined in relation to inflection sites. (This is a radical simplification that avoids more technical Athabaskan prefix terminology; Rice (2000), Hoijer (1945), and Sapir and Hoijer (1966) are basic comparative references.) These lexical zones have degrees of internal complexity, but this does not need to be accounted for in an inflectional FST, which simply must generate and accept correct verb paradigms.

The inflectional tier includes categories of viewpoint aspect, mood, as well as number and person agreement for subjects and objects. For the basic, “skeleton” FST described in Arppe et al. (2017), it was determined that three insertion points in the verb word were necessary to accurately generate intransitive inflections: 1) the outer inflectional zone directly to the right of the outer lexical prefixes (to handle the distributive plural), 2) the middle zone between the areal and the inner lexical prefixes (where third-person unspecified subject prefix ts ’as–, and third-person plural subject gi– are found), and finally 3) the inner, TAMA (tense-aspect-mood-agreement) chunk zone, between the inner lexical and the stem-classifier combination. There are many allomorphic co-occurrence restrictions between TAMA chunks and lexical portions. See Section 2 for a full overview of this area.

Computationally, FST uses a ‘chunking’, or portman- teau, approach to the combination of aspect, mood and agreement prefixes to the left of the classifier, sequences called “TAMA chunks” in this paper, even though there is no true tense marking in this zone. The classifier is a single segment, one of which is the vowel i in Tsuut’ina; many of the viewpoint aspect prefixes are zero-marked, or marked by vowels, or by a vowel plus a glide (such as yi-) This whole area is often collapsed into single syllables whose internal complexity

Figure 1: FST conventions for inflectional zones of náguidił̓td ‘s/he jumps down’ (see Rice (2001)) would be quite hard to model in a fully decomposed form. While the TAMA chunking approach has some support from linguistic studies—see Rice et al. (2002) for psycholinguistic results involving Dene Sų́liné, Young and Morgan (1987), Faltz (1998), and McDonough (2000) for Navajo, Holden (2013) for Dene Sų́liné and Leer (1999) (inter alia) for comparison across multiple Dene languages, from the perspective of FST modelling it simply made the complexity more manageable, as only the junctions between the TAMA chunk and the surrounding morphemes are visible to the model.

Because both the lexical and inflectional tiers of the morphology are discontinuous, we make use of three separate finite-state models for each of the three inflectional zones, a fourth for the lexical tier (including the stem at the right edge and the possible preceding discontinuous lexical prefixes), specified with the lexical formalism (Beesley and Karttunen, 2003). Using finite-state operations, the three inflectional component FSTs are inserted in the appropriate slots within the lexical tier (see Arppe et al. (2017), 58, ex. 2) for the master specification). The morphophonemic processes are modeled with contextual rewrite rules using xfst (Beesley and Karttunen, 2003), with the resultant fifth FSM then composed together with the morphological FSM. A sixth FSM is concatenated with this to link flag-diacritics with morphological feature tags. Figure 2 outlines the structure of these six interlocking constituent FSMs.

The slots for inflectional morphemes within the lexical tier are indicated by a specific notation (see Figure 1 above): “.” (period) stands for the inner boundary, where the TAMA chunk is to be inserted, “ ” (underscore) for the middle boundary (where object agreement and third-person subjects are located), and “=” (equal sign) for the outer boundary (where the distributive plural prefix can occur). A system of flag diacritics then filter out disallowed combinations (i.e. implementing co-occurrence restrictions).

1.3. Next Steps

Arppe et al. (2017) demonstrated that it was possible to model Dene verb morphology using this architecture,

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at least for a handful of intransitive verbs, but the true
test of its robustness would come with the expansion
to transitive verbs and a much wider sample of many
hundreds of verbs with many new argument structures.
The current expansion handles 1,557 lemmas (approx-
imately) from the Onespot-Sapir glossary (see Section
3.1 below).\footnote{The full source code for the Tsuut’ina FST is available at\url{https://github.com/giellalt/lang-srs}.} To describe this, the following sections
will review the structure of the verb, with special atten-
tion to areas that impact the design of an FST.

2. An Overview of Participant Marking
in Tsuut’ina Verbal Morphology

While the overall architecture described in the preced-
ing section (and in \cite{Arppe2017} and \cite{Lovick2018}) is sufficient for modelling intransitive verb
forms in Tsuut’ina (and Upper Tanana), in which gram-
matical subjects may be realized through combinations
of outer, middle, and inner inflectional prefixes, it does
not address the morphological realization of additional,
non-subject discourse participants in more complex in-
flected forms. Indeed, a single inflected form such as (1) can index up to three event participants with
pronominal markers appearing in several places in the verb-word (in boldface)\footnote{In additional to the standard labels defined in the Leipzig
Glossing Rules, the following abbreviations are also used in
this paper: AR ‘areal’, ASRT ‘assertion’, CON ‘conative’,
DIST ‘distributive’, DO ‘direct object’, IO ‘indirect object’,
POT ‘potential (optative)’, STAT ‘stative’ TERM ‘termina-
tive’, VV ‘voice/valence marker’, 3D ‘distal third-person ob-
ject’.}:

\begin{verbatim}
(1) moghànínischúd-áát’a
   mi- oghà- ni- nis-
   3SG.IO to 2SG.DO 1SG.SBJ:ni.IPFV
   s- chúd \textit{=}i \textit{=}áát’a
   VV feed.IPFV FUT ASRT
‘I am going to feed you to it.’ (Doris Roan,
speaker; October 23, 2012)
\end{verbatim}

In this example, inflectional markers related to event
participants appear at several points: (1) at the far left-
edge of the verb-word, with an 3SG indirect object mi-
marked before the incorporated postposition oghà- ‘to’;
(2) after that postposition, with the 2SG direct object ni-
; and (3) immediately before the verb stem, with a port-
manteau morpheme nis- representing the 1SG subject
form of the ni-imperfective paradigm with an s- voice-
valence marker. While ditransitive forms such as this in
which three distinct event participants are realized mor-
phologically are relatively rare in Tsuut’ina, pronomi-
nal marking of event participants in each of these three
positions is not: verb forms containing object marking
are frequent, and thus need to be modelled.

In order to extend the previously proposed FST archi-
tecture to represent non-subject event participants, then,
several other linguistic facts need to be taken into con-
sideration:

1. Object-marking patterns need to be implemented
to represent both the indirect and direct object
morphology seen in (1) above, which was not
present in previous models that explored the repre-
sentation of discontinuous morphology (\cite{Arppe2017})
and common derivational paths (\cite{Lovick2018}). As we note below, this sometimes
involves defining an additional inflectional FSM
(e.g., for indirect object morphology not present in
prior models) or refining the existing inflectional
FSMs to process both subject and object markers.

2. Interactions between subject and object-marking
morphology need to be represented adequately in
an expanded computational model. As in many
other Dene languages, the forms of object mark-
ers often depend on subject person and number,
with third-person objects having different realiza-
tions when acted on by third-person vs. non-third-
person subjects (see Section 3.2.2). Similarly,
some subject markers’ positions may differ based
on the presence or absence of certain object mark-
ers. This is the case with gi- 3PL, which typically
appears as a middle prefix (2a), but can also ap-
pear at the left edge of the word when combining
with yi- 3D in 3PL>3SG.IO contexts (2b):

\begin{verbatim}
(2) a. soghàgistà
   si- oghà- gi- is-
   1SG.IO to 3PL 3.SBJ:ni.IPFV:s.VV
   tà handle-animate.IPFV
‘they will give something (animate) to me.’
\end{verbatim}
b. giyoghàstà
   gi- yi- oghà- is-
   3PL 3D.IO to 3.SBJ:ni.IPVF:3.VV
   tà
   handle-animate.IPVF

‘they will give something (animate) to him/her/it.’

Other inflectional markers already defined in previous, intransitive-only models of Tsuut’ina verbal morphology also require adaptation to reflect their distribution when other event participants are present. The distributive plural dà-, an inflectional prefix, may only appear when one of the participants is plural or impersonal. Prior models would therefore reject forms with singular subjects that contained dà-, whereas a revised model that incorporates additional event participants also needs to accept cases where the subject is singular, but the object is plural or impersonal (e.g., dàgimiyis?i ‘I saw each and every one of them’);

3. Individual verb lexemes in Tsuut’ina differ in the number of participants involved in the associated verbal event and how those participants are realized morphologically with the above subject, direct object, and indirect object markers. Section 3.2 begins by detailing the participant marking patterns in Tsuut’ina for which an expanded model must account.

While many of these classes resemble cross-linguistically common argument marking patterns—intransitive verbs realized with prototypically subject-related inflection, or transitive verbs realized with both direct object and subject inflection—other less familiar patterns are also attested in Tsuut’ina. (See Sections 3.2.4 & 3.2.7 below).

An expansion of the FST model of Tsuut’ina verbal morphology that aims to include all the attested patterns of verbal participant marking thus presents a potentially valuable “stress test” of the existing finite-state architecture for Dene languages, particularly in its ability to generate and recognize a much wider range of verb forms. As we note below, applying such a model to a much larger lexical sample also raises questions about current conceptions of what constitutes a lemma in morphologically rich languages such as Tsuut’ina, and of where the boundary lies between inflectional and derivational information in Dene verbal morphology.

### 3. Expansion of the Inflectional Tsuut’ina FST

The current expansion is meant to generate full inflectional paradigms for a comprehensive range of verbs as represented by the Onespot-Sapir glossary (see Section 3.1.3). This includes all transitive, oblique object and ditransitive cases in this database. Numerous morphological complexities specific to transitivity in Dene languages must be handled, along with a multiplicity of minor argument structure with distinct prefixing patterns (see below). A model of the derivational morphology is beyond the scope of the current model.

We have not followed, however, a very rigorous distinction between inflection and derivation for our FST model. In particular, several aspectual categories normally seen as derivational are included in the inflectional FST either because it made the modelling itself much easier (see discussion of the transitional or inchoative and semelfactive prefixes in Section 3.2.3) and of the conative in Section 3.2.5) or in order to make the model’s output fit with Tsuut’ina community language teaching traditions and priorities (see Section 3.1’s discussion of the repetitive and progressive aspects). The following section 3.1 will review the language source data used for this expansion, and Section 3.2 will address the new characteristics of FST modelling of transitive verbs and the other argument structure types.

### 3.1. Re-elicitation and Organization of the Onespot-Sapir Glossary

The source material was an unpublished glossary collected by Edward Sapir and John Whitney-Onespot in Tsuut’ina in 1922 that contains numerous verb paradigms. In the 1990s, Tsuut’ina community linguist and speaker Bruce Starlight and collaborator Gary Donovan started transcribing and editing Sapir and Whitney-Onespot’s notebooks, occasionally expanding on incomplete paradigms or adding related words. This curation and editorial process is outlined in further detail in Starlight et al. (2016).

Paradigms were transferred into a preliminary lexical database and labelled for argument structure, transitivity, aspect, and TAMA chunk subtype by co-author Holden (sometimes in consultation with co-author Cox), and the specific allomorph combination of the stem + lexical prefixes for each TAMA value was recorded (with some temporarily excluded because their TAMA pattern was unclear, or some other factor that required verification by speakers).

The next step was lemmatization. Normally any non-inflectional material (barring noted exceptions) required the creation of a lemma, which would stand for a group of inflected wordforms. The lemmas are thus similar to lexemes, with some caveats: we treated repetitive and progressive aspects (linguistically derivational) as inflections to make the paradigms compatible with Tsuut’ina community language education.

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5 It should be noted that the current FSM has not yet implemented the optative (aka potential) mood forms due to their rarity in the Onespot-Sapir data. However, because this inflection is highly regular, we are confident in being able to include it soon.
preferences: verbs are typically taught as a “basic set” of four variants: imperfective (aka non-past), perfective (aka past), progressive, and repetitive. Taking a strict view of the inflection-derivation distinction would have broken up these sets. Some Onespot-Sapir paradigms seemed to be split between inventive and progressive aspects (both derivational), with no obvious meaning change. Following a pedantic division of inflection and derivation would have broken up what is functionally a natural complete set into two incomplete paradigms, in contrast with community preferences, and producing some inflections that are not used or common. The third-person singular wordform was chosen as this citation form, a convention already adopted for the intransitive model (Arppe et al., 2017).

3.2. Expansions Needed for the Onespot-Sapir Glossary

The Onespot-Sapir list contains close to 9 thousand verbal wordforms with many argument structure types, of which several are new to the FST model. The lexc excerpt below shows the argument structures and associated flag diacritics, with all except the first two being novel to the expanded FST.

LEXICON Root

LEXICON Transitive-Markers

| SubjectOnly; |
| SubjectAndDirectObject; |
| SubjectAndObliqueObject; |
| SubjectDirectObjectOrObliqueObject; |
| ObliqueObjectOnly; |
| SubjectDirectObjectOrObliqueObject; |

Given that inflectional material can be found in several zones of the verb, expanding the range of verbs and argument structures requires an additional inflectional prefix position as well as an increase in the range of prefixes found in existing slots. The expansions could therefore be sorted by argument structure or by prefix zone. To avoid repetition, we will take a blended approach: in sections 3.2.1 through 3.2.7 below, we will first lay out additions to each of the FST inflectional zones as well the new zone that came with the expansion, focusing on cross-linguistically well known argument structure types, before wrapping up the section with the less common and more Dene-specific argument structures (subsections 3.2.5, 3.2.7), describing their characteristics as well as the prefix zones they occupy.

3.2.1. Inner zone TAMA inflections

The point directly to the left of the stem-classifier combination is the most complex site of inflection in Dene languages, where aspect, mood and person agreement are found. Prefix sequences here are treated as cumulative morphemes informally called “TAMA chunks”.

Although from a strictly linguistic standpoint most Dene languages, including Tsuut’ina, arguably do not express tense in this zone, some of these morphemes are referred to with tense names (past=PFV, present=IPFV, future=POT) in Tsuut’ina language teaching, and we adopt the “fuzzy” term TAMA here.

The most frequent morphemes here are the imperfective and perfective aspects and the optative or potential mood. (The progressive aspect, which is strictly speaking derivational in Dene languages, is also included as a value of this “category”.)

The TAMA chunking approach was adopted for practical reasons laid out in Section 1.2 above; for the same reason, a few surrounding lexical prefixes (the classifier to the right of the TAMA inflection, and the transitional prefix to its left) are included with the TAMA sequence. This approach to the inner prefixes was already in place for the intransitive model (minus the transitional paradigms), but the expansion saw the addition of a much wider range of imperfective and perfective allomorphs.

Dene languages have derivational situation aspect marking (see Rice (2000) for a further discussion) in dynamic, transitive transitional verbs such as (2b) above, the low tone is present with the mi– object prefix (e.g., nagiministà ‘I am setting them (gimi–, with low-tone i–) down’), but absent with a full nominal complement (e.g., tilch’ikà nañistà ‘I am setting the dogs down’ (no low tone)). To handle this, we added the specific argument structure “transitional transitive” in addition to distinct transitional TAMA chunk allomorphs.

3.2.2. Middle zone inflections

The “outer subject” prefixes is– ‘impersonal subject’ and gi– ‘third person plural subject’ in this zone were already in the intransitive model in (Arppe et al., 2017). This is the primary insertion point for the direct object prefixes, so adding these was a significant expansion to this zone. Flag diacritics for some of these values and the corresponding prefixes are exemplified in the lexc excerpt below.

LEXICON Transitive-Markers

The decision was made to handle third-person direct objects in their own continuation lexicon, as shown in the next set of lexc definitions, due to a number of unique complexities, one of which being a proximal/distal third-person distinction. A distal third-person object is one acted on by another third-person actant. In these cases, the usual third-person object marker mi– is replaced by the distal third person object marker yi–. For example, in the verb mìyà?ì ‘we saw it’ (mi– 3DO + yà?ì see.1PL.PFV), mi– is the third-person standard or proximal object prefix. In the case of two third person actants, the verb form would be yà?ì ‘s/he saw it’ (yi– 3D + yi– see.3.PFV), where mi– is replaced by distal third-person object marker yi–.
Tsuut'ina object agreement prefixes are not required when a full nominal object is present. In practice this affects almost exclusively the third person inflections (first- and second-person pronouns are infrequent and emphatic in Tsuut'ina). For example, in the sentence ĺístłíyí?í “s/he saw a horse”, ĺístłí means ‘horse’ and yí?í means ‘s/he saw (it)’. Another such contrast is seen in the lexc definitions below. Because the overt nominal ĺístłí ‘horse’ is present, the verb has no third-person direct object prefix. In contrast, the form yá?í “s/hesawit” mentioned above (with no overt direct object) the third-person distal prefix is present (yá?í = yi-3D + yí?í see 3.PFV). In the lexc file we treated these as two allomorphs of the third-person object prefixes, one of which was zero, as shown in the lexc definitions reproduced below:

LEXICON 3SG-Direct-Objects
@U.SUBJECTNUMBER.SG@ @U.SUBJECTPERSON.3@ @U.DIRECTOBJECT.NOMINAL@ Filter-Transitives;
@U.SUBJECTNUMBER.SG@ @U.SUBJECTPERSON.3@ @U.DIRECTOBJECT.NONE@ @P.PREFIX.MIDDLE@yi Filter-Transitives;

The flag @U.DIRECTOBJECT.NOMINAL@ tells the FST to use the zero allomorph (i.e., no prefix) when an object noun is present, while the flag @U.DIRECTOBJECT.NONE@ is followed by @P.PREFIX.MIDDLE@yi, telling the FST to add the object prefix yi– in the absence of a direct object noun. The reflexive and reciprocal objects are handled in their own continuation lexica as well, due to a number of linguistic complexities (see lexc definitions below).

LEXICON Reflexive-Direct-Objects
@U.SUBJECTNUMBER.SG@ @U.SUBJECTPERSON.1@ @U.OBJECTNUMBER.PL@ @U.OBJECTPERSON.2@ Distributive;
@U.SUBJECTNUMBER.SG@ @U.OBJECTNUMBER.PL@ @U.OBJECTPERSON.2@ Distributive;
@U.SUBJECTNUMBER.SG@ @U.OBJECTNUMBER.SG@ NoDistributive;

LEXICON Reciprocal-Direct-Objects
@U.OBJECTNUMBER.PL@ @U.OBLIQUEOBJECT.PL@ Distributive;
@U.OBJECTNUMBER.PL@ @U.OBLIQUEOBJECT.PL@ Distributive;
@U.OBJECTNUMBER.SG@ @U.OBLIQUEOBJECT.PL@ Distributive;
@U.OBJECTNUMBER.SG@ @U.OBLIQUEOBJECT.SG@ Distributive;
@U.OBJECTNUMBER.SG@ @U.OBLIQUEOBJECT.SG@ NoDistributive;

Furthermore, for any verbs whose object markers occur in the left-edge (historically oblique) inflection zone (see below), the distributive can refer to either subjects or (oblique or formerly oblique) objects. This is accounted for in a special lexicon for subjects with oblique objects, shown in the following lexc definitions.

LEXICON SubjectAndObliqueObject
@U.SUBJECTNUMBER.PL@ @U.OBLIQUEOBJECT.PL@ Distributive;
@U.SUBJECTNUMBER.PL@ @U.OBLIQUEOBJECT.PL@ Distributive;
@U.SUBJECTNUMBER.SG@ @U.OBLIQUEOBJECT.PL@ Distributive;
@U.SUBJECTNUMBER.SG@ @U.OBLIQUEOBJECT.SG@ Distributive;

3.2.3. Outer Zone Inflections
The outer insertion point only takes the dà– distributive prefix. While this inflection point was already present in the initial model, the current expansion meant a new set of rules for the distributive to account for restrictions and a wider range of possible uses.

First of all, while dà– usually pluralizes the subject, for transitive stems the distributive can refer to plurality of either the subject or the object. In this case, the lexicon shown below is needed, which excludes only the singular subject-singular object combination. In other transitive cases, the second line would be marked NoDistributive if subject and direct object are both singular.

LEXICON Filter-Transitives
@U.SUBJECTNUMBER.SG@ @U.OBJECTNUMBER.SG@ Filter-Ditransitives;

3.2.4. Left-edge Inflections
In this expanded model, a fourth inflectional zone was necessary at the left edge of the verb word. If you recall the verb structure outlined in Section 1.2 and Section 2, Dene verb themes frequently incorporate

LEXICON SubjectAndDirectObject
@U.SUBJECTNUMBER.PL@ @U.OBJECTNUMBER.PL@ Distributive;
@U.SUBJECTNUMBER.SG@ @U.OBJECTNUMBER.PL@ Distributive;
@U.SUBJECTNUMBER.SG@ @U.OBJECTNUMBER.SG@ Distributive;
@U.OBJECTNUMBER.PL@ @U.OBJECTNUMBER.PL@ NoDistributive;
postpositions at or toward their left edge (in the outer lexical zone). Often the postposition/preverb is lexicalized so its meaning is not transparent. The incorporation of a postposition affects the verb’s valence. This is the case notably with transfer verbs where the postposition holding the recipient is the one incorporated in the verb. This was seen in example (1) above, where at the left edge the third-person object *mi–* is added to refer to the object of the feeding, while the normal direct object position of *s+chut* contains second-person object *ni–* ‘you’, resulting in a ditransitive verb. The verb “inherits” the incorporated postposition complement, resulting in double object marking (if it is not a phrase). The FST assigns the flag diacritic @U.VALENCE.DITRANSITIVE@ to these cases. When the analytical construction was a two-actant verb with an oblique object complement, the incorporation of the postposition results in a direct transitive verb where the direct object inflection occurs at the left edge, rather than the standard middle position. The FST treats these as oblique object verbs with the flag diacritic @U.VALENCE.OBLIQUEOBJECT@. As with the case of the direct objects, the object prefix is suppressed when an overt nominal is present, so the FST must implement a null allomorph in these cases, as shown in the lexicon below.

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LEXICON 3SG-Oblique-Objects
@D.SUBJECTPERSON.3@  
@U.OBLIQUEOBJECT.NOMINAL@  
@D.SUBJECTPERSON.3@  
@U.OBLIQUEOBJECT.NONE@  

As with the transitive verbs, the 3rd person, reflexive and reciprocal were handled in separate lexica, because the same rules regarding distal/proximal alternations and classifier changes apply.

### 3.2.5. Conative Paradigms

The conative is a “situation aspect” derivation (see Rice [2000, 260–263]). At its most compositional, it contributes a meaning loosely glossable as ‘attempt’ or ‘at’ to the verb (e.g. ‘shoot at’ versus just ‘shoot’). In other cases the conative is vestigial or it is hard to see what its exact contribution is, but it is associated with dynamic transitive verbs, as in (3), where it appears as a high tone *i–* morpheme that merges with the preceding object prefix.

(3)  
yízi
  yi–  zi
3D CON call.IPfv
‘s/he is calling him/her’

Formally the conative appears as a high tone or *i–* morpheme directly to the left of the TAMA sequence in most Dene languages, but in Tsuut’ina, unusually, it occurs between the direct object prefixes and the third-person subject prefixes, directly in the middle of the middle zone of the FST inflectional model, so the chunking approach with TAMA will not work. This became apparent with the expanded inventory of verbs from the Onespot-Sapir glossary. Because the FST architecture was not designed to break up the middle inflectional zone, a unique flag diacritic was added to conative verbs, @U.VALENCE.DO–EXPERIENCER@, which ensured that the conative prefix was inserted in verbs that were lexically specified to be of this type.

#### 3.2.6. Object Experiencer Verbs

The left-edge position is also an inflection site used to generate what we termed object experiencer verbs—single-actant predicates whose object markers refer to the semantic experiencer of an event, and the subject position in the TAMA and middle positions are empty, arguably filled with a zero-marked dummy third person inflection. These often refer to states or events such as sickness or emotions, where there is no tangible agent that could be identified as acting on the (morphologically object-encoded) experiencer. In tamiyilil ‘he/she/it is floating’ in (4), for example, the person floating is expressed by the object marker *mi–*.

(4)  
tamiyilil
  ta– mi–  i–  yi–  0–  li
on 3.DO CON 3.PROG VV
‘he/she/it is floating (in one spot)’

Morphologically there are two types of object experiencer verbs: those whose object markers occur in the standard middle slot, termed direct object experiencer verbs, and those inflected at the left edge, where the object marker derives, at last historically, from the object of an incorporated postposition, deemed oblique object experiencer verbs. (4) above is a direct object experiencer verb, while (5) below is an oblique object experiencer verb. In (4) below, the third-person plural prefixes *gimi–* refer to the people experiencing sickness.

(5)  
gimádagüdïllo
  gi–  mi–  á– dà–  gá–  di–  0–
3PL 3.IO by DIST AR STAT 3.IPfv
  lo
many lie
‘they are all sick’

The meaning ‘sick’ is produced from the lexicalized combination of the stem *-lo* ‘many lie’, the prefix *gí–*, and the incorporated postposition *á–* ‘by’.

To implement object experiencer verbs, the FST must exclude any subject other than third person and specify the proximal third-person object for third person experiencer. (There can be no distal third person marking for these themes, as the morphological subject is suppressed.) We used the flag diacritics @U.VALENCE.DO–EXPERIENCER@ and @U.VALENCE.DO–EXPERIENCER@ for direct-
oblique-object experiencer verbs, respectively, to prevent any subject person-number combinations other than third-person singular (with zero-marked imperfective allomorph) from being realized.

3.2.7. Restricted Argument Structures

Additional minor argument structures were needed for verbs which, for pragmatic or other reasons, had restrictions on non-third persons as either subjects or objects. For example, impersonal verbs (typically referring to agentless events such as weather or celestial situation) such as gudìsghal ‘it is getting dark (outside)’ can only take a dummy singular third-person, and no distributive marker. The flag diacritic Θ. ∅ U . VALENCE . IMPERSONAL was used for such verbs to prevent other person forms. There are also third-person subject-only verbs which, while not ‘impersonal’ in the above agentless sense, would be pragmatically odd with first or second persons. This is the case, for instance, of taunnimόsh ‘it is boiling’ (barring a story with anthropomorphic water or kettles). Analogously, the transitive verb iyin ‘to sing (it)’, can only take third-person objects. To prevent first- and second-person inflections from being included in these cases, sequences of flag diacritics such as ∅ R . OBJECTNUMBER . SG @ R . OBJECTPERSON . 3 @ were added to require that only third-person singular forms were generated and recognized.

4. Size and Performance

The current extended lexicon contains altogether 1,557 lexemes, distributed among various argument structure types and subtypes as shown in Table 1. On average, these lexemes have 1.62 suppletive verb theme variants, with a median of 1.0 and a maximum of 11 theme allomorphs per lexeme (resulting from multiple allomorphic variants for the same aspectual value). This means that some suppletive forms are missing from the Onespot-Sapir glossary, and must be elicited from fluent speakers.

| n_lexemes | n_allomorphs | Argument structure |
|-----------|--------------|--------------------|
| 842       | 1.50         | Intransitive       |
| 630       | 1.83         | Transitive         |
| 39        | 1.15         | Transitive-SubjSuppr[essed] |
| 25        | 1.36         | ObliqueObjectExperiencer |
| 9         | 1.67         | ObliqueObject      |
| 3         | 1.33         | Transitive-Conative |
| 2         | 2.00         | Intransitive-SubjP[ural]Only |
| 1         | 1.00         | Transitive-D[irect]Obj3SgOnly |
| 1         | 1.00         | DirectObjectExperiencer |
|           | 4.00         | Ditransitive       |
| 1         | 1.00         | Intransitive-SubjSuppr[essed] |
| 1         | 1.00         | Intransitive-Subj3rdPersonOnly |

1557 1.62 TOTAL

Table 1: Counts of lemmas and average theme allomorphs for different argument structure types

When compiled with Foma, this entire FST is quite large, at 63.2 MB in overall size, with 1,664,399 states, 4,143,483 arcs, and more than 9 x 10^{18} paths (before pruning based on flag-diacritics). The number of verbal wordforms that this FST covers is nevertheless finite, adding up to 1,472,669 forms in total that take 15 minutes to output using the pairs command in Foma. In terms of speed, this expanded FST is noticeably slow in analyzing wordforms (2min 2.57s for 1000 random word-forms, on a 2020 Macbook Pro with 32GB of RAM and a 2.3 GHz Quad-Core Intel Core i7 (CPU) but alarmingly snail-paced in generating the same 1000 wordforms (43min 6.27s). This is caused by the original design of the FST, where the flag-diacritics that constrain the acceptable strings are largely specified at the right edge of the FST, thus resulting during the FST lookup, reading the network from left-to-right, in the generation of a huge number of possible strings before encountering the limiting flag diacritics. In linguistic analysis, though, the wordform string strongly restricts possible analyses, resulting in a more acceptable but still slow speed. A possible fix would be to specify constraining flag-diacritics at the left edge of the FST, at the beginning of the lexical tier, which, though feasible, would involve reconfiguring the matching flag-diacritics in the three inflectional FSTs, which would then follow the constraining flag-diacritics (e.g. switching P-flags into R-flags). Another solution is to enumerate all the wordform-analysis pairs, as their number is finite, and subsequently create a wordform-based FST. We have already attempted this, producing a slightly smaller FST of 44.4 MB, with 2,350,317 states, 2,910,952 arcs, and 1,455,806 paths, without any flag-diacritics. Most importantly, this word-form based FST is many degrees of magnitude faster than the original flag-based one, analyzing 1000 random word-forms in 0.663s and generating those same word-forms in 1.411s; for 100k random wordforms, the analysis and generation speeds are 3.713s and 1min 16.46s, respectively.

5. Conclusion and next steps

We have demonstrated that a working full-scale finite-state model can be created for Tsuut’ina, and thus Dene languages in general, implementing all argument types of verbs, the morphologically most complex word class, with a comprehensive lexicon. This expansion has its performance challenges, i.e. its relatively large size and concerningly slow speed would render real-time paradigm generation by the model impractical. However, we have envisioned solutions to these challenges. Since the set of inflections is finite, we can generate the entire vocabulary that the more intricate flag-based FST specifies, and use that as a basis for a wordform-based FST that is acceptable speed-wise. Another pressing task is to elicit or uncover missing allomorphic variants of the verb themes that remained unconfirmed.

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