A Language-Independent Feature Schema for Inflectional Morphology

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Abstract

This paper presents a universal morphological feature schema that represents the finest distinctions in meaning that are expressed by overt, affixal inflectional morphology across languages. This schema is used to universalize data extracted from Wiktionary via a robust multidimensional table parsing algorithm and feature mapping algorithms, yielding 883,965 instantiated paradigms in 352 languages. These data are shown to be effective for training morphological analyzers, yielding significant accuracy gains when applied to Durrett and DeNero's (2013) paradigm learning framework.

1 Introduction

Semantically detailed and typologically-informed morphological analysis that is broadly cross-linguistically applicable and interoperable has the potential to improve many NLP applications, including machine translation (particularly of morphologically rich languages), parsing (Choi et al., 2015; Zeman, 2008; Mikulová et al., 2006), n-gram language models, information extraction, and co-reference resolution.

To do large-scale cross-linguistic analysis and translation, it is necessary to be able to compare the meanings of morphemes using a single, well-defined framework. Haspelmath (2010) notes that while morphological categories will never map with perfect precision across languages and can only be exhaustively defined within a single language, practitioners of linguistic typology have typically recognized that there is sufficient simi-larity in these categories across languages to do meaningful comparison. For this purpose, Haspel-math (2010) proposes that typologists precisely define dedicated language-independent comparative concepts and identify the presence of these concepts in specific languages. In this spirit, we present a universal morphological feature schema, in which features that have a status akin to those of comparative concepts are used to represent the finest distinctions in meaning that are expressed by inflectional morphology across languages. This schema can in turn be used to universalize morphological data from the world's languages, which allows for direct comparison and translation of morphological material across languages. This greatly increases the amount of data available to morphological analysis tools, since data from any language can be specified in a common format with the same features.

Wiktionary constitutes one of the largest available sources of complete morphological paradigms across diverse languages, with substantial ongoing growth in language and lemma coverage, and hence forms a natural source of data for broadly multilingual supervised learning. Wiktionary paradigm table formats, however, are often complex, nested, 2-3 dimensional structures intended for human readability rather than machine parsing, and are broadly inconsistent across languages and Wiktionary editions. This paper presents an original, robust multidimensional table parsing system that generalizes effectively across these languages, collectively yielding significant gains in supervised morphological paradigm learning in Durrett and DeNero's (2013) framework.

2 Universal Morphological Feature Schema

The purpose of the universal morphological feature schema is to allow any given overt, affixal (non-root) inflectional morpheme in any language

to be given a precise, language-independent definition. The schema is composed of a set of features that represent semantic "atoms" that are never decomposed into more finely differentiated meanings in any natural language. This ensures that the meanings of all inflectional morphemes are able to be represented either through single features or through multiple features in combination. These features capture only the semantic content of morphemes, but can be integrated into existing frameworks that precisely indicate morpheme form (Sagot and Walther, 2013) or automatically discover it (Dreyer and Eisner, 2011; Hammarström, 2006; Goldsmith, 2001). The fact that the schema is meant to capture only the meanings of overt, non-root affixal morphemes restricts the semantic-conceptual space that must be captured by its features and renders an interlingual approach to representing inflectional morphology feasible.

The universal morphological feature schema is most similar to tagset systematization efforts across multiple languages, such as the Universal Dependencies Project (Choi et al., 2015) and Interset (Zeman, 2008). While these efforts encode similar morphological features to the current schema, their goal is different, namely to systematize pre-existing tagsets, which include lexical and syntactic information, for 30 specific languages. The goal of the schema presented here is to capture the most basic meanings encoded by inflectional morphology across all the world's languages and to define those meanings in a language-independent manner. Because of its wide-scope, our universal morphological feature schema will likely need to include other features and even other dimensions of meaning, for which the authors invite suggestions.

2.1 Construction Methodology

The first step in constructing the universal morphological feature schema was to identify the dimensions of meaning (e.g. case, number, tense, mood, etc.) that are expressed by inflectional morphology in the world's languages. These were identified by surveying the linguistic typology literature on parts of speech and then identifying the kinds of inflectional morphology that are typically associated with each part of speech.

For each dimension, we identified the finest distinctions in meaning made within that dimension by a natural language. Some higher-level 'cover features' representing common cross-linguistic groupings were also included. For example, features such as indicative (IND) and subjunctive (SBJV) represent groupings of basic modality features which occur in multiple languages and show similar usage patterns (Palmer, 2001).

Each dimension has an underlying semantic basis used to define its features. To determine the underlying semantic basis for each dimension, the literature in linguistic typology and in description-oriented linguistic theory was surveyed for explanations of each dimension that offered ways to precisely define the observed features.

2.2 Contents of the Schema

The universal morphological feature schema represents 23 dimensions of meaning with 212 features. Because space limitations preclude a detailed discussion of the semantic basis of each dimension and the definitions of each feature, Table 1 presents each dimension of meaning, the labels of its features, and citations for the main sources for the semantic bases of each dimension. To the extent possible, feature labels conform to the Leipzig Glossing Rules (Comrie et al., 2008) and to the labels in the sources used to define the semantic basis for each dimension of meaning. A substantially expanded exploration and analysis of these dimensions and schema framework may be found in Sylak-Glassman et al. (To appear).

Note that because gender categories are not necessarily defined by semantic criteria and rarely map neatly across languages, this schema treats gender features as open-class.[1]

3 Wiktionary Data Extraction and Mapping

Wiktionary contains a wealth of training data for morphological analysis, most notably inflectional paradigm tables. Since its pages are primarily written by human authors for human readers, and there are no overarching standards for how paradigms should be presented, these tables contain many inconsistencies and are at best semi-structured. Layouts differ depending on the *edition language* in which a word is being defined and within an edition depending on the word's language and part of speech. The textual descriptors used for morphological features are also not systematically defined. These idiosyncrasies cause

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[1] To limit feature proliferation, the schema encodes gender categories as features that may be shared across languages within a phylogenetic stock or family, in order to capture identical gender category definitions and assignments that result from common ancestry, as may be possible for the 25 historical noun classes in the Bantu stock (Demuth, 2000).

Dimension	Features	Semantic Basis
Aktionsart	ACCMP, ACH, ACTY, ATEL, DUR, DYN, PCT, SEMEL, STAT, TEL	Cable (2008), Vendler (1957), Comrie (1976a)
Animacy	ANIM, HUM, INAN, NHUM	Yamamoto (1999), Comrie (1989)
Aspect	HAB, IPFV, ITER, PFV, PRF, PROG, PROSP	Klein (1994)
Case	ABL, ABS, ACC, ALL, ANTE, APPRX, APUD, AT, AVR, BEN, CIRC, COM, COMPV, DAT, EQU, ERG, ESS, FRML, GEN, INS, IN, INTER, NOM, NOMS, ON, ONHR, ONVR, POST, PRIV, PROL, PROPR, PROX, PRP, PRT, REM, SUB, TERM, VERS, VOC	Blake (2001), Radkevich (2010)
Comparison	AB, CMPR, EQT, RL, SPRL	Cuzzolin and Lehmann (2004)
Definiteness	DEF, INDEF, NSPEC, SPEC	Lyons (1999)
Deixis	ABV, BEL, DIST, EVEN, MED, NVIS, PROX, REF1, REF2, REM, VIS	Bhat (2004), Bliss and Ritter (2001)
Evidentiality	ASSUM, AUD, DRCT, FH, HRSY, INFER, NFH , NVSEN, QUOT, RPRT, SEN	Aikhenvald (2004)
Finiteness	FIN, NFIN	Binary finite vs. nonfinite
Gender+	BANTU1-23, FEM, MASC, NAKH1-8, NEUT	Corbett (1991)
Info. Structure	FOC, TOP	Lambrecht (1994)
Interrogativity	DECL, INT	Binary declarative vs. interrogative
Mood	ADM, AUNPRP, AUPRP, COND, DEB, IMP, IND, INTEN, IRR, LKLY, OBLIG, OPT, PERM, POT, PURP, REAL, SBJV, SIM	Palmer (2001)
Number	DU, GPAUC, GRPL, INVN, PAUC, PL, SG, TRI	Corbett (2000)
Parts of Speech	ADJ, ADP, ADV, ART, AUX, CLF, COMP, CONJ, DET, INTJ, N, NUM, PART, PRO, V, V.CVB, V.MSDR, V.PTCP	Croft (2000), Haspelmath (1995)
Person	0, 1, 2, 3, 4, EXCL, INCL, OBV, PRX	Conventional person, obviation and clusivity
Polarity	NEG, POS	Binary positive vs. negative
Politeness	AVOID, COL, FOREG, FORM, FORM.ELEV, FORM.HUMB, HIGH, HIGH.ELEV, HIGH.SUPR, INFM, LIT, LOW, POL	Brown and Levinson (1987), Comrie (1976b)
Possession	ALN, NALN, PSSD, PSSPNO+	Type of possession, characteristics of possessor
Switch-Reference	CN-R-MN+, DS, DSADV, LOG, OR, SEQMA, SIMMA, SS, SSADV	Stirling (1993)
Tense	1DAY, FUT, HOD, IMMED, PRS, PST, RCT, RMT	Klein (1994), **?**)
Valency	DITR, IMPRS, INTR, TR	Number of verbal arguments from zero to three
Voice	ACFOC, ACT, AGFOC, ANTIP, APPL, BFOC, CAUS, CFOC, DIR, IFOC, INV, LFOC, MID, PASS, PFOC, RECP, REFL	Klaiman (1991)

Table 1: Dimensions of meaning and their features, both sorted alphabetically

numerous difficulties for automatic paradigm extraction, but the redundancy of having data presented in multiple ways across different editions gives us an opportunity to arrive at a consensus description of an inflected form, and to fill in gaps when the coverage of one edition diverges from that of another.

To make these data available for morphological analysis, we developed a novel multidimensional table parser for Wiktionary to extract inflected forms with their associated descriptors. Although we describe its function in Wiktionary-specific terms, this strategy can be generalized to extract data tuples from any HTML table with correctly marked-up header and content cells. We extracted additional descriptors from HTML headings and table captions, then mapped all descriptors to features in the universal schema.

3.1 Extraction from HTML Tables

In its base form, the table parser takes advantage of HTML's distinction between header and content cells to identify descriptors and potential inflected forms, respectively, in an arbitrary inflection table. Each content cell is matched with the headers immediately up the column, to the left of the row, and in the "corners" located at the row and column intersection of the previous two types of headers. Matching headers are stored in a list ordered by their distance from the content cell. Figure 1 shows an example where *prenais* is assigned the following descriptors:

– Directly up the column: **tu**, **second**, **singular**, **simple**.

– Directly to the left of the row: **imperfect**, **simple tenses**.

– In corners located at the row and column intersection of any headers identified by the previous two methods: **indicative**, **person**.

– Important structured fields found outside the table, including **French** and **Verb**.

Figure 1: A portion of the English-edition Wiktionary conjugation table for the French verb *prendre* 'take.' The inflected form *prenais* and its row, column, and corner headers are highlighted.

Further, when additional content cells intervene between headers, as they do between **simple** and **singular**, the more distant header is marked as "distal." This labeling is important for proper handling of the column header **simple** in this example: It only applies to the top half of the table, and should be left out of any labeling of the inflected forms in the lower half. This distance information, and a hierarchy of positional precedence, is used in Section 3.4 to discount these and other potentially irrelevant descriptors in the case of conflicts during the subsequent mapping of descriptors to features in the universal schema. In general, the positionally highest ranking header value for each schema dimension are utilized and lower-ranking conflicting values are discarded.

3.2 Extraction from Parenthetical Lists

For some languages, inflected forms are presented inline next to the headword, instead of in a separate table, as shown for the German noun *Haus* 'house':

Haus n (*genitive* **Hauses**, *plural* **Häuser**, *diminutive* **Häuschen** n or **Häuslein** n)

Here, the italic n indicates a neuter noun. The inflection data inside the parentheses are extracted as simple tuples containing the lemma, inflected form, and inflectional relationship (e.g. **Haus**, **Häuser**, *plural*).

3.3 Improving Extraction Accuracy

The approach described above is sufficient to parse most Wiktionary data, but a large percentage of Wiktionary inflection tables do not use the correct tags to distinguish between header and content cells, an important component of the parsing procedure. In particular, table authors frequently use only the content cell tag to mark up all of a table's cells, and create "soft" headers with a distinct visual appearance by changing their styling (as with Czech verbs, such as *spadat* 'to be included, fall off'). This is indistinguishable to human viewers, but a naïve parse mistakes the soft headers for inflected forms with no descriptors. Hence we investigated several methods for robustly identifying improperly marked-up table headers and overriding the HTML cell-type tags in a preprocessing step.

Visual identification. Since most of the soft headers on Wiktionary have a distinct background color from the rest of their containing tables, we initially added a rule that treated content cells that defined a background color in HTML or inline CSS as header cells. However, the mere presence of this attribute was not a reliable indicator since some tables, such as those for Latin nouns (e.g. *aqua* 'water'), gave every cell a background color. This caused them to be erroneously considered to consist entirely of headers, resulting in missing data. Other tables used background color for highlighting, as with Faroese nouns (e.g. *vatn* 'water') and the **past historic** row in Figure 1, whose inflected forms were considered to be headers. For these reasons, visual cues were assessed as an unreliable method of identification.

Frequency-based methods. Another, more successful strategy for header discrimination header discrimination utilized the frequency characteristics of cell text, regardless of the cell's type. Although Wiktionary's inflection tables have many different layouts, words with the same language and part of speech pair often share a single template with consistent descriptors. In addition, many simple descriptors, such as **singular**, occur frequently throughout a single edition. Each inflected form, however, can be expected to appear on only a few pages (and in most cases just one). We exploited this tendency by counting the number of pages where each distinct cell text in a Wiktionary edition appeared, and, for each language, manually determined a cutoff point above which any cell with matching text was considered a header. Cells containing only punctuation were excluded from consideration, to avoid problems with dashes that occurred in many tables as a content cell indicating that no such form existed. This strategy surmounted all the problems identified thus far, including both the improper tagging of headers as content cells and the overspecification of background colors.

3.4 Mapping Inflected Forms to Universal Features

Using the results of the frequency-based preprocessing step to the table parsing algorithm, the first two authors manually inspected the list of parsed cells and their frequencies within each language, and then determined both a threshold for inclusion as a header feature (descriptor) and a universal representation for each header feature. When possible header features were above the threshold, but judged not to be contentful, they were not given a universal schema representation.

All inflected forms found by our scrape of Wiktionary were assigned complete universal representation vectors by looking up each of their Wiktionary descriptors using the mapping described in

the above paragraph and then concatenating the results. Any conflicts within a dimension were resolved using a positional heuristic that favored descriptors nearer to the inflected form in its original HTML table, with column headings assigned higher precedence than row headings, which had higher precedence to corner headings, based on an empirical assessment of positional accuracy in case of conflict.

Ultimately, the process of extraction and mapping yielded instantiated paradigms for 883,965 unique lemmas across 352 languages (of which 130 had more than 100 lemmas), with each inflected form of the lemma described by a vector of features from the universal morphological feature schema.

4   Seeding Morphological Analyzers

To test the accuracy, consistency, and utility of our Wiktionary extraction and feature mappings, the fully mapped data from the English edition of Wiktionary were used as input to Durrett and DeNero's (2013) morphological paradigm learner. While the results were comparable to those obtained by the hand-tooled and language-specific table parsers of Durrett and DeNero (2013) given an equivalent quantity of training data, the number of language and part of speech combinations which could be subjected to analysis using data from our general-purpose Wiktionary parser and mapping to features in the universal schema was far greater: 123 language-POS pairs (88 distinct languages) versus Durrett and DeNero's 5 pairs (3 languages).[2] In addition, when the available training data were increased from 500 lemmas to the full amount (a number that varied per language but was always > 2000), χ^2 tests demonstrated that the gain in wordform generation accuracy was statistically significant ($p < 0.05$) for 44% (14/32) of the tested language-POS pairs. In the language-POS pairs without significant gains, wordforms were predictable using smaller amounts of data. For example, nearly half (8/18) of the language-POS pairs in this category were nouns in Romance languages, whose pluralization patterns typically involve simply adding /-s/ or some similar variant. Some of the language-POS pairs with significant gains contained multiple inflection classes and/or morpheme altering processes such as vowel harmony, umlaut, or vowel shortening. These lin-

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[2]Language-POS pairs were considered to be suitable for analysis if they possessed 200 or more lemmas that exhibited the maximal paradigm possible.
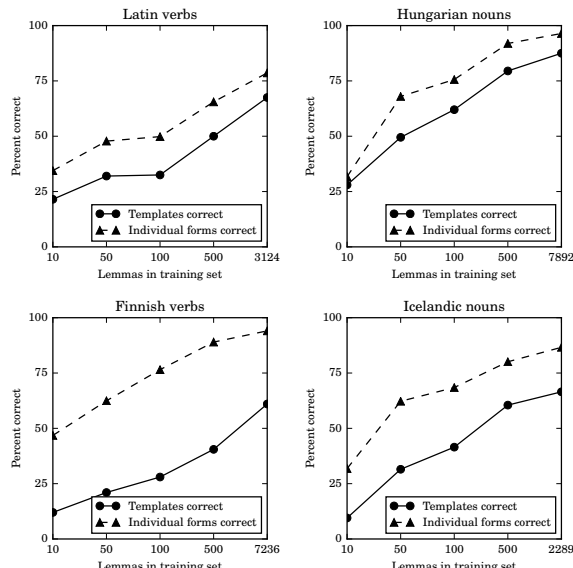

Figure 2: Examples of significant improvements in per-lemma paradigm and wordform generation accuracy with varying amounts of training data

guistic characteristics introduce complexity that reduces the number of exemplars of any given morpheme form, which increases the value of additional data. Figure 2 shows the influence of additional training data on paradigm and wordform generation accuracy for the four languages in which the addition of the full amount of training data provided the most significant improvement (all $p < 0.001$).

5   Conclusion

The proposed universal morphological feature schema incorporates findings from research in linguistic typology to provide a cross-linguistically applicable method of labeling inflectional morphemes according to their meaning. The schema offers many potential benefits for NLP and machine translation by facilitating direct meaning-to-meaning comparison and translation across language pairs. We have also developed original, robust and general multidimensional table parsing and feature mapping algorithms. We then applied these algorithms and universal schema to Wiktionary to generate a significant sharable resource, namely standardized universal feature representations for inflected wordforms from 883,965 instantiated paradigms across 352 languages. We have shown that these data can be used to successfully train morphological analysis tools, and that the increased amount of data available can significantly improve their accuracy.

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