Proposal for a Master's thesis

Typology of verbal valency systems: A quantitative study based on Universal Dependencies

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Draft as of December 22, 2022

Abstract

Issues of verbal valency has long occupied a central place in the study of argument structure and the interface between lexicon and grammar. However, the cross-lingual comparison of valency systems and their general typology have proved challenging due to both disagreements on the linguistic basis of comparison and the difficulty in arriving at categorical types. For this thesis, I propose clustering experiments on the automatic induction of valency frames and of verb classes using morphosyntactically annotated data from the Universal Dependencies (UD) treebanks and the interpretation and analysis of the results through information-theoretic metrics of complexity and similarity. The aim of the proposed quantitative typological study is to explore the utility and limits of unsupervised clustering methods and dependency-annotated corpora in the cross-lingual comparison of verbal valency systems, in hopes that it may also yield quantitative insights on the complex issue.

1 Introduction

Universal Dependencies (UD) treebanks, a multilingual collection of dependency treebanks based on a shared, cross-lingually consistent annotation scheme (Nivre et al., 2020) and covering 138 languages with 243 treebanks in its most recent `v2.11` release (Zeman, Nivre, et al., 2022), have enabled significant advances in the development of multilingual dependency parsers and other NLP technologies (Zeman, Hajič,

et al., 2018; Zeman, Popel, et al., 2017). This proposed thesis will explore their potential in typology research through a cross-lingual quantitative study of verbal valency systems.

The starting point of this study is the assumption, consistent with those behind Levin (1993) and other work on *verb classes*, that the syntactic behavior of verbs are at least in part determined by their lexical semantics, and that, as such, verb classes based on their syntactic distribution should be semantically coherent as well. This study will test this assumption computationally by performing clustering experiments on a subset of UD treebanks in order to explore whether the UD annotations support an automated induction of the valency frames in a language and whether verb classes can be further inducted based on the distribution of verbs across the valency frames. In the process of the experiments, factors that have an impact on the outcome of clustering, particularly with respect to data quantity and quality, as well as typological features of languages, will be examined. The results of these clustering experiments will then, in combination with a computationally derived cross-lingual lexicon, support typological investigations into possible universals in the organization of verbal lexicon.

This proposal itself is organized as follows: relevant literature on valency theory and dependency grammar is surveyed in §2 to provide the theoretical background for the proposed study; §3 formulates the key research questions the study seeks to address; §4 lays out the data sources and potential methodology to be used in the study; §5 reports on the preliminary results from a small pilot study; §6 provides a work plan and suggests a tentative timeline for completing the thesis; §7 concludes the proposal.

2 Background and related work

2.1 Valency and valency phenomena

In chemistry, *valency*, or *valence*, refers to the combining power of an atom or radical. The valency of any atom can be measured by the number of hydrogen atoms that it can combine with or displace in a chemical compound (Law and Rennie, 2020). This same term was introduced to linguistics by analogy and refers to the combining power of a word, primarily a verb or predicate, with other words or elements of the sentence.

Lucien Tesnière is generally credited with introducing the term valency to linguistics with his syntactic theory of valency and dependence, as presented in the posthumously published *Éléments de syntaxe structurale* (1959; English translation

2015).[1] In another of Tesnière's analogies, each verbal node, being the center of sentence structure, is not unlike a "theatrical performance" with the verb expressing the process and the nouns being the *actants* (what we would now call *arguments*) in this performance. Just like how atoms of different elements allow for a greater or lesser number of bonds, different verbs can combine with a greater or lesser number of actants, i.e., their valency.

While the term valency is borrowed into linguistics from chemistry, the study of the phenomena which are covered by or otherwise overlap with valency has a much longer tradition, dating to the early beginnings of linguistics from the kāraka concept of semantic relation between verb and noun (Ganeri, 2011) in Pāṇinian grammar to modern case grammar (Fillmore, 1968).

Implicit in the focus on verbal valency is the assumption, shared by most linguistic theories, of the centrality of the verb in determining either or both the syntactic and semantic structure of a sentence. This assumption has also been corroborated by psycholinguistic evidence (Healy and Miller, 1970) and places valency and the issues of *argument structure* squarely at the center of the inquiry into the interface between syntax and lexical semantics.

In generative grammar, the syntactic valency of a verb is treated under a similar notion of *subcategorization* (Chomsky, 1965). As an example, a transitive verb must be followed by a direct object, whereas an intransitive verb cannot. As such, transitive and intransitive verbs form subcategories of the category of verb. Verbs are thus further assigned to *subcategorization frames* which specify the number and type of complements, i.e., objects and obliques, (and of subjects as well in later theories), that the verb can be subcategorized for. In addition to being syntactically driven, a notable feature of generative theories' treatment of valency is that the subcategorization frames are considered as part of the lexical entry of the verb. Later work in generative grammar, in particular Jackendoff (1972, 1987, 1992), following Katz and Fodor (1963) and Gruber (1962), further developed a theory of thematic relations and posited that argument structure serves as the interface between syntactic and thematic structures.

As compared to broader distinctions such as those made between transitive and intransitive verbs, Levin (1993) categorized verbs in a much more fine-grained manner based on their syntactic behavior into different verb classes. Starting from the assumption that the syntactic behavior of verbs are determined semantically, Levin reasons that patterning together classes of verbs based on their diathesis alternations should result in semantically coherent verb classes. Levin's work has been highly in-

[1] It should be noted that while Tesnière is rightly credited with the introduction of a theory of linguistic valency, the metaphor of valency itself has made appearances as early as in Peirce (1897), among others (Przepiórkowski, 2018).

fluential both in the development of valency theory, where it spurred further work on verb classes, and in computational approaches to lexical semantics, where the VerbNet (Kipper et al., 2006, 2008; Kipper-Schuler, 2005) is a prominent example of projects extending the Levin verb classes into a computational lexicon that links with other resources such as WordNet (Fellbaum, 1998; Miller, 1995), PropBank (Kingsbury and Palmer, 2002) and FrameNet (C. F. Baker, Fillmore, et al., 1998; Fillmore and C. Baker, 2015).

Another computational project focused on verbal valency, FrameNet differs from VerbNet in terms of their theoretical foundations, in that it derives from a divergent line of research that stemmed from Charles Fillmore's frame semantics (Fillmore, 1977a,b, 1982), which in turn has its roots to his earlier work on case grammar (Fillmore, 1968, 1970). While they are often computationally interoperable to varying extents, there remains a key conceptual distinction made in frame semantics Fillmore (1968), namely the *frames*-driven analysis of argument encoding. While the verbal lexicon continues to play a role in placing selectional restrictions on the frames in which a given verb can be found in, the frames are themselves said to have semantics through their grouping of frame elements, which are similar to thematic roles but local to their specific frames. The frame semantics approach is consolidated by further development in construction grammar where the frames are viewed as a level of constructions on their own, cf. e.g., Goldberg (1992, 1995)'s *argument structure constructions*. Furthermore, construction grammar theories often argue for frames to be considered distinct or autonomous constructions, as it is not strictly predictable from other constructions.

2.2 Typological perspectives on valency and dependency

It is perhaps not surprising that, besides introducing the analogy of valency, Tesnière (1959) also introduced the notion of dependency into modern linguistics. In terms of their mathematical foundations, dependency grammar, based on the notion of dependencies, can be viewed in contrast with constituency grammars which are based on the notion of substitution instead (Stabler, 2019). However, even most iterations of generative grammar theories, which are primarily constituency-based, incorporate some version of a head-dependent relationship (cf. X-bar theory). de Marneffe and Nivre (2019) cited the easiness of generalization across languages, its operationalization of human sentence processing facts, and the transparency and simplicity of representation as reasons why dependency-based representations have become increasingly widely adopted in linguistic theory and even more so in NLP.

The usefulness of dependency grammar in allowing for cross-lingual generalizations and comparisons of linguistic structures should not be understated. Universal Dependencies (UD) (de Marneffe, Manning, et al., 2021; Nivre, 2015) is in partic-

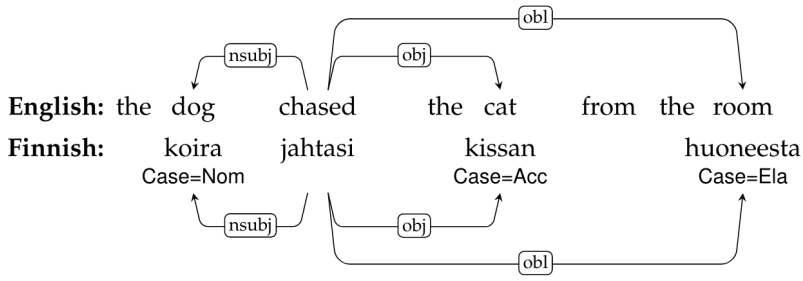

Figure 1: Simplified UD annotation for equivalent sentences from English (top) and Finnish (bottom) (de Marneffe, Manning, et al., 2021).

ular an initiative that develops a uniform grammatical annotation system that are cross-lingually consistent. The basic structure of the UD annotation is to segment *sentences* into *syntactic words* which are annotated with their *morphological properties* and linked together by *syntactic relations*. A comparison of UD annotations of equivalent sentences in two languages show how they can show both the structural parallel and differences between how two languages encode the same sentence:

Croft et al. (2017) address UD specifically and propose more typologically-informed modifications to the dependency annotations of UD.

Already Tesnière (1959) was paying attention to the cross-lingual differences in the argument structure of semantically equivalent sentences. Tesnière described the process of *metataxis*, by which syntactic structures of one language are "translated" to those of another. Such a process points to the key typological interest in valency systems, namely the mismatch between how languages encode the

In terms of possible universals, Tsunoda (1981, 1985) proposes a hierarchy of verbs:

Effective action » Perception » Pursuit » Knowledge » Feeling » Relation

Malchukov, 2005 takes the semantic map approach and proposes a two-dimensional transitivity hierarchy with the semantic map method.

C. F. Baker and Lorenzi (2020) and Ellsworth et al. (2021) explores the cross-lingual alignment of frames based on FrameNet; in contrast, Say (2014) rejects the equating of minor valency classes cross-lingually and studies how the individual verbs are grouped (verb classes)

Further work on verb class induction based on syntactic patterns includes Basili et al. (1993), Korhonen et al. (2006), Navarretta (2000), Sun and Korhonen (2009), and Sun, Korhonen, and Krymolowski (2008), Sun, McCarthy, et al. (2013) in particular includes diathesis alternation as input feature. Schulte im Walde (2003, 2006) and Schulte im Walde and Brew (2002) in German; Snider and Diab (2006) in Arabic.

Other work focus on the induction of semantic verb classes such as Fürstenau and Rambow (2012), Majewska, McCarthy, et al. (2018), and Majewska, Vulić, et al. (2020)

Some related work on semantic role induction: Abend et al. (2009), Bickel et al. (2014), Dowty (1991), Sayeed et al. (2018), Titov and Klementiev (2012), Watanabe et al. (2010), and Yamada et al. (2021)

3 Research questions

The aim of this thesis study is twofold: the first is exploratory and computational, namely whether the existing computational resources based on dependency grammar can be effectively utilized in quantitative typology; the second is investigative and typological, whether a corpus-based study of valency features reveals patterns or universals in how languages organize their valency systems.

Levin (1993) observes in her study of English verb classes that

> Distinctions induced by diathesis alternations help to provide insights into verb meaning, and more generally into the organization of the English verb lexicon, that might not otherwise be apparent, bringing out unexpected similarities and differences between verb. (p.15)

A typological study extends this aims to examine linguistic universals in verb lexicon organization that may not be obvious within a monolingual study. Will we see cross-lingual patterns or universals in how verb classes aggregate and within each cross-lingual clusters, different strategies being used to encode the verb classes? If a universal exists for a hierarchy of transitive verbs for example, this should show up in the verb classes. In construction grammar: different strategies for the same construction, e.g. adpositions and case markings

If we consider valency frames primarily a feature of the verbal lexicon, then cross-lingually, this means the comparison of the distribution of verbs across different verb classes and valency frames allows us to test possible universals regarding the organization of the verbal lexicon. The object of cross-lingual comparison therefore is crucially *not* the valency frames or verb classes themselves, but the organization of the frames and classes.

Difficulty in a finite categorical classification of valency class systems, can be overcome through statistical, information theoretic methods.

4 Data and methodology

This section presents the proposed data sources and methodology of the thesis. §4.1 introduces the Universal Dependencies treebanks as well as additional resources that

Language	#	Sents	Words	Language	#	Sents	Words	Language	#	Sents	Words
Afrikaans	1	1,934	49,276	German	4	208,440	3,753,947	Old Russian	2	17,548	168,522
Akkadian	1	101	1,852	Gothic	1	5,401	55,336	Persian	1	5,997	152,920
Amharic	1	1,074	10,010	Greek	1	2,521	63,441	Polish	3	40,398	499,392
Ancient Greek	2	30,999	416,988	Hebrew	1	6,216	161,417	Portuguese	3	22,443	570,543
Arabic	3	28,402	1,042,024	Hindi	2	17,647	375,533	Romanian	3	25,858	551,932
Armenian	1	2502	52630	Hindi English	1	1,898	26,909	Russian	4	71,183	1,262,206
Assyrian	1	57	453	Hungarian	1	1,800	42,032	Sanskrit	1	230	1,843
Bambara	1	1,026	13,823	Indonesian	2	6,593	141,823	Scottish Gaelic	1	2,193	42,848
Basque	1	8,993	121,443	Irish	1	1,763	40,572	Serbian	1	4,384	97,673
Belarusian	1	637	13,325	Italian	6	35,481	811,522	Skolt Sámi	1	36	321
Bhojpuri	1	254	4,881	Japanese	4	67,117	1,498,560	Slovak	1	10,604	106,043
Breton	1	888	10,054	Karelian	1	228	3,094	Slovenian	2	11,188	170,158
Bulgarian	1	11,138	156,149	Kazakh	1	1,078	10,536	Spanish	3	34,693	1,004,443
Buryat	1	927	10,185	Komi Permyak	1	49	399	Swedish	3	12,269	206,855
Cantonese	1	1,004	13,918	Komi Zyrian	2	327	3,463	Swedish Sign Language	1	203	1,610
Catalan	1	16,678	531,971	Korean	3	34,702	446,996	Swiss German	1	100	1,444
Chinese	5	12,449	285,127	Kurmanji	1	754	1,0260	Tagalog	1	55	292
Classical Chinese	1	15,115	74,770	Latin	3	41,695	582,336	Tamil	1	600	9,581
Coptic	1	1,575	40,034	Latvian	1	13,643	219,955	Telugu	1	1,328	6,465
Croatian	1	9,010	199,409	Lithuanian	2	3,905	75,403	Thai	1	1,000	22,322
Czech	5	127,507	2,222,163	Livvi	1	125	1,632	Turkish	3	9,437	91,626
Danish	1	5,512	100,733	Maltese	1	2,074	44,162	Ukrainian	1	7,060	122,091
Dutch	2	20,916	306,503	Marathi	1	466	3,849	Upper Sorbian	1	646	11,196
English	7	35,791	620,509	Mbyá Guaraní	2	1,144	13,089	Urdu	1	5,130	138,077
Erzya	1	1,550	15,790	Moksha	1	65	561	Uyghur	1	3,456	40,236
Estonian	2	32,634	465,015	Naija	1	948	12,863	Vietnamese	1	3,000	43,754
Faroese	1	1,208	10,002	North Sámi	1	3,122	26,845	Warlpiri	1	55	314
Finnish	3	34,859	377,619	Norwegian	3	42,869	666,984	Welsh	1	956	16,989
French	7	45,074	1,157,171	Old Church Slavonic	1	6,338	57,563	Wolof	1	2,107	44,258
Galician	2	4,993	164,385	Old French	1	17,678	170,741	Yoruba	1	100	2,664

Table 1: Languages in UD v2.5 with number of treebanks (#), sentences (Sents) and words (Words) (Nivre et al., 2020).

will be used as reference and validation in this study. The rest of the section, §4.2-4.5, presents the main computational methods to be used in the thesis.

4.1 Data sources

Universal Dependencies (UD) is designed to be a cross-linguistically consistent system for annotating morphosyntactic information within a dependency grammar framework (de Marneffe, Manning, et al., 2021). The UD treebanks (Zeman, Nivre, et al., 2022) is the collection of cross-lingual treebanks annotated in the UD framework by an open community of more than 300 contributors. See 1 for a table of languages available in UD v2.5, as an example.

A subset of the UD treebanks, the **Parallel Universal Dependencies (PUD)** treebanks were originally developed for the CoNLL-2017 Shared Task (Zeman, Popel, et al., 2017) and include 1000 sentences in 18 languages that were randomly picked

from newswire and Wikipedia and annotated according to UD v2 guidelines. The 18 languages are English, German, French, Italian, Spanish, Arabic, Hindi, Chinese, Indonesian, Japanese, Korean, Portuguese, Russian, Thai, Turkish, Czech, Finnish and Swedish. Of the sentences, 750 were originally English, while the remaining 250 sentences come from German, French, Italian and Spanish texts and translated to other languages through English. While facing obvious limitation in terms of language coverage, corpus size, and possible artifacts due to the so-called "translationese", parallel corpora allow for cross-lingual comparison with a smaller data size and will also be considered in this thesis.

In additional to the main data source of UD treebanks, additional resources will be used in the study as reference and to perform validation and evaluation of the intermediate results. As an example, the valency frames and verb classes as induced from the UD treebanks will be validated, where possible, against the expert-annotated data from **ValPaL**(Hartmann et al., 2013).

introduce ValPaL a bit more, mention VerbNet, PropBank, FrameNet as necessary

4.2 Representing verb instances / feature selection

In the first step, the specific uses of verbs are abstracted through a feature selection process. Each instance of verb use will be represented by syntactic features of the sentence, namely only features that are considered part of valency frame encoding are included. This is in order to focus on whether semantically coherent verb classes can be induced on valency frame information alone. In selecting the features, cross-lingual differences in valency frame coding will be taken into account, e.g. whether a language uses morphological cases or word order to encode valency frame information.

Examples from EN, DE, ZH

4.3 Clustering

The clustering process after feature selection consists of two steps, but the clustering algorithms used need not be the same. The first is the automatic induction of valency frames in a language given the selected features. Given the valency frames in a language, each verb will then be represented by its distribution over the valency frames, which are then clustered into the verb classes. Since we intend to perform unsupervised clustering, the number of valency frames and the number of verb classes are not known beforehand. This requires either using of algorithms that do not require a predefined number of clusters (e.g. Ward clustering), or experimenting with cluster

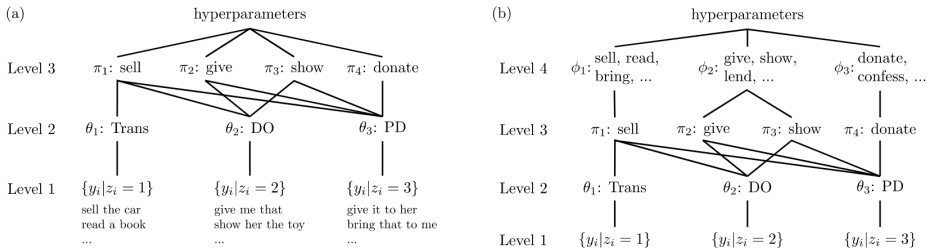

Figure 2: (a) Model 1, a Hierarchical Dirichlet Process applied to learning verb argument structure constructions. (b) Model 2, an extension of Model 1 to learn verb alternation classes.

sizes with each language (cf. Schulte im Walde, 2006, which used the k-means algorithm with a predefined the gold standard number). Due to the lack the gold standard for many of the languages to be experimented on, the latter seems preferable. The agglomerative clustering method will be used.

Given the relative low dimensionality of hand-selected features, complex clustering algorithms are not anticipated to be necessary. Nevertheless, other clustering algorithms should also be investigated (Xu and Tian, 2015). Given the two levels of clustering, an approach to be explored is the Hierarchical Dirichlet process, which is particularly suited for clustering grouped data (cf. Parisien and Stevenson (2010), Fig. 2, where a Hierarchical Dirichlet process was extended to account for diathesis alternations).

4.4 Cross-lingual verb sense alignment

A cross-lingual aligned list of counterpart verbs will be needed to compare the verb classes and valency frames. The easiest way to do this is likely through existing cross-lingual word lists such as LanguageNet, part of the PanLex project. http://uakari.ling.washington.edu/languagenet/available/

Alternatively, lexicon induction from cross-lingual word embeddings and other NLP methods may also be considered.

4.5 Information theory

Complexity and point-wise mutual information, cf. in Say (2014).

Complexity & Point-wise mutual information (PMI)

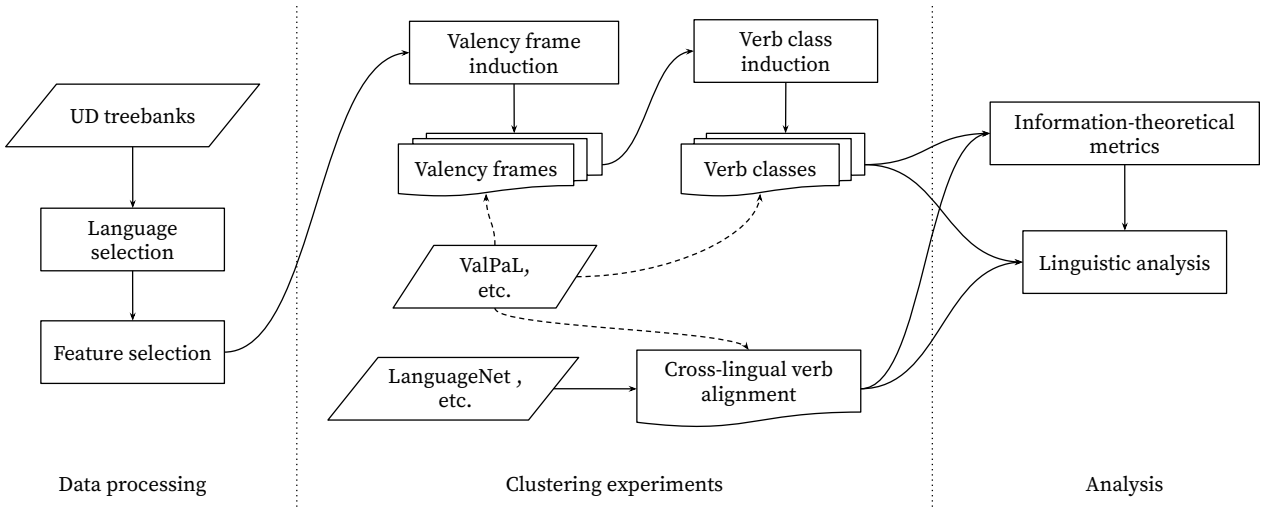

Figure 3: Flowchart depicting the data sources and processes as described in the proposal. Dotted lines depict validation steps.

5 Preliminary results

This section will present preliminary results of a small pilot study where verb clustering is done on English and German treebanks from the Parallel UD dataset and the results are compared against the ValPaL database and manually inspected. (work-in-progress)

6 Work plan

This section presents a work plan and the tentative timeline for the thesis project.

describe the processes

This thesis study is intended to be completed within roughly three months after the submission of this proposal, with a statutory maximum of six months.

Given time constraints, an iterative process is envisioned and priority will be put on completing a functional pipeline of the computational part already in the first month of the work, i.e. January, allowing for more flexibility later in the project. Iterative improvements will then be made upon the code and alternate methods tested. The primary experimental parts should conclude by the end of second month to allow for time needed for the write-up and revisions in the final month.

7 Conclusion

This thesis aims to contribute to the study of valency by using corpus linguistic approaches. The aim of study is not dissimilar to that of projects such as ValPaL or studies by Say (2014) but instead of focusing on a limited set of samples, it attempts to make the best use of the available cross-lingual corpora. Exploring linguistic universals regarding the organization of verb lexicon and valency systems contributes to the overall project of typological investigations, as well as shedding new light on the valency theories.

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