

Saarland University  
Department of Language Science and Technology  
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**Master's Thesis**

**EXPLORING CROSS-LINGUISTIC  
PATTERNS IN VERBAL VALENCY**

A QUANTITATIVE TYPOLOGICAL STUDY

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## ACKNOWLEDGMENTS

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# ABSTRACT

Issues of verbal valency have long occupied a central place in the study of language structure, as it stands at the interface between syntax and semantics, as well as between grammar and lexicon. However, the cross-lingual comparison of valency systems and their general typology have proved challenging due to both disagreements on the basis of comparison and the difficulty in arriving at categorical types. This thesis advocates a quantitative and functionalist approach to tackling this challenge. Using morphosyntactically annotated data from the Universal Dependencies (UD) treebanks, it experiments with corpus-based transitivity ratio metrics and novel entropy-based measures for valency system analysis. These experiments reveal areal and genetic patterns of transitivity among languages and suggest universal effects of learnability and efficiency on valency systems. In doing so, it hopes to contribute to a better understanding of verb valency typology and its underlying drivers.





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# CHAPTER 1.

## INTRODUCTION

Verbal valency deals with the relationship between verbs and their arguments, such as subjects and objects. It occupies a central place in investigations into language structure, as it lies at the interface between syntax and semantics, as well as between grammar and lexicon. It also exhibits considerable cross-lingual variations. A typological study of verb valency is therefore crucial to getting a better picture of the range and pattern of variations as well as to understanding the underlying causes of the similarities and differences. However, the study of cross-lingual differences and similarities in valency systems is not without difficulties. This reflects a diversity of both theoretical and methodological challenges that result from the same central role valency plays in language structure.

On the theoretical side, valency frames is alternately viewed either as syntactic expressions of lexical semantics, where the argument structure is determined by verbal meaning, or constructions in their own right that interact with verbs and their arguments to produce sentence meaning. The corollary of this debate extends to the relationship between valency structures and the lexicon: whereas the former view favors a lexeme-based approach, where valency information is an inherent part of a verb's lexical entry, the latter advocates a frame-based approach, where the valency frames are separate constructions with its own semantic contribution associated with but not determined by the verb.

The theoretical debates inevitably have implications for typological research on valency and, of greater interest to typology, valency systems. Most prominently, this makes agreeing on a sound *tertium comparationis* (Latin for “the third part of comparison”), or shared point of comparison, difficult. A lexeme-based approach would argue for verb classes to be the basis of comparison between languages, while a frame-based approach would attempt to find cross-lingually valid valency frames and see how they are distributed in different languages. However, regardless of the view subscribed, features of valency systems on their own pose methodological challenges. This is namely due to

## *Chapter 1. Introduction*

the fact that neither verb classes nor valency frames lend themselves to easy categorical types of how a language organize them, at least not in the same way a language can be said to have a SOV, SVO or OSV word order.

Such theoretical and methodological complexity also translates to challenges in formulating any expected cross-lingual similarities and differences and what may have caused them. This present thesis makes an attempt to address them. The goal of the study is twofold: (1) Firstly, it advocates for a quantitative and functionalist approach to the study of verb valency. By employing empirical and corpus-based methods, this approach remains relatively theory-agnostic and enables the characterization of valency systems without relying on rigid categorical types, which in turn facilitates cross-lingual comparison; (2) Secondly, it seeks to be explanatory as well and uses the methods developed to identify typological differences across languages as well the test hypotheses for possible universals motivated by view of language as having evolved for communication and thus language structure as reflecting pressures in the communication context.

The remainder of this thesis is structured as follows: §2 provides more background and theoretical framework on functional typology, dependency grammar, and valency grammar. The main data source, Universal Dependencies treebanks, is introduced in §3, where its suitability to typological research in general and compatibility with this study in particular are highlighted. §4 presents a first experiment using corpus-based versions of the transitivity ratio metric and shows that they reveal areal and genetic patterns of transitivity among languages. §5 introduces a further set of experiments using novel entropy-based metrics to measure the average surprisal of valency frames given the verb and vice versa. Hypotheses regarding the correlation between these metrics and verb or valency frame frequency are posited and tested, suggesting that learnability and efficiency effects shape valency structures of languages in a universal way. Lastly, §6 discusses the implications as well as limitations of the studies, suggests future directions, and concludes the thesis.

## CHAPTER 2.

# BACKGROUND AND THEORETICAL FRAMEWORK

### 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).<sup>1</sup> 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

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<sup>1</sup>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).

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 influential 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). 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), Sun, Korhonen, and Krymolowski (2008), and Sun, McCarthy, et al. (2013) in English, Schulte im Walde (2003, 2006) and Schulte im Walde and Brew (2002) in German, Snider and Diab (2006) in Arabic. Sun, McCarthy, et al. (2013) in particular included diathesis alternation as input feature. Other work focused instead on the induction of semantic verb classes such as Fürstenau and Rambow (2012), Majewska, McCarthy, et al. (2018), and Majewska, Vulić, et al. (2020). And work such as 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), among others, worked on the induction of semantic roles, a topic arguably tightly related to the induction of

## 2.2. Typological perspectives on valency and dependency

the verb classes.

Another computational project focused on verbal valency, FrameNet (C. F. Baker, Fillmore, et al., 1998; Fillmore and C. Baker, 2015) 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 in his earlier work on case grammar (Fillmore, 1968, 1970). While they are often computationally interoperable to some extent, 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) in particular is an initiative that aims to develop a uniform grammatical annota-

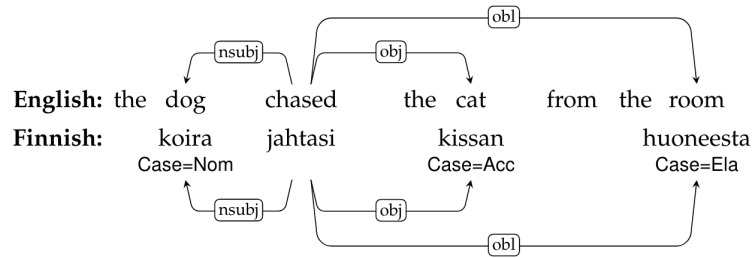


Figure 2.1.: Simplified UD annotation for equivalent sentences from English (top) and Finnish (bottom) (de Marneffe, Manning, et al., 2021).

tion 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 shows how they can show both the structural parallel and differences between how two languages encode the same sentence, as seen in Fig. 2.1, where both the similarities between how English and Finnish encoded semantically equivalent sentences (same syntactic relationships between the arguments and the verb) and the differences (case markings in Finnish, preposition in English) are easily discernable. And further enhancements have also been proposed that would make the UD annotation scheme more compatible with contemporary typological theory (Croft et al., 2017).

Specifically on verbal valency, already Tesnière (1959) was paying attention to the cross-lingual differences in the argument structure of semantically equivalent sentences while describing his dependency grammar. 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 clear typological interest in valency systems, namely the mismatch between how languages encode their argument structure.

#### transitivity

In terms of possible universals that can be observed, Tsunoda (1981, 1985) proposed a transitivity hierarchy of verbs:

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

The idea is that languages that encode verbs that are lower in this hierarchy as transitive verbs will encode all those above them too as transitive, with the



## *2.2. Typological perspectives on valency and dependency*

effective action being the most prototypical transitive verb, hence most likely to be transitive in a language. This approach is further extended by Malchukov (2005) who used the semantic map method and proposed a two-dimensional transitivity hierarchy with the semantic map method.

There has been some recent work from advocates of both the lexeme- and frames-based approaches on the cross-lingual alignment of their respective units of linguistic analysis. On the frames-based side, C. F. Baker and Lorenzi (2020) and Ellsworth et al. (2021) explored the cross-lingual alignment of frames based on FrameNet; in contrast, Say (2014) rejected the equating of minor valency classes cross-lingually and studied how verb classes compare cross-lingually instead, seeing that as a more valid method of measuring how languages organize their verbal lexicon differently.



## CHAPTER 3.

### DATA

#### 3.1. UNIVERSAL DEPENDENCIES

this section will be reworked

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.

**Universal Dependencies (UD)** is the main source of primary data used for the present study. It is designed as a cross-linguistically consistent system for annotating morphosyntactic information within a dependency grammar framework (de Marneffe, Manning, et al., 2021).

The v2 update to the UD annotation guidelines also introduced changes that intend to decrease the reliance on language-specific categories (Nivre et al., 2020). Inevitably, these efforts had to be balanced against the practicality of computational efficiency but nevertheless converged in many cases with proposals by typologists, as the core principles converged with a functional typology approach. Croft et al. (2017)

1. UD needs to be satisfactory on linguistic analysis grounds for individual languages.
2. UD needs to be good for linguistic typology, i.e., providing a suitable basis for bringing out cross-linguistic parallelism across languages and language families.
3. UD must be suitable for rapid, consistent annotation by a human annotator.

### Chapter 3. Data

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

- UD must be easily comprehended and used by a non-linguist, whether a language learner or an engineer with prosaic needs for language processing. We refer to this as seeking a *habitable* design, and it leads us to favor traditional grammar notions and terminology.
- UD must be suitable for computer parsing with high accuracy.
- UD must support well downstream language understanding tasks (relation extraction, reading comprehension, machine translation, ...).

The **Universal Dependencies** 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 3.1 for a table of languages available in UD v2.5, as an example.

The thesis uses the UD v2.11 release.

### 3.2. DATA SELECTION

Explain the choices made in data selection, exclusions of certain tree-banks e.g. L2 speakers, code-switch, lemmatization issues, unavailable texts



## CHAPTER 4.

# COMPARING TRANSITIVITY ACROSS LANGUAGES

### 4.1. FROM TRANSITIVITY CATEGORIES TO TRANSITIVITY RATIOS

It is logical when doing cross-linguistic comparison to start with simpler metrics and features before developing to more complex ones. On the one hand, it is true that regardless of how we approach the task of verb classification, i.e., to categorize the verbs of a language into verb classes according to their syntacto-semantic properties and behavior, we would expect to arrive at fine-grained verb classes à la Levin (1993) in the end. On the other hand, such an expectation does not render obsolete the more basic distinctions like that of verb *transitivity*. In part, this is due to their utility as convenient starting points of comparison for verbs within a language, but their simplicity also translates to being more cross-lingually valid bases of typological comparison.

This first experiment deals with metrics of *transitivity*, i.e., the ability of a verb to take one or more objects. It is surely a more familiar and intuitive concept as compared to the finer-grained metrics of valency to follow in the experiments in the next chapter. In traditional grammars, a basic binary distinction is made between *intransitive* verbs, which take only a subject and no objects and *transitive* verbs, which take one or more objects. Additional categories, some overlapping, make finer distinctions, such as *ditransitive* verbs (those taking two objects), *ambitransitive* verbs (those that can be used both transitively and intransitively), etc.

I focus here on the simple distinction between transitive and intransitive verbs, but, hewing to a functional and quantitative outlook, find that binary categories do not sufficiently capture the nuances of verb use. An example illustrating why comes from the study of near-synonyms: (Biber et al., 1998), an early corpus linguistics study, compares the English verbs *begin* and *start* in the British National Corpus (BNC). At first glance, English appears to have

provided us with two verbs that are not only semantically synonymous but share valency properties as well, as they can both be used in transitive and intransitive constructions:

- (1) a. I had better issue a survival kit before we *start/begin*.  
**intransitive**
- b. Then they *started/began* the quota system.  
**transitive with noun phrase**
- c. They'd *started/begun* leaving before I arrived.  
**transitive with -ing clause**
- d. One of the wheels had *started/begun* to wobble.  
**transitive with to clause**

This however belies their different usage patterns as observed in the BNC: while both uses are clearly grammatical for both verbs, *begin* is used more often in a transitive frame than *start* across different genres in the BNC: in fiction, 78% of *begin* occurrences (196/250) are with various transitive patterns vs. only 60% for *start* (149/250); transitive uses are less frequent in academic texts in general but the observation of relatively higher transitivity for *begin* still holds (57% vs. 36%, or 110/192 vs. 51/142).

To capture such differences in levels of transitivity, I propose measuring **transitivity ratios** based on language corpora, defined as the percentage of verb instances that are transitive. The verbs of a language can then be thought of as on a spectrum of transitivity, with strictly intransitive verbs on the one end, strictly transitive verbs on the opposite end, and all other verbs<sup>1</sup> somewhere in between.

## 4.2. EXPERIMENT 1: TOKEN-LEVEL TRANSITIVITY RATIOS

### 4.2.1. CALCULATING TRANSITIVITY RATIO FROM UD

Necessarily then, and in contrast with transitivity categories, any values are calculated on an *ad hoc* basis in a given corpus. Unless we expect the corpus to be a representative sample of all language use in that language, which is certainly not the case for the UD corpora used here, the absolute values of these ratios at a lexeme-level cannot be directly interpreted. Instead, intralinguistic

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<sup>1</sup>Note that not all of them are ambitransitive verbs, as the approach here is only concerned with the surface realization of transitivity. In particular, this means instances of pro-drop of objects are counted as intransitive, where some would argue for a null object analysis instead.



#### 4.2. Experiment 1: Token-level transitivity ratios

analysis will take the form of analyzing the distribution of verbs according to their observed transitivity ratios. I take on an additional assumption, that the corpus would reflect the general tendency towards (in-)transitivity of the language, if too piecemeal for individual verbs, which justifies the cross-lingual comparison of transitivity ratios at a token-level as well.

The UD annotation scheme facilitates the investigation of transitivity at lexeme- and token-levels, as the relevant dependency relations `NSUBJ` and `OBJ` mark respectively the first and second core arguments of a verb with their typical syntactic roles as subject and object. This is defined without respect to specific cases (even though typically the nominative and the accusative in languages with a case system) or semantic roles (even though they would typically be the proto-agent and the proto-patient) in an effort to avoid *a priori* categories to the extent possible. The renaming of the `DOBJ` relation to `OBJ`, among the changes introduced by UD v2 (Nivre et al., 2020), reflects the same laudable effort.

Despite the typologically sound UD dependency relation annotations, arriving at a clear definition of transitivity ratio in the UD context is still not trivial upon close examination. In fact, I consider four different definitions of a quantitative transitivity ratio within the UD annotation scheme here:

1. the ratio of verb instances with both `NSUBJ` and `OBJ` dependents, as compared to verb instances with an `NSUBJ` dependent
2. the ratio of verb instances with an `OBJ` dependent, as compared to verb instances with an `NSUBJ` dependent
3. the ratio of verb instances with an `OBJ` dependent, as compared to all verb instances
4. the ratio of verb instances with an `OBJ` dependent, as compared to verb instances with either an `NSUBJ` or an `OBJ` dependent

Def. 1 is an attempt at enforcing a definition of the transitive object as the *second* core argument of the verb by excluding from calculation instances where the first core argument (i.e., subject) is not realized. This turns out counterproductive for two reasons. Firstly, this does not sit well with the core definition on transitivity, as instances of verb use where the subject is not expressed should not count against the fact that the verb is taking a transitive object; secondly, this is undesirable in practice when accounting for typological variations, as the metric would be biased against pro-drop languages that drops subject pronouns more often than objects such as Spanish.

Revising def. 1 and dropping the requirement in the numerator for verbs to have an NSUBJ dependent gives us def. 2. However, this is not sufficient, as the opposite problem surfaces, where subject-dropping languages are likely to have a smaller denominator, resulting in a high transitivity ratio that is not representative. Def. 3 drops the NSUBJ requirement from the denominator as well. This still faces problems, as verb instances where both subject and object are dropped would affect the denominator, and such usage, e.g., non-predicative usage of verbs, is unlikely to be equally frequent in different languages and would therefore interfere with the cross-lingual comparability of our transitivity ratio focusing on argument structure of verb predicates. Taking all these potential drawbacks into consideration, we arrive at def. 4 with the number of verb instances with either an NSUBJ or an OBJ dependent in the denominator.

#	Definition
1	$[+NSUBJ, +OBJ] / [+SUBJ]$
2	$[+OBJ] / [+NSUBJ]$
3	$[+OBJ] / [\pm NSUBJ, \pm OBJ]$
4	$[+OBJ] / [+NSUBJ] \text{ or } [+OBJ]$

Table 4.1.: Potential definitions of transitivity ratio considered in §4.2, represented with feature matrices

While there is a strong case for Def. 4 being the most principled definition, I nevertheless implement all four definitions in this experiment to empirically verify the intuitions. They are also represented with feature matrices in Tab. 4.1 for quick reference.

#### 4.2.2. TRANSITIVITY RATIOS AND THE LEXICON

Transitivity ratio statistics for each verb lexeme based on the definitions are first compiled. From there, per-language statistics that will become the basis for our cross-lingual comparison are computed: I calculate the lexeme-level and token-level transitivity ratios for each language, respectively the arithmetic mean of the lexeme transitivity ratios and the mean of lexeme transitivity ratios weighted by the frequency of the lexeme. In addition to the transitivity ratio metrics, an additional metric, percentage of transitive verbs, i.e., the percentage of verbs in the observed lexicon that are not strictly intransitive (defined as never observed to take an OBJ), is calculated for comparison purposes, as it should correspond better with the traditional binary distinction between transitive and intransitive verbs.

#### 4.2. Experiment 1: Token-level transitivity ratios

I perform the experiment on the selected subset of UD data as described in §???. For the analysis, I include only languages with at least 100 observed verb lexemes (56 out of 79 languages); the full results from the experiments can be found in the accompanying data and appendices.

def.	lexeme tr., token tr.	tr. verb %, lexeme tr.	tr. verb %, token tr.
1	$\rho(54) = .83, p = .000$	$\rho(54) = .61, p = .000$	$\rho(54) = .70, p = .000$
2	$\rho(54) = .81, p = .000$	$\rho(54) = -.17, p = .221$	$\rho(54) = -.03, p = .817$
3	$\rho(54) = .77, p = .000$	$\rho(54) = .64, p = .000$	$\rho(54) = .73, p = .000$
4	$\rho(54) = .87, p = .000$	$\rho(54) = .61, p = .000$	$\rho(54) = .61, p = .000$

Table 4.2.: Spearman’s rank correlation between the transitivity metrics

To compare between the different definitions of transitivity, we compute Spearman’s rank correlations between the lexeme- and token-level means of transitivity ratios according to each of our four definitions, as well as between the transitive verb percentage and each of them. The correlation statistics are listed in Tab. 4.2. We observe overall strong correlations between the mean transitivity ratios at lexeme- and token-levels for all four definitions, with the highest observed for definition 4 ( $\rho(54) = .87, p = .000$ ) and lowest observed for definition 3 ( $\rho(54) = .77, p = .000$ ). The strong correlation is not surprising as we have no reason to expect the more frequent verbs to behave differently from the less frequent verbs with regard to transitivity ratios. This can also be confirmed by correlation tests between verb frequency and verb transitivity ratios for each language, which show no strong correlation.

The correlation statistics between the transitive verb percentages and the transitivity ratios are slightly more revealing. If nothing else, they help us eliminate definition 2 from the competition as it shows no statistically significant correlation ( $\rho(54) = -.17, p = .221$  for lexeme-level transitivity ratios and  $\rho(54) = -.03, p = .817$  for token-level) while strong correlations are observed for all three other definitions (see Tab. 4.2).

In the absence of a practical reason based on correlation statistics to select a definition among the remaining three over the others, the rest of the analysis uses def. 4, which I have considered *a priori* to be the most principled. Further intralinguistic analyses are done by plotting histograms of the distributions of verbs among the transitivity ratios in different languages, as shown in Fig. 4.1.

Most distributions are bimodal with peak at both ends, which supports the overall cross-lingual validity of a binary conception of transitivity. But exceptions abound as well, among others Indonesian (unimodal with peak in the

middle), Catalan, Galician, Spanish (unimodal with peak on right). And even between the bimodal distributions, they are notably rarely symmetric, with differing levels of skew towards either end.

#### 4.2.3. GENETIC AND AREAL PATTERNS IN TRANSITIVITY

Language	# Verbs	Tr. verb %	Language	# Verbs	Tr. verb %
Catalan	627	98.2%	Hebrew	531	52.0%
Spanish	941	92.9%	O.C. Slavonic	211	54.5%
Indonesian	330	91.2%	Slovak	279	55.9%
French	733	90.9%	Lithuanian	212	58.0%
German	1998	89.7%	Gothic	195	58.5%
Norwegian	765	89.7%	Russian	2558	59.3%
Galician	339	88.8%	Japanese	381	61.2%
English	771	88.7%	Polish	1059	61.9%
Danish	212	88.7%	Latvian	787	63.8%
Naija	200	88.5%	Coptic	127	65.4%
...	...	...	...	...	...

(a) by transitive verb percentage

Language	# Verbs	Token tr.	Language	# Verbs	Token tr.
Catalan	627	75.9%	Irish	107	30.9%
Galician	339	70.4%	Faroese	114	32.5%
Afrikaans	117	65.1%	Hebrew	531	33.5%
Vietnamese	150	64.2%	Japanese	381	33.5%
Cl. Chinese	1166	63.8%	Polish	1059	34.1%
Chinese	369	62.9%	Russian	2558	37.4%
Pomak	229	61.8%	Dutch	497	37.5%
Spanish	941	61.1%	Latvian	787	37.7%
Hindi	202	60.7%	Serbian	214	38.4%
Anc. Greek	1111	58.5%	Arabic	407	39.7%
...	...	...	...	...	...

(b) by token-level transitivity ratio

Table 4.3.: Most and least transitive languages by different metrics

Tab. 4.3a and 4.3b list the most and least ‘transitive’ languages in our study, respectively according to the transitive verb percentage and the token-level transitivity ratio. Recall that token-level transitivity ratios are favored over lexeme-level ones for cross-lingual comparison.

Among the most transitive languages are Romance (Catalan, Spanish, French,

#### 4.2. Experiment 1: Token-level transitivity ratios

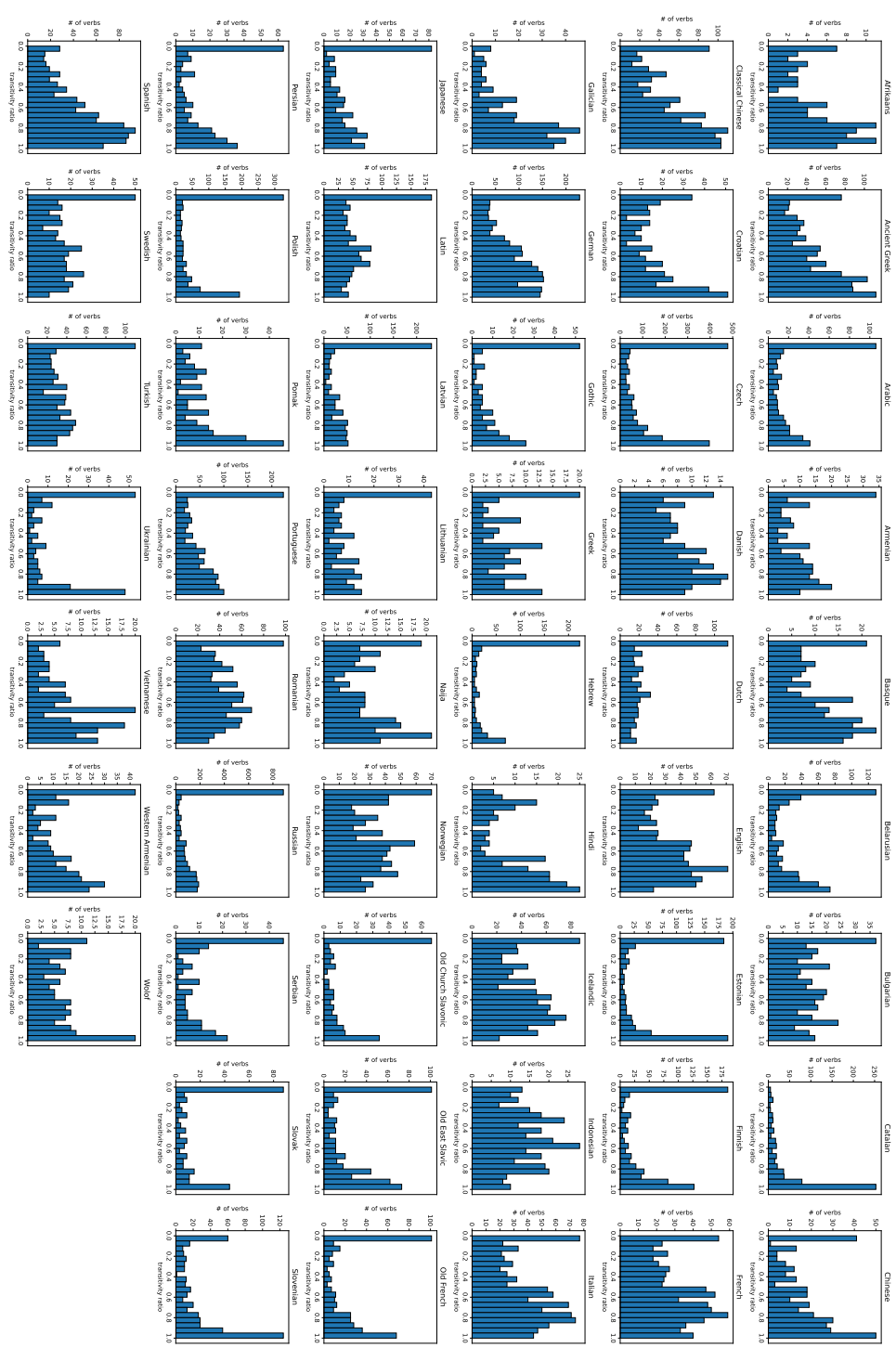
Galician) and Germanic (German, Norwegian, English, Danish) languages of Europe, Sinitic languages (Chinese, Classical Chinese, particularly when measured by token-level transitivity ratio), Indonesian, Hindi. On the opposite end of the spectrum are Hebrew, Irish, Japanese, as well as Baltic (Lithuanian, Latvian) and Slavic (Slovak, Russian, Polish) languages, which have the lowest transitivity ratios.

To look at any potential areal patterns in transitivity, the token-level transitivity ratio results for European languages are also mapped in Fig. 4.2. (A less Eurocentric study of areal patterns is unfortunately difficult for the lack of enough language samples in the UD.) A particularly high transitivity area can be observed in the Iberian peninsular as well as another relatively high transitivity area in the Balkans, in contrast to eastern and northern Europe with lower transitivity.

Where the languages overlap, these observations match well with those from Say (2014)'s survey of transitivity in European languages (as measured by the percentage of verbs that are transitive from a fixed list), who observed high transitivity areas in western Europe except Irish and south-western Balkans, and a corresponding low transitivity area in eastern Europe.

## Chapter 4. Comparing transitivity across languages

Figure 4.1.: Histograms showing the binned distributions of verbs according to their transitivity ratio in different languages



## 4.2. Experiment 1: Token-level transitivity ratios

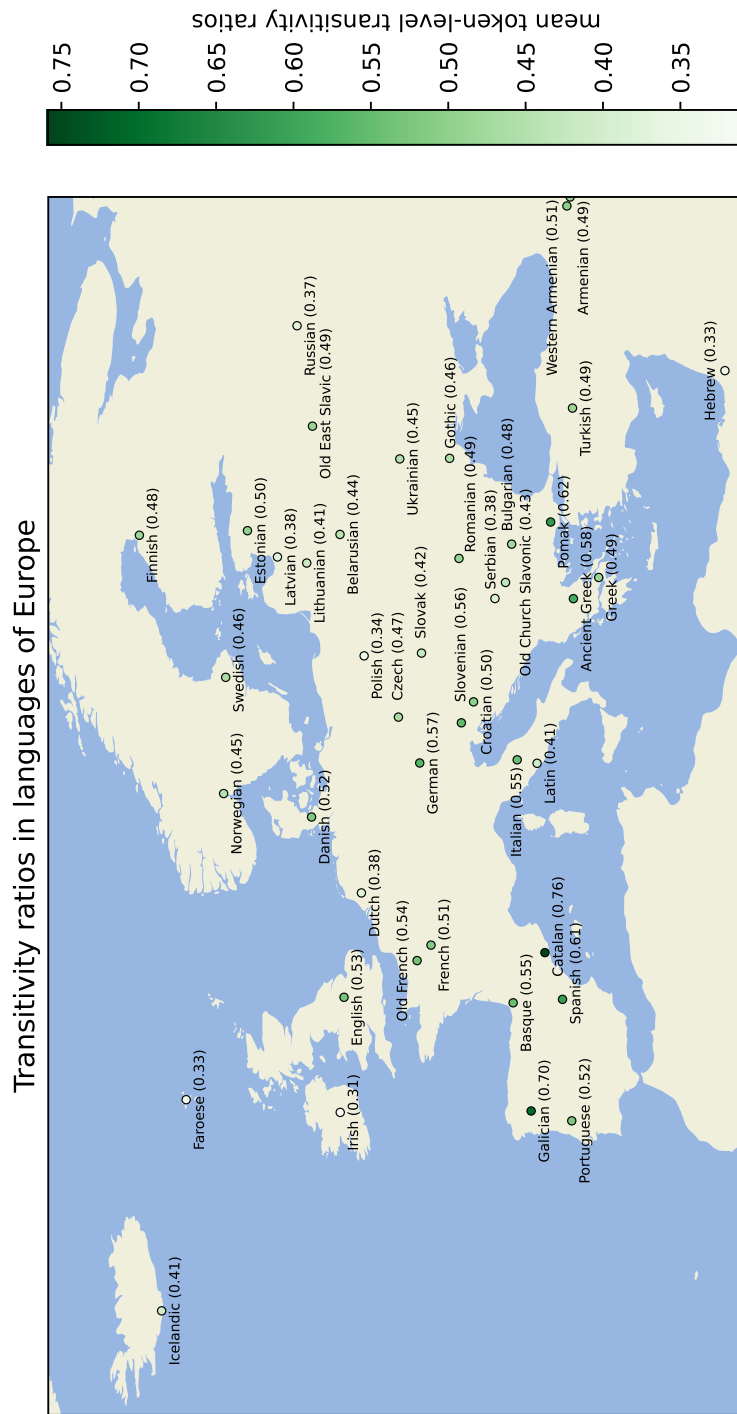


Figure 4.2.: Mean transitivity ratios in languages of Europe





## CHAPTER 5.

# ENTROPY-BASED MEASURES OF VERBAL VALENCY

While the previous chapter has demonstrated that corpus-based transitivity ratios can serve as a useful basis for typological comparison, it is still a relatively simple metric that captures one aspect of verbal valency. Put another way, transitivity ratio can be seen as a subset of the scope needed for a more holistic investigation into verbal valency, as it concerns only one type of verb dependent, i.e., the object, and one feature of this dependent, i.e., its presence or absence.

This chapter undertakes to expand the scope of investigation accordingly, to cover both more verb dependent types and more features of them. Instead of performing exhaustive comparisons on each individual feature of each dependent, the focus is on the variability of *valency frame alternations* (also called diathesis alternations), i.e., the range of valency frames in which a verb appears and how likely it is to appear with each frame. New entropy-based measures of verbal valency are proposed and tested in conjunction with hypotheses about the structure of valency systems.

The sections are organized as follows: §5.1 provides a brief background on cognitive and psycholinguistic perspectives on language structure, in particular relating to the frequency effect and valency frame alternation, which motivate the hypotheses tested in the experiments; in §5.2, the feature selection and extraction procedures of valency frame encoding from UD are described, as they form the basis for the experiments in this chapter.

Four experiments are then presented: Experiment 2 (§5.3) defines entropy measures of variability of individual dependencies and seeks to quantitatively verify the verb specificity test that is used to distinguish core and non-core dependents (complements and adjuncts); Experiment 3 (§5.4) uses joint entropy to define the valency frame entropy measure and tests its correlation with verb frequency; Experiment 4 (§5.5) examines cross-lingual variations in how languages encode the valency frames, by means of an ablation study using con-

ditional entropy to assess the contribution of word order and case marking to the overall valency frame entropy; Experiment 5 (§5.6) takes a frame-based approach and, in symmetry to Experiment 3, calculates the correlation between verb entropy and frame frequency.

### 5.1. VALENCY FRAME, FREQUENCY AND THE EFFICIENT ORGANIZATION OF THE LEXICON

Cognitive linguists and typologists have increasingly sought to integrate the two approaches in the same functionalist research paradigm (Croft, 2016). Among others is research that seeks to examine and explain language-internal and cross-linguistic features of human languages through the lens of communicative efficiency, at various levels including the lexicon, syntax and morphology (see Gibson et al., 2019 for a survey).

An early example where efficiency is used to explain phenomena in human languages is the work of George Kingsley Zipf (1935, 1949). He first studied what is now known as Zipf's law, the empirical observation of the negative correlation between word length and frequency, that "the magnitude of words tends, on the whole, [stands] in an inverse (not necessarily proportionate) relationship to the number of occurrences", and sought to explain it through the principle of least effort.

Frequency is a particularly frequent lens through which the lexicon is examined and the correlation between frequency and other features often subjects of hypotheses. Its importance has been further underlined by psycholinguistic studies which show a consistent "frequency effect" for both open and closed class word (Marslen-Wilson, 1990; Segui et al., 1982), where more frequently occurring words have a higher resting activation, making their lexical retrieval easier. That the most frequent lexical items are also more likely to be associated with irregularity is not surprising. This correlation between frequency and irregularity has most often been hypothesized and studied for morphology Wu et al. (2019). Bybee (1998) considers lexicon from a learnability perspective and postulates a trade-off in the lexical memory that "being easier to access, they are less likely to be replaced by regular formations".

When it comes to verbal valency, psycholinguistic studies have also consistently shown the effect of semantic and syntactic attributes of the verb on online sentence processing (Collina et al., 2001; Shapiro et al., 1987). Results differ on whether subcategorization (syntactic), thematic frames (semantic) or both have an effect on lexical processing. Shapiro et al. (1987) reported that RTs for lexical decisions increased as the function of the number of thematic

options instead of subcategorization options. In contrast, Shetreet et al. (2007) reported on an fMRI study on Hebrew speakers, shows that the number of options in terms of subcategorization and thematic frames is better correlated to activity in the cortical areas that are associated with linguistic processing, as opposed to the number of complements or thematic frames.

In the following experiments, I will test a few hypotheses between frequency metrics on the one hand and entropy metrics on the other hand and show that, regardless of the theoretical stance, how a language structures its valency system reflects trade-offs predicted by considerations of efficiency and learnability.

## 5.2. EXTRACTING VALENCY FRAME ENCODING FROM UD

As briefly discussed in the data chapter, UD annotations make available a range of information related to the morphosyntactic encoding of valency frame, beyond the transitivity information that we have already used. The following experiments in this chapter make use of this for a more fine-grained characterization of the variation in valency frame encoding for different verbs using entropy-based measures. To do so, **valency frame encoding**, i.e., the scope of the morphosyntactic features that compose a valency frame, must first be extracted from the UD annotations so that variation patterns can be consistently captured. The extraction procedures are described in this section.

### 5.2.1. DEPENDENCY RELATIONS

From UD annotations, I start by determining which dependency relations of the verb to include as part of the valency frame. The distinction between argument (complement) and adjunct is a well-established one in linguistics, the former being obligatory and the latter optional. UD annotations schema (de Marneffe, Dozat, et al., 2014), including in the up-to-date v2 guidelines<sup>1</sup>, makes the distinction between *core arguments* (i.e. subject and object) and everything else (called *non-core dependents*) instead. All core arguments as classified by UD are included in the analysis. This includes nominal dependents (*nominal subject*, *object*, *indirect object*) as well as clausal dependents (*clausal subject*, *clausal complement*, *clausal complement*).

As the non-core dependents still include arguments which complete the verbal meaning (in particular, *obliques*), and, as I will further in §5.3, a priori dis-

<sup>1</sup><https://universaldependencies.org/u/dep/>, archived on 30-07-2023 at <https://web.archive.org/web/20230730071650/https://universaldependencies.org/u/dep/>

UD label	Dependent
<i>core arguments</i>	
NSUBJ	nominal subject
OBJ	object
CSUBJ	clausal subject
CCOMP	clausal complement
XCOMP	open clausal complement
IOBJ	indirect object
<i>non-core dependents</i>	
OBL	oblique nominal
EXPL	expletive
ADVMOD	adverbial modifier
ADVCL	adverbial clause modifier

Table 5.1.: UD dependency relation labels included in valency frame extraction

tinctions between arguments and adjuncts are unnecessary for this study, possibly even counterproductive, given the quantitative experiment design. Thus, a subset of non-core dependents are included as well, namely oblique nominal, expletive, adverbial modifier and adverbial clause modifier. Other non-core dependents from UD are excluded for various reasons, either due to relatively low cross-lingual uniformity in interpretation (e.g., *dislocated element*), or due to being suprasentential elements (e.g. *vocative*, *discourse element*). Tab. 5.1 shows the list of dependents included in the study.

It is important to note that the basis of cross-linguistic comparison will be the taxonomy of the dependencies (in §5.3) and the valency frames they compose (in §5.4-5.6). The validity of the study is therefore predicated on the cross-lingual validity of the UD relations, which, while certainly not perfect, is as good as one can do, given that UD is designed with it in mind, but otherwise agnostic as far as linguistic theory is concerned. In other words, it does not matter whether the UD category *indirect object* corresponds to the traditional grammatical category of indirect object, in so far as the cross-linguistically dependents serving equivalent functions are consistently annotated.

### 5.2.2. FEATURE EXTRACTION

For each of dependent relations in Tab. 5.1, I extract three features: (1) the presence or absence of dependency relations attached to a verb token, (2) the

### 5.3. Experiment 2: Verb specificity between core and non-core dependents

relative word order information, whether specific dependents precede or follow the head verb, and (3) morphological case marking on the dependents, if any. In terms of implementation, the valency frame of each verb token is represented in a feature array encoding the three types of feature with the size of  $3 \times$  the number of dependents. Any verbs that share the same feature array are said to have the same valency frame.

## 5.3. EXPERIMENT 2: VERB SPECIFICITY BETWEEN CORE AND NON-CORE DEPENDENTS

Verb specificity (Haspelmath and Hartmann, 2015) any non-specific dependent relations would become part of the baseline however the verb specificity

The less verb specific a dependency is, the more uniform it will be between verbs resulting in lower entropy in general. This is on an entropy per dependency relation level. Recall the bimodal distribution of transitive verbs, verbs that are highly transitive or highly intransitive will have high entropy wrt object, carrier more information. Verb specific feature leads to higher entropy. - IF core vs non-core distinction holds, we'll see higher entropy values for core dependencies than for non-core. Because core dependencies are more verb specific.

### 5.3.1. METHODOLOGY

Let  $X_1, X_2, \dots, X_n$  be discrete random variables where each  $X_k$  represents a UD dependency relation (e.g., NSUBJ, OBJ, ...). These variables have corresponding sample spaces  $\mathcal{X}_1, \mathcal{X}_2, \dots, \mathcal{X}_n$ , which represent the possible outcomes of each variable with regard to its presence, linearized order, and any case information. Additionally, let there be a variable  $V$  that represents the choice of a verb from the lexicon  $\mathcal{V}$ .

The entropy of each dependency relation given a specific verb  $v \in \mathcal{V}$  quantifies the average surprisal associated with that dependency relation. It is defined as:

$$H(X_k|V = v) = - \sum_{x_k \in \mathcal{X}_k} P(x_k|V = v) \log_2 P(x_k|V = v)$$

Here,  $P(x_k|V = v)$  represents the conditional probability of the outcome  $x_k$  of the dependency relation  $X_k$  given that the verb variable  $V$  takes on the value  $v$ . The entropy of  $X_k$  is calculated by summing the products of these probabilities

with their logarithms (base 2) taken, each corresponding to a possible outcome  $x_k$ .

- are there any frequency effect here - if not, normalize the entropy

### 5.3.2. RESULTS

### 5.3.3. ANALYSIS

## 5.4. EXPERIMENT 3: FREQUENCY CORRELATION WITH VALENCY FRAME ENTROPY

This experiment introduces a valency frame entropy metric, conditioned on the verb, that measures the average amount of surprisal, i.e., uncertainty, associated with the valency frame alternation for a verb, and hypothesize a positive correlation between a verb's frequency and the valency frame entropy conditioned on it that should hold across languages. In other words, the more frequent a verb is, the more information content one can expect on average from its valency frames.

A learnability perspective on the lexicon provides one motivation behind the hypothesis. Taking the view that the lexicon is acquired from linguistic experience, more exposure to and access of the more frequent words leads to higher resting activation (cf. Bybee, 1998), therefore allowing for more complexity or uncertainty being retained in the lexicon. This is analogous to the correlation between word frequency and irregularity in morphological patterns. However, whereas morphological irregularity is a purely formal feature, the choice of valency frame often entails a semantic choice as well.

If viewed from a production and comprehension perspective, the hypothesis is also potentially relevant to the Uniform Information Density (UID) hypothesis (Fenk and Fenk-Oczlon, 1980; Levy and Jaeger, 2006), which posits that language speakers prefer a more even distribution of surprisal values across utterances in order to maximize but not overload the capacity of the communication channel. Less frequent verbs would already have high surprisal, having high entropy in the valency frames associated with it is undesirable due to channel capacity constraints. I note, however, that UID hypothesis has mostly focused on surprisal at a token/phoneme-level. This is the case for the verb in question, but the valency entropy measures aspects of the morphosyntax of the sentence instead and requires a clearer formulation of the relationship between the frames and the tokens that compose it. Nevertheless, at a high level the hypothesis here is congruent what is expected given the UID hypothesis.

### 5.4. Experiment 3: Frequency correlation with valency frame entropy

#### 5.4.1. METHODOLOGY

The **valency frame entropy** is formalized as the joint entropy of the relevant UD dependency relations, i.e., number of bits needed to encode the entire valency frame. Denoted as  $H_{\text{joint}}(X_1, X_2, \dots, X_n|V = v)$ , it quantifies the uncertainty associated with the combined set of random variables  $X_1, X_2, \dots, X_n$ , again given a specific value  $v$  for the verb variable  $V$ . This is defined as:

$$H_{\text{joint}}(X_1, X_2, \dots, X_n|V = v) = - \sum_{x_1 \in \mathcal{X}_1} \dots \sum_{x_n \in \mathcal{X}_n} P(x_1, x_2, \dots, x_n|V = v) \log_2 P(x_1, x_2, \dots, x_n|V = v)$$

Here,  $P(x_1, x_2, \dots, x_n|V = v)$  represents the joint probability distribution of the outcomes  $x_1, x_2, \dots, x_n$  of the random variables  $X_1, X_2, \dots, X_n$ , given that the verb variable  $V$  takes on the value  $v$ . The joint entropy is calculated by summing the products of these joint probabilities with their logarithms (base 2) taken, each corresponding to a specific combination of outcomes  $x_1, x_2, \dots, x_n$ .

In practice, for this study, the valency frame entropy is calculated as cross-entropy, following other studies using entropy measures (Hahn et al., 2021) in an effort to reduce artifacts. Treebanks of the same language are combined and then split randomly into two halves, resulting in two sets of distributions  $X_1, \dots, X_n$  and  $X'_1, \dots, X'_n$ . It follows that the joint cross-entropy between them is:

$$H_{\text{joint-cross}}(X_1, \dots, X_n, X'_1, \dots, X'_n|V = v) = - \sum_{x_1 \in \mathcal{X}_1} \dots \sum_{x_n \in \mathcal{X}_n} P(x_1, \dots, x_n|V = v) \log_2 P'(x_1, \dots, x_n|V = v)$$

The difference from the standard entropy measure is that the probabilities and their logarithms are estimated from the two different distributions with the same image. Add-one smoothing is used to prevent fringe cases where a frame is observed in only one of the two distributions.

The correlation between verb frequency and valency frame entropy as conditioned on it is assessed using Spearman's rank correlation coefficient (Spearman, 1904), which measures the correlation between two rank variables.

At first glance, there may be concerns that because the verb frequency here is also the number of observation made for estimating valency frame entropy. This is however unfounded, as the goal here is observational and not causal investigation. I additionally take a subsample.

For the subsampling threshold, we take a heuristically determined

#### 5.4.2. RESULTS

- correlation results - subsampling The correlation results are included in the appendix.

Add correlations strength results

Citation for interpreting the strength of the correlation (Schober et al., 2018)

#### 5.4.3. ANALYSIS

### 5.5. EXPERIMENT 4: WORD ORDER OR CASE?

#### CROSS-LINGUAL VARIATION IN VALENCY ENCODING STRATEGIES

- comparing the delta between different languages - reliance on wo / case information to encode

#### 5.5.1. METHODOLOGY

#### 5.5.2. RESULTS

#### 5.5.3. ANALYSIS

### 5.6. EXPERIMENT 5: FREQUENCY CORRELATION WITH VERB ENTROPY

so far a lexeme-based view of valency constructionist view would yield symmetrical predictions that the entropy of lexical choice would correlate with frequency of the valency frame

#### 5.6.1. METHODOLOGY

The entropy value for the verb given a single slot is

$$H(V|X_k = x) = - \sum_{v \in \mathcal{V}} P(v|X_k = x) \log_2 P(v|X_k = x)$$

extend it to multiple argument slots, we have

$$H(V|X_1 = x_1, \dots, X_n = x_n) = - \sum_{v \in \mathcal{V}} P(v|X_1 = x_1, \dots, X_n = x_n) \log_2 P(v|X_1 = x_1, \dots, X_n = x_n)$$



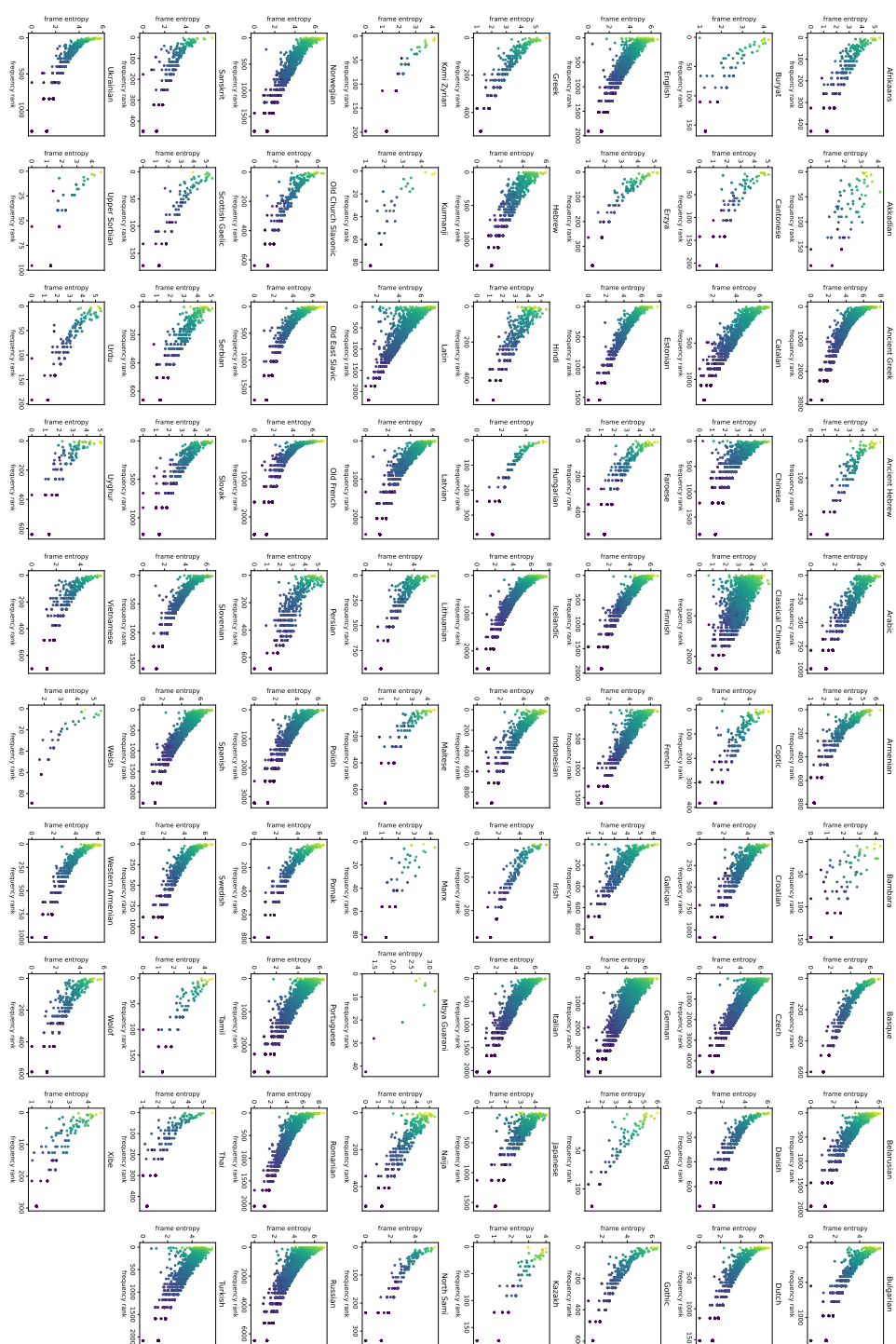
## *5.6. Experiment 5: Frequency correlation with verb entropy*

### 5.6.2. RESULTS

### 5.6.3. ANALYSIS

## Chapter 5. Entropy-based measures of verbal valency

Figure 5.1.: Scatter plots showing relationship between valency frame entropy and frequency rank of verbs, color shows number of frames associated with the verb



## CHAPTER 6.

## CONCLUSION

Code and results for the thesis will be made available at the following repository: <https://github.com/siyutao/verbal-valency-ud>



## APPENDIX A.

### EXPERIMENT 1 ADDITIONAL RESULTS

language name	total	tr verb percent	4 mean	4 weighted mean
Akkadian	45	62.22%	73.38%	80.32%
Armenian	227	70.48%	51.53%	48.98%
Welsh	17	70.59%	35.53%	9.45%
Gheg	50	86.00%	65.95%	64.82%
Norwegian	765	89.67%	48.30%	44.80%
Old East Slavic	500	65.80%	55.43%	48.87%
English	771	88.72%	55.51%	52.90%
French	733	90.86%	55.15%	51.29%
Slovenian	514	79.57%	64.30%	55.55%
Hebrew	531	51.98%	35.94%	33.50%
Kurmanji	21	52.38%	27.94%	38.02%
Italian	921	82.41%	55.70%	54.50%
Turkish	773	73.74%	47.20%	48.54%
Finnish	682	69.94%	53.94%	48.41%
Indonesian	330	91.21%	49.74%	51.21%
Ukrainian	228	66.23%	50.64%	45.33%
Dutch	497	75.65%	38.10%	37.51%
Polish	1059	61.95%	47.67%	34.07%
Portuguese	1203	77.47%	52.46%	52.45%
Kazakh	30	63.33%	45.43%	39.91%
Latin	1143	72.35%	44.50%	40.85%
Old French	422	70.14%	52.96%	53.50%
Spanish	941	92.88%	65.36%	61.08%
Buryat	27	51.85%	35.67%	36.83%
Icelandic	997	86.56%	51.81%	41.05%
Estonian	672	67.71%	53.48%	49.69%

Continued on next page

*Appendix A. Experiment 1 Additional Results*

language name	total	tr verb percent	4 mean	4 weighted mean
Croatian	386	84.97%	58.34%	50.27%
Gothic	195	58.46%	50.92%	45.80%
North Sami	75	76.00%	49.35%	37.91%
Naija	200	88.50%	54.92%	45.43%
German	1998	89.69%	57.18%	56.84%
Latvian	787	63.79%	45.18%	37.71%
Chinese	369	83.74%	60.56%	62.90%
Irish	107	77.57%	54.22%	30.87%
Xibe	62	70.97%	65.22%	58.37%
Bambara	50	62.00%	54.14%	43.08%
Lithuanian	212	58.02%	44.38%	41.48%
Galician	339	88.79%	71.14%	70.44%
Vietnamese	150	84.00%	62.00%	64.25%
Greek	145	77.24%	50.65%	48.68%
Catalan	627	98.25%	81.12%	75.86%
Swedish	391	86.45%	47.79%	46.49%
Russian	2558	59.34%	43.43%	37.35%
Czech	2083	72.88%	54.72%	46.76%
Erzya	87	54.02%	40.36%	36.01%
Thai	69	69.57%	51.99%	63.16%
Basque	249	78.71%	56.54%	54.51%
Slovak	279	55.91%	44.26%	42.32%
Tamil	41	80.49%	50.32%	42.73%
Maltese	67	43.28%	30.35%	27.34%
Ancient Greek	1111	81.55%	60.97%	58.47%
Ancient Hebrew	89	73.03%	53.43%	48.40%
Mbya Guaraní	5	60.00%	57.33%	51.46%
Urdu	69	85.51%	62.27%	65.23%
Romanian	1002	79.84%	48.65%	48.86%
Persian	308	72.73%	54.05%	50.27%
Japanese	381	61.15%	50.06%	33.54%
Hungarian	73	60.27%	44.39%	40.16%
Hindi	202	83.66%	61.24%	60.74%
Classical Chinese	1166	79.42%	60.76%	63.84%
Faroese	114	71.93%	40.13%	32.51%
Sanskrit	106	74.53%	57.49%	51.74%

Continued on next page

language name	total	tr verb percent	4 mean	4 weighted mean
Arabic	407	72.48%	46.74%	39.65%
Wolof	155	87.10%	55.11%	53.52%
Bulgarian	348	81.32%	47.10%	47.64%
Cantonese	45	73.33%	55.92%	50.99%
Pomak	229	72.49%	63.20%	61.76%
Old Church Slavonic	211	54.50%	46.60%	43.49%
Upper Sorbian	10	70.00%	40.82%	38.59%
Danish	212	88.68%	54.47%	51.92%
Komi Zyrian	25	32.00%	28.64%	25.52%
Manx	25	72.00%	47.98%	22.92%
Afrikaans	117	82.91%	60.90%	65.13%
Belarusian	587	68.14%	49.27%	44.41%
Coptic	127	65.35%	41.30%	43.55%
Serbian	214	73.36%	47.94%	38.45%
Western Armenian	299	75.92%	54.87%	50.66%
Scottish Gaelic	53	77.36%	37.74%	16.17%
Uyghur	80	53.75%	37.84%	32.95%





## BIBLIOGRAPHY

- Abend, Omri, Roi Reichart, and Ari Rappoport (Aug. 2009). “Unsupervised Argument Identification for Semantic Role Labeling”. In: *Proceedings of the Joint Conference of the 47th Annual Meeting of the ACL and the 4th International Joint Conference on Natural Language Processing of the AFNLP*. ACL-IJCNLP 2009. Suntec, Singapore: Association for Computational Linguistics, pp. 28–36.
- Baker, Collin F., Charles J. Fillmore, and John B. Lowe (Aug. 1998). “The Berkeley FrameNet Project”. In: *36th Annual Meeting of the Association for Computational Linguistics and 17th International Conference on Computational Linguistics, Volume 1*. ACL 1998. Montreal, Quebec, Canada: Association for Computational Linguistics, pp. 86–90. DOI: 10 . 3115 / 980845 . 980860 . URL: <https://aclanthology.org/P98-1013> (visited on 12/16/2022).
- Baker, Collin F. and Arthur Lorenzi (May 2020). “Exploring Crosslinguistic Frame Alignment”. In: *Proceedings of the International FrameNet Workshop 2020: Towards a Global, Multilingual FrameNet*. Marseille, France: European Language Resources Association, pp. 77–84. ISBN: 979-10-95546-58-0. URL: <https://aclanthology.org/2020.framenet-1.11> (visited on 09/25/2022).
- Basili, Roberto, Maria Pazienza, and Paola Velardi (1993). “Hierarchical Clustering of Verbs”. In: *Acquisition of Lexical Knowledge from Text*. URL: <https://aclanthology.org/W93-0107> (visited on 11/23/2022).
- “Lexico-Grammar” (1998). In: *Corpus Linguistics: Investigating Language Structure and Use*. Ed. by Douglas Biber, Randi Reppen, and Susan Conrad. Cambridge Approaches to Linguistics. Cambridge: Cambridge University Press, pp. 84–105. ISBN: 978-0-521-49957-6. DOI: 10 . 1017 / CB09780511804489 . 005. URL: <https://www.cambridge.org/core/books/corpus-linguistics/lexicogrammar/8849B881ECF55E7890631A75C0515B59> (visited on 04/04/2023).
- Bickel, Balthasar, Taras Zakharko, Lennart Bierkandt, and Alena Witzlack-Makarevich (Jan. 1, 2014). “Semantic Role Clustering: An Empirical Assessment of Semantic Role Types in Non-Default Case Assignment”. In: *Studies in Language* 38.3, pp. 485–511. ISSN: 0378-4177, 1569-9978. DOI: 10 . 1075 / sl . 38 . 3 .

## Bibliography

- 03bic. URL: <https://www.jbe-platform.com/content/journals/10.1075/sl.38.3.03bic> (visited on 09/25/2022).
- Bybee, Joan (1998). "The Emergent Lexicon". In: Chomsky, Noam (1965). *Aspects of the Theory of Syntax*. Cambridge, MA: The MIT Press.
- Collina, S., P. Marangolo, and P. Tabossi (2001). "The Role of Argument Structure in the Production of Nouns and Verbs". In: *Neuropsychologia* 39.11, pp. 1125–1137. ISSN: 0028-3932. DOI: 10.1016/S0028-3932(01)00058-6. PMID: 11527549.
- Croft, William (Nov. 1, 2016). "Typology and the Future of Cognitive Linguistics". In: *Cognitive Linguistics* 27.4, pp. 587–602. ISSN: 1613-3641. DOI: 10.1515/cog-2016-0056. URL: <https://www.degruyter.com/document/doi/10.1515/cog-2016-0056/html?lang=en> (visited on 06/14/2023).
- Croft, William, Dawn Nordquist, Katherine Looney, and Michael Regan (2017). "Linguistic Typology Meets Universal Dependencies". In: *Proceedings of the 15th International Workshop on Treebanks and Linguistic Theories (TLT15), Bloomington, IN, USA, January 20-21, 2017*. Ed. by Markus Dickinson, Jan Hajic, Sandra Kübler, and Adam Przepiórkowski. Vol. 1779. CEUR Workshop Proceedings. CEUR-WS.org, pp. 63–75. URL: <http://ceur-ws.org/Vol-1779/05croft.pdf> (visited on 08/22/2022).
- De Marneffe, Marie-Catherine, Timothy Dozat, Natalia Silveira, Katri Haverinen, Filip Ginter, Joakim Nivre, and Christopher D. Manning (May 2014). "Universal Stanford Dependencies: A Cross-Linguistic Typology". In: *Proceedings of the Ninth International Conference on Language Resources and Evaluation (LREC'14)*. LREC 2014. Reykjavik, Iceland: European Language Resources Association (ELRA), pp. 4585–4592. URL: [http://www.lrec-conf.org/proceedings/lrec2014/pdf/1062\\_Paper.pdf](http://www.lrec-conf.org/proceedings/lrec2014/pdf/1062_Paper.pdf) (visited on 11/24/2022).
- De Marneffe, Marie-Catherine, Christopher D. Manning, Joakim Nivre, and Daniel Zeman (July 13, 2021). "Universal Dependencies". In: *Computational Linguistics* 47.2, pp. 255–308. ISSN: 0891-2017. DOI: 10.1162/coli\_a\_00402. URL: [https://doi.org/10.1162/coli\\_a\\_00402](https://doi.org/10.1162/coli_a_00402) (visited on 08/22/2022).
- De Marneffe, Marie-Catherine and Joakim Nivre (2019). "Dependency Grammar". In: *Annual Review of Linguistics* 5.1, pp. 197–218. DOI: 10.1146/annurev-linguistics-011718-011842. eprint: <https://doi.org/10.1146/annurev-linguistics-011718-011842>. URL: <https://doi.org/10.1146/annurev-linguistics-011718-011842>.
- Dowty, David (1991). "Thematic Proto-Roles and Argument Selection". In: *Language* 67.3, pp. 547–619. ISSN: 0097-8507. DOI: 10.2307/415037. JSTOR:

415037. URL: <https://www.jstor.org/stable/415037> (visited on 09/18/2019).
- Ellsworth, Michael, Collin Baker, and Miriam R. L. Petruck (2021). “FrameNet and Typology”. In: *Proceedings of the Third Workshop on Computational Typology and Multilingual NLP*. Proceedings of the Third Workshop on Computational Typology and Multilingual NLP. Online: Association for Computational Linguistics, pp. 61–66. DOI: 10.18653/v1/2021.sigtyp-1.6. URL: <https://www.aclweb.org/anthology/2021.sigtyp-1.6> (visited on 11/01/2021).
- Fellbaum, Christiane, ed. (1998). *WordNet: An Electronic Lexical Database*. Language, Speech, and Communication. Cambridge, Mass: MIT Press. 423 pp. ISBN: 978-0-262-06197-1.
- Fenk, August and Gertraud Fenk-Oczlon (Jan. 1, 1980). “Konstanz Im Kurzzeitgedächtnis - Konstanz Im Sprachlichen Informationsfluß?” In: *Zeitschrift für experimentelle und angewandte Psychologie* 27, pp. 400–414.
- Fillmore, Charles J. (1968). “The Case for Case”. In: *Universals in Linguistic Theory*. Ed. by Emmon Bach and Robert T. Harms. New York: Rinehart and Winston, pp. 21–119.
- (1970). “The Grammar of HITTING and BREAKING”. In: URL: [https://www1.icsi.berkeley.edu/pubs/ai/ICSI\\_grammarofhitting12.pdf](https://www1.icsi.berkeley.edu/pubs/ai/ICSI_grammarofhitting12.pdf) (visited on 09/18/2022).
  - (1977a). “Scenes-and-Frames Semantics”. In: *Linguistic Structure Processing*. Ed. by Antonio Zampolli. Fundamental Studies in Computer Science. Amsterdam: North Holland Publishing Company, pp. 55–82. ISBN: 978-0-444-85017-1.
  - (Dec. 20, 1977b). “The Case for Case Reopened”. In: *Grammatical Relations*. Ed. by Peter Cole and Jerrold M. Sadock. BRILL, pp. 59–81. ISBN: 978-90-04-36886-6 978-90-04-36852-1. DOI: 10.1163/9789004368866\_005. URL: <https://brill.com/view/book/edcoll/9789004368866/BP000005.xml> (visited on 11/24/2022).
  - (1982). “Frame Semantics”. In: *Linguistics in the Morning Calm*. Ed. by Linguistic Society of Korea. Seoul, Korea: Hanshin Publishing Company, pp. 111–137.
- Fillmore, Charles J. and Collin Baker (Jan. 1, 2015). “A Frames Approach to Semantic Analysis”. In: *The Oxford Handbook of Linguistic Analysis*. Ed. by Bernd Heine and Heiko Narrog. Oxford University Press. ISBN: 978-0-19-967707-8. DOI: 10.1093/oxfordhb/9780199677078.013.0013. URL: <https://academic.oup.com/edited-volume/28050/chapter/211991006> (visited on 11/23/2022).

## Bibliography

- Fürstenau, Hagen and Owen Rambow (2012). “Unsupervised Induction of a Syntax-Semantics Lexicon Using Iterative Refinement”. In: *\*SEM 2012: The First Joint Conference on Lexical and Computational Semantics –Volume 1: Proceedings of the Main Conference and the Shared Task, and Volume 2: Proceedings of the Sixth International Workshop on Semantic Evaluation (SemEval 2012)*. \*SEM/SemEval 2012. Montréal, Canada: Association for Computational Linguistics, pp. 180–188. URL: <https://www.aclweb.org/anthology/S12-1026> (visited on 09/18/2019).
- Ganeri, Jonardon (July 21, 2011). “Kāraka: Meanings in Composition”. In: *Artha: Meaning*. Oxford University Press. ISBN: 978-0-19-807413-7. DOI: 10.1093/acprof:oso/9780198074137.001.0001. URL: <http://www.oxfordscholarship.com/view/10.1093/acprof:oso/9780198074137.001.0001/acprof-9780198074137> (visited on 11/22/2022).
- Gibson, Edward, Richard Futrell, Steven P. Piantadosi, Isabelle Dautriche, Kyle Mahowald, Leon Bergen, and Roger Levy (May 1, 2019). “How Efficiency Shapes Human Language”. In: *Trends in Cognitive Sciences* 23.5, pp. 389–407. ISSN: 1364-6613. DOI: 10.1016/j.tics.2019.02.003. URL: <https://www.sciencedirect.com/science/article/pii/S1364661319300580> (visited on 07/12/2022).
- Goldberg, Adele E. (Jan. 1, 1992). “The Inherent Semantics of Argument Structure: The Case of the English Ditransitive Construction”. In: 3.1, pp. 37–74. ISSN: 1613-3641. DOI: 10.1515/cogl.1992.3.1.37. URL: <https://www.degruyter.com/document/doi/10.1515/cogl.1992.3.1.37/html> (visited on 11/24/2022).
- (Mar. 1995). *Constructions: A Construction Grammar Approach to Argument Structure*. Cognitive Theory of Language and Culture Series. Chicago, IL: University of Chicago Press. 271 pp. ISBN: 978-0-226-30086-3. URL: <https://press.uchicago.edu/ucp/books/book/chicago/C/bo3683810.html> (visited on 11/23/2022).
- Gruber, Jeffrey S. (1962). “Studies in Lexical Relations”. PhD thesis. Massachusetts Institute of Technology.
- Hahn, Michael, Judith Degen, and Richard Futrell (2021). “Modeling Word and Morpheme Order in Natural Language as an Efficient Trade-off of Memory and Surprisal”. In: *Psychological Review* 128.4, pp. 726–756. ISSN: 1939-1471. DOI: 10.1037/rev0000269.
- Haspelmath, Martin and Iren Hartmann (2015). “Comparing Verbal Valency across Languages”. In: Malchukov, Andrej and Bernard Comrie. *Valency Classes in the World’s Languages: Volume 1 Introducing the Framework, and Case Studies from Africa and Eurasia*. Vol. 1. 2 vols. Berlin; Boston: De Gruyter Mouton, pp. 41–71. ISBN: 978-3-11-033294-0.

- Healy, Alice F. and George A. Miller (June 1, 1970). "The Verb as the Main Determinant of Sentence Meaning". In: *Psychonomic Science* 20.6, pp. 372–372. ISSN: 2197-9952. DOI: 10.3758/BF03335697. URL: <https://doi.org/10.3758/BF03335697> (visited on 11/17/2022).
- Jackendoff, Ray S. (1972). *Semantic Interpretation in Generative Grammar*. Studies in Linguistic Series. Cambridge, MA: The MIT Press. 400 pp. ISBN: 978-0-262-10013-7. URL: <https://babel.lac.on.worldcat.org/oclc/323868> (visited on 11/22/2022).
- (1987). "The Status of Thematic Relations in Linguistic Theory". In: *Linguistic Inquiry* 18.3, pp. 369–411. ISSN: 0024-3892. JSTOR: 4178548. URL: <https://www.jstor.org/stable/4178548> (visited on 11/22/2022).
  - (Apr. 22, 1992). *Semantic Structures*. MIT Press. 340 pp. ISBN: 978-0-262-60020-0. Google Books: 7wbYlHis6OEC.
- Katz, Jerrold J. and Jerry A. Fodor (1963). "The Structure of a Semantic Theory". In: *Language* 39.2, pp. 170–210. ISSN: 0097-8507. DOI: 10.2307/411200. JSTOR: 411200. URL: <https://www.jstor.org/stable/411200> (visited on 11/22/2022).
- Kingsbury, Paul and Martha Palmer (May 2002). "From TreeBank to PropBank". In: *Proceedings of the Third International Conference on Language Resources and Evaluation (LREC'02)*. LREC 2002. Las Palmas, Canary Islands - Spain: European Language Resources Association (ELRA). URL: <http://www.lrec-conf.org/proceedings/lrec2002/pdf/283.pdf> (visited on 12/16/2022).
- Kipper, Karin, Anna Korhonen, Neville Ryant, and Martha Palmer (May 2006). "Extending VerbNet with Novel Verb Classes". In: *Proceedings of the Fifth International Conference on Language Resources and Evaluation (LREC'06)*. LREC 2006. Genoa, Italy: European Language Resources Association (ELRA). URL: <http://www.lrec-conf.org/proceedings/lrec2006/pdf/468.pdf> (visited on 11/23/2022).
- (Mar. 1, 2008). "A Large-Scale Classification of English Verbs". In: *Language Resources and Evaluation* 42.1, pp. 21–40. ISSN: 1572-8412. DOI: 10.1007/s10579-007-9048-2. URL: <https://doi.org/10.1007/s10579-007-9048-2> (visited on 09/18/2019).
- Kipper-Schuler, Karin (2005). "VerbNet: A Broad-Coverage, Comprehensive Verb Lexicon". PhD thesis. USA: University of Pennsylvania.
- Korhonen, Anna, Yuval Krymolowski, and Ted Briscoe (May 2006). "A Large Subcategorization Lexicon for Natural Language Processing Applications". In: *Proceedings of the Fifth International Conference on Language Resources and Evaluation (LREC'06)*. LREC 2006. Genoa, Italy: European Language Re-

## Bibliography

- sources Association (ELRA). URL: [http://www.lrec-conf.org/proceedings/lrec2006/pdf/558\\_pdf.pdf](http://www.lrec-conf.org/proceedings/lrec2006/pdf/558_pdf.pdf) (visited on 11/23/2022).
- Valency (*Valence*) (Mar. 19, 2020). In: *A Dictionary of Chemistry*. Ed. by Jonathan Law and Richard Rennie. Oxford University Press. ISBN: 978-0-19-884122-7. URL: <https://www.oxfordreference.com/view/10.1093/acref/9780198841227.001.0001/acref-9780198841227> (visited on 11/22/2022).
- Levin, Beth (1993). *English Verb Classes and Alternations: A Preliminary Investigation*. Chicago, Ill.: Univ. of Chicago Press. ISBN: 978-0-226-47532-5 978-0-226-47533-2.
- Levy, Roger and T. Florian Jaeger (Dec. 4, 2006). "Speakers Optimize Information Density through Syntactic Reduction". In: *Proceedings of the 19th International Conference on Neural Information Processing Systems*. NIPS'06. Cambridge, MA, USA: MIT Press, pp. 849–856.
- Majewska, Olga, Diana McCarthy, Ivan Vulić, and Anna Korhonen (May 2018). "Acquiring Verb Classes Through Bottom-Up Semantic Verb Clustering". In: *Proceedings of the Eleventh International Conference on Language Resources and Evaluation (LREC 2018)*. LREC 2018. Miyazaki, Japan: European Language Resources Association (ELRA). URL: <https://aclanthology.org/L18-1153> (visited on 11/23/2022).
- Majewska, Olga, Ivan Vulić, Diana McCarthy, and Anna Korhonen (Dec. 2020). "Manual Clustering and Spatial Arrangement of Verbs for Multilingual Evaluation and Typology Analysis". In: *Proceedings of the 28th International Conference on Computational Linguistics*. COLING 2020. Barcelona, Spain (Online): International Committee on Computational Linguistics, pp. 4810–4824. DOI: 10.18653/v1/2020.coling-main.423. URL: <https://aclanthology.org/2020.coling-main.423> (visited on 11/23/2022).
- Malchukov, Andrej L. (Jan. 1, 2005). "Chapter 4 - Case Pattern Splits, Verb Types and Construction Competition". In: *Competition and Variation in Natural Languages*. Ed. by Mengistu Amberber and Helen De Hoop. Perspectives on Cognitive Science. Oxford: Elsevier, pp. 73–117. DOI: 10.1016/B978-008044651-6/50006-9. URL: <https://www.sciencedirect.com/science/article/pii/B9780080446516500069> (visited on 12/20/2022).
- Marslen-Wilson, William (1990). "Activation, Competition, and Frequency in Lexical Access". In: *Cognitive Models of Speech Processing: Psycholinguistic and Computational Perspectives*. ACL-MIT Press Series in Natural Language Processing. Cambridge, MA, US: The MIT Press, pp. 148–172. ISBN: 978-0-262-01117-4.

- Miller, George A. (Nov. 1, 1995). “WordNet: A Lexical Database for English”. In: *Communications of the ACM* 38.11, pp. 39–41. ISSN: 0001-0782. DOI: 10.1145/219717.219748. URL: <https://doi.org/10.1145/219717.219748> (visited on 11/23/2022).
- Navarretta, Costanza (Dec. 2000). “Semantic Clustering of Adjectives and Verbs Based on Syntactic Patterns”. In: *Proceedings of the 12th Nordic Conference of Computational Linguistics (NODALIDA 1999)*. NoDaLiDa 2000. Trondheim, Norway: Department of Linguistics, Norwegian University of Science and Technology, Norway, pp. 124–132. URL: <https://aclanthology.org/w99-1013> (visited on 11/23/2022).
- Nivre, Joakim (2015). “Towards a Universal Grammar for Natural Language Processing”. In: *Computational Linguistics and Intelligent Text Processing*. Ed. by Alexander Gelbukh. Lecture Notes in Computer Science. Cham: Springer International Publishing, pp. 3–16. ISBN: 978-3-319-18111-0. DOI: 10.1007/978-3-319-18111-0\_1.
- Nivre, Joakim, Marie-Catherine de Marneffe, Filip Ginter, Jan Hajič, Christopher D. Manning, Sampo Pyysalo, Sebastian Schuster, Francis Tyers, and Daniel Zeman (May 2020). “Universal Dependencies v2: An Evergrowing Multilingual Treebank Collection”. In: *Proceedings of the 12th Language Resources and Evaluation Conference*. LREC 2020. Marseille, France: European Language Resources Association, pp. 4034–4043. ISBN: 979-10-95546-34-4. URL: <https://aclanthology.org/2020.lrec-1.497> (visited on 08/22/2022).
- Peirce, Charles S. (1897). “The Logic of Relatives”. In: *The Monist* 7.2, pp. 161–217. ISSN: 0026-9662. URL: <https://doi.org/10.5840/monist18977231> (visited on 09/18/2022).
- Przepiórkowski, Adam (Jan. 1, 2018). “The Origin of the Valency Metaphor in Linguistics”. In: *Lingvisticæ Investigationes* 41.1, pp. 152–159. ISSN: 0378-4169, 1569-9927. DOI: 10.1075/li.00017.prz. URL: <https://www.jbe-platform.com/content/journals/10.1075/li.00017.prz> (visited on 09/18/2022).
- Say, Sergey (Jan. 1, 2014). “Bivalent Verb Classes in the Languages of Europe: A Quantitative Typological Study”. In: *Language Dynamics and Change* 4.1, pp. 116–166. ISSN: 2210-5832, 2210-5824. DOI: 10.1163/22105832-00401003. URL: [https://brill.com/view/journals/ldc/4/1/article-p116\\_4.xml](https://brill.com/view/journals/ldc/4/1/article-p116_4.xml) (visited on 06/20/2022).
- Sayeed, Asad, Pavel Shkadzko, and Vera Demberg (May 2018). “Rollenwechsel-English: A Large-Scale Semantic Role Corpus”. In: *Proceedings of the Eleventh International Conference on Language Resources and Evaluation (LREC 2018)*.

## Bibliography

- LREC 2018. Miyazaki, Japan: European Language Resources Association (ELRA). URL: <https://aclanthology.org/L18-1488> (visited on 06/07/2022).
- Schober, Patrick, Christa Boer, and Lothar A. Schwarte (May 2018). "Correlation Coefficients: Appropriate Use and Interpretation". In: *Anesthesia & Analgesia* 126.5, p. 1763. ISSN: 0003-2999. DOI: 10.1213/ANE.0000000000002864. URL: [https://journals.lww.com/anesthesia-analgesia/Fulltext/2018/05000/Correlation\\_Coefficients\\_\\_Appropriate\\_Use\\_and.50.aspx](https://journals.lww.com/anesthesia-analgesia/Fulltext/2018/05000/Correlation_Coefficients__Appropriate_Use_and.50.aspx) (visited on 07/23/2023).
- Schulte im Walde, Sabine (Apr. 2003). "Experiments on the Choice of Features for Learning Verb Classes". In: *10th Conference of the European Chapter of the Association for Computational Linguistics*. EACL 2003. Budapest, Hungary: Association for Computational Linguistics. URL: <https://aclanthology.org/E03-1037> (visited on 11/23/2022).
- (2006). "Experiments on the Automatic Induction of German Semantic Verb Classes". In: *Computational Linguistics* 32.2, pp. 159–194. DOI: 10.1162/coli.2006.32.2.159. URL: <https://aclanthology.org/J06-2001> (visited on 11/16/2022).
- Schulte im Walde, Sabine and Chris Brew (July 2002). "Inducing German Semantic Verb Classes from Purely Syntactic Subcategorisation Information". In: *Proceedings of the 40th Annual Meeting of the Association for Computational Linguistics*. ACL 2002. Philadelphia, Pennsylvania, USA: Association for Computational Linguistics, pp. 223–230. DOI: 10.3115/1073083.1073121. URL: <https://www.aclweb.org/anthology/P02-1029> (visited on 09/18/2019).
- Segui, Juan, Jacques Mehler, Uli Frauenfelder, and John Morton (Jan. 1982). "The Word Frequency Effect and Lexical Access". In: *Neuropsychologia* 20.6, pp. 615–627. ISSN: 00283932. DOI: 10.1016/0028-3932(82)90061-6. URL: <https://linkinghub.elsevier.com/retrieve/pii/S0028393282900616> (visited on 07/01/2023).
- Shapiro, L. P., E. Zurif, and J. Grimshaw (Dec. 1987). "Sentence Processing and the Mental Representation of Verbs". In: *Cognition* 27.3, pp. 219–246. ISSN: 0010-0277. DOI: 10.1016/S0010-0277(87)80010-0. PMID: 3691026.
- Shetreet, Einat, Dafna Palti, Naama Friedmann, and Uri Hadar (Aug. 1, 2007). "Cortical Representation of Verb Processing in Sentence Comprehension: Number of Complements, Subcategorization, and Thematic Frames". In: *Cerebral Cortex* 17.8, pp. 1958–1969. ISSN: 1047-3211. DOI: 10.1093/cercor/bhl105. URL: <https://doi.org/10.1093/cercor/bhl105> (visited on 06/11/2023).
- Snider, Neal and Mona Diab (July 2006). "Unsupervised Induction of Modern Standard Arabic Verb Classes Using Syntactic Frames and LSA". In: *Proceed-*



- ings of the COLING/ACL 2006 Main Conference Poster Sessions. COLING-ACL 2006. Sydney, Australia: Association for Computational Linguistics, pp. 795–802. URL: <https://aclanthology.org/P06-2102> (visited on 11/23/2022).
- Spearman, C. (1904). “The Proof and Measurement of Association between Two Things”. In: *The American Journal of Psychology* 15.1, pp. 72–101. ISSN: 0002-9556. DOI: 10.2307/1412159. JSTOR: 1412159. URL: <https://www.jstor.org/stable/1412159> (visited on 07/23/2023).
- Stabler, Edward P. (2019). “Three Mathematical Foundations for Syntax”. In: *Annual Review of Linguistics* 5.1, pp. 243–260. DOI: 10.1146/annurev-linguistics-011415-040658. URL: <https://doi.org/10.1146/annurev-linguistics-011415-040658> (visited on 08/16/2019).
- Sun, Lin and Anna Korhonen (Aug. 2009). “Improving Verb Clustering with Automatically Acquired Selectional Preferences”. In: *Proceedings of the 2009 Conference on Empirical Methods in Natural Language Processing*. EMNLP 2009. Singapore: Association for Computational Linguistics, pp. 638–647. URL: <https://aclanthology.org/D09-1067> (visited on 11/23/2022).
- Sun, Lin, Anna Korhonen, and Yuval Krymolowski (2008). “Verb Class Discovery from Rich Syntactic Data”. In: *Computational Linguistics and Intelligent Text Processing*. Ed. by Alexander Gelbukh. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, pp. 16–27. ISBN: 978-3-540-78135-6. DOI: 10.1007/978-3-540-78135-6\_2.
- Sun, Lin, Diana McCarthy, and Anna Korhonen (Aug. 2013). “Diathesis Alternation Approximation for Verb Clustering”. In: *Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics (Volume 2: Short Papers)*. ACL 2013. Sofia, Bulgaria: Association for Computational Linguistics, pp. 736–741. URL: <https://aclanthology.org/P13-2129> (visited on 11/23/2022).
- Tesnière, Lucien (1959). *Éléments de syntaxe structurale*. Paris: C. Klincksieck.
- (2015). *Elements of Structural Syntax*. John Benjamins Publishing Company. ISBN: 978-90-272-1212-2. DOI: 10.1075/z.185. URL: <https://library.oapen.org/handle/20.500.12657/30722> (visited on 08/22/2022).
- Titov, Ivan and Alexandre Klementiev (Apr. 2012). “A Bayesian Approach to Unsupervised Semantic Role Induction”. In: *Proceedings of the 13th Conference of the European Chapter of the Association for Computational Linguistics*. EACL 2012. Avignon, France: Association for Computational Linguistics, pp. 12–22. URL: <https://aclanthology.org/E12-1003> (visited on 09/18/2022).
- Tsunoda, Tasaku (Jan. 1, 1981). “Split Case-Marking Patterns in Verb-Types and Tense/Aspect/Mood”. In: 19.5-6, pp. 389–438. ISSN: 1613-396X. DOI: 10.1515/ling.1981.19.5-6.389. URL: <https://www.degruyter.com/>

## Bibliography

- document/doi/10.1515/ling.1981.19.5-6.389/html?lang=en (visited on 09/25/2022).
- Tsunoda, Tasaku (1985). “Remarks on Transitivity”. In: *Journal of Linguistics* 21.2, pp. 385–396. ISSN: 0022-2267. JSTOR: 4175793. URL: <https://www.jstor.org/stable/4175793> (visited on 09/25/2022).
- Watanabe, Yotaro, Masayuki Asahara, and Yuji Matsumoto (July 2010). “A Structured Model for Joint Learning of Argument Roles and Predicate Senses”. In: *Proceedings of the ACL 2010 Conference Short Papers*. ACL 2010. Uppsala, Sweden: Association for Computational Linguistics, pp. 98–102. URL: <https://aclanthology.org/P10-2018> (visited on 09/25/2022).
- Wu, Shijie, Ryan Cotterell, and Timothy O’Donnell (July 2019). “Morphological Irregularity Correlates with Frequency”. In: *Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics*. ACL 2019. Florence, Italy: Association for Computational Linguistics, pp. 5117–5126. DOI: 10.18653/v1/P19-1505. URL: <https://aclanthology.org/P19-1505> (visited on 07/20/2023).
- Yamada, Kosuke, Ryohei Sasano, and Koichi Takeda (Aug. 2021). “Semantic Frame Induction Using Masked Word Embeddings and Two-Step Clustering”. In: *Proceedings of the 59th Annual Meeting of the Association for Computational Linguistics and the 11th International Joint Conference on Natural Language Processing (Volume 2: Short Papers)*. ACL-IJCNLP 2021. Online: Association for Computational Linguistics, pp. 811–816. DOI: 10.18653/v1/2021.acl-short.102. URL: <https://aclanthology.org/2021.acl-short.102> (visited on 11/23/2022).
- Zeman, Daniel, Jan Hajič, Martin Popel, Martin Potthast, Milan Straka, Filip Ginter, Joakim Nivre, and Slav Petrov (Oct. 2018). “CoNLL 2018 Shared Task: Multilingual Parsing from Raw Text to Universal Dependencies”. In: *Proceedings of the CoNLL 2018 Shared Task: Multilingual Parsing from Raw Text to Universal Dependencies*. CoNLL 2018. Brussels, Belgium: Association for Computational Linguistics, pp. 1–21. DOI: 10.18653/v1/K18-2001. URL: <https://aclanthology.org/K18-2001> (visited on 12/14/2022).
- Zeman, Daniel, Joakim Nivre, et al. (Nov. 15, 2022). *Universal Dependencies 2.11*. Universal Dependencies Consortium. URL: <https://lindat.mff.cuni.cz/repository/xmlui/handle/11234/1-4923> (visited on 11/25/2022).
- Zeman, Daniel, Martin Popel, Milan Straka, Jan Hajic, Joakim Nivre, Filip Ginter, Juhani Luotolahti, Sampo Pyysalo, Slav Petrov, Martin Potthast, Francis Tyers, Elena Badmaeva, Memduh Gokirmak, Anna Nedoluzhko, Silvie Cinkova, Jan Hajic jr., Jaroslava Hlavacova, Václava Kettnerová, Zdenka Uresova, Jenna Kanerva, Stina Ojala, Anna Missilä, Christopher D. Manning, Sebas-

- tian Schuster, Siva Reddy, Dima Taji, Nizar Habash, Herman Leung, Marie-Catherine de Marneffe, Manuela Sanguinetti, Maria Simi, Hiroshi Kanayama, Valeria dePaiva, Kira Drostanova, Héctor Martínez Alonso, Çağrı Çöltekin, Umut Sulubacak, Hans Uszkoreit, Vivien Macketanz, Aljoscha Burchardt, Kim Harris, Katrin Marheinecke, Georg Rehm, Tolga Kayadelen, Mohammed Attia, Ali Elkahky, Zhuoran Yu, Emily Pitler, Saran Lertpradit, Michael Mandl, Jesse Kirchner, Hector Fernandez Alcalde, Jana Strnadová, Esha Banerjee, Ruli Manurung, Antonio Stella, Atsuko Shimada, Sookyoung Kwak, Gustavo Mendonca, Tatiana Lando, Rattima Nitisaroj, and Josie Li (2017). “CoNLL 2017 Shared Task: Multilingual Parsing from Raw Text to Universal Dependencies”. In: *Proceedings of the CoNLL 2017 Shared Task: Multilingual Parsing from Raw Text to Universal Dependencies*. Proceedings of the CoNLL 2017 Shared Task: Multilingual Parsing from Raw Text to Universal Dependencies. Vancouver, Canada: Association for Computational Linguistics, pp. 1–19. DOI: 10.18653/v1/K17-3001. URL: <http://aclweb.org/anthology/K17-3001> (visited on 12/09/2022).
- Zipf, George Kingsley (1935). *The Psycho-Biology of Language: An Introduction to Dynamic Philology*. The Psycho-Biology of Language: An Introduction to Dynamic Philology. Oxford, England: Houghton Mifflin.
- (1949). *Human Behavior and the Principle of Least Effort*. Human Behavior and the Principle of Least Effort. Oxford, England: Addison-Wesley Press, pp. xi, 573. xi, 573.