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FrameNet at 25: Results and Applications

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Abstract

This paper, a follow-up to Boas/Ruppenhofer/Baker (2024), reports on the results and applications of the FrameNet database. It spells out how FrameNet data have been used in linguistic theory, computational linguistics, multilingual lexicography, and foreign language teaching and learning. The paper also provides more information about the organization of the FrameNet project, inlcuding organizational, financial, and personal challenges.

Keywords: computational lexicography; corpus lexicography; FrameNet; frame semantics; online dictionary

1. Introduction

This paper is a follow-up to our paper *FrameNet at 25* published in a previous issue of this journal (Boas/Ruppenhofer/Baker 2024)[1]. In our previous paper, we presented, on the occasion of its 25th “anniversary”, the Berkeley FrameNet project with an emphasis on its main product, namely the FrameNet lexicographic database of English that is based on the principles of Frame Semantics (Fillmore 1982a). In that paper, we first discussed the intellectual roots of FrameNet (FN), which are based on Fillmore’s (1968) seminal paper *The Case for Case*, as well as subsequent research by Fillmore and his associates on Frame Semantics (Fillmore 1985, Fillmore & Atkins 1992/1994). Then, we provided an overview of the workflow and architecture underlying FN, with a specific focus on how information in FN is organized and how it can be accessed by humans and computers. In addition, we showed how semantic frames are also a useful tool for full text annotation and how the FN database was modified to also house entries of grammatical constructions, parallel in structure to lexical entries. The paper concluded with a discussion of some methodological issues underlying the design and workflow of FN.

The current paper builds on our previous paper by providing additional discussions of how the data produced by FN have been used in a variety of different research domains, including multilingual lexicography, linguistic theory, computational linguistics, and the teaching and learning of languages. This paper is structured as follows. Discussing the Breathing frame, Section 2 first sets the stage by reviewing the organization of information in FN lexical entries as presented in our previous paper (see Boas/Ruppenhofer/Baker 2024). Section 3 summarizes how FN insights have influenced research in lexicography, linguistic theory, computational linguistics, and applied linguistics. Section 4 reviews various efforts to automate crucial aspects of the FN workflow that to date have been carried out manually, namely development of new frames and annotation of corpus sentences. Section 5 shows how FrameNet data have been used by several different applied research projects. Section 6 offers insights into the different challenges encountered by the FrameNet project since its inception in 1997, specifically challenges surrounding organizational and funding issues. Finally, Section 7 provides a summary of our paper.

2. Structure of FrameNet

The FrameNet (FN) lexical database of English is organized around semantic frames, which are represented in terms of an intensional definition, in prose, and an extensional definition (the list of lexical units which evoke the frame) and a list of frame elements (participants and props involved in events, other aspects for non-lexical frames), each of which also has its own textual definition (for details, see Boas/Ruppenhofer/Baker 2024: 6). For example, the `Breathing` frame in Figure 1 consists of a frame definition that includes the relevant frame elements (FEs) (situation-specific semantic roles) and an example sentence (e.g., *Lee breathed the hot desert air*), together with definitions of the two core FEs Agent and Air.[2] Semantic frames as well as the lexical entries of lexical units (a lexical unit is a word in one of its senses or a multiword unit)[3] are the result of a corpus-based workflow that involves several stages (see Fillmore et al. 2003, Ruppenhofer et al. 2016).[4]

FN contains different types of semantic frame types, such as events (e.g. `Commerce_buy`), states (e.g. `Awareness`), attributes (e.g. `Legality`), relations (e.g. `Leadership`), and entities (e.g. `Money`), which are organized in a frame hierarchy representing different types of frame-to-frame relations (see Petruck et al. 2004). For each frame, FN provides a list of lexical units that evoke the meaning of the frame in the mind of the hearer. LUs evoking the `Breathing` frame involve verbs such as *blow*, *breathe*, *huff*, and *suspire* as well as nouns such as *breath*, *exhalation*, and *sigh*. The meaning shared by all LUs evoking a frame is given by the frame definition, while each LU entry also provides its own definition (which in many cases comes from a dictionary), giving it a more specific meaning.

For example, one of the LUs evoking the `Breathing` frame is the verb *to gasp*. Figure 2 shows the first part of its lexical entry, including its definition and the core FEs Agent and Air, the non-core FEs Circumstances, Depictive, External_ cause, etc., along with their different syntactic realizations. Specifically, in the first row of the frame element realization table we see that the FE Agent is always realized as an external (Ext) noun phrase (NP)

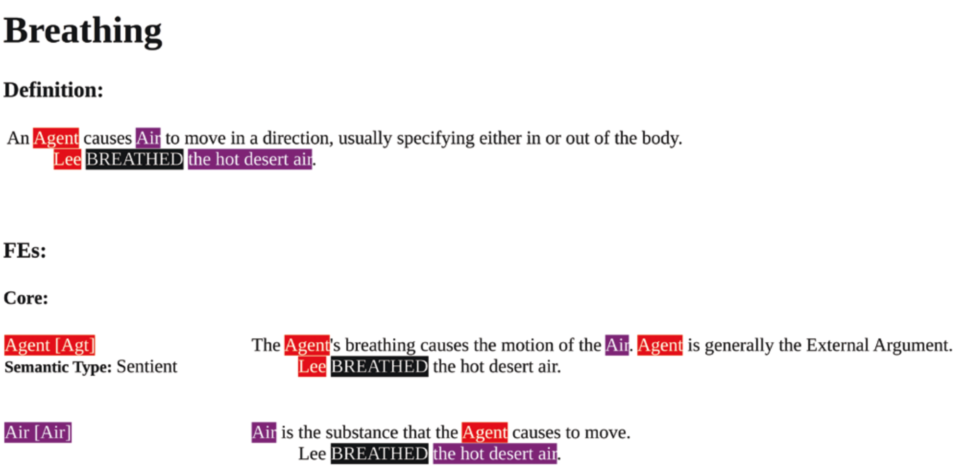

Figure 1. Partial FN frame definition of the `Breathing` frame[5]

and that there are a total of twenty annotated example sentences illustrating this specific realization. While some FEs such as Agent, Air, and Circumstances have only one syntactic realization, other FEs such as Depictive, Internal_cause, and Time can have multiple syntactic realizations. Clicking on the hyper-linked numbers in the FE realization table will display the relevant annotated sentences forming the basis for the information about how FEs are realized syntactically.

Besides information about how each FE is realized syntactically, each lexical entry also includes a detailed valence table illustrating how combinations of different FEs (so-called Frame Element Configurations) of the same frame are realized syntactically. For example, the valence table for *to gasp* in Figure 3, which is also based on the manually annotated corpus examples, shows a total of 8 different frame element configurations (FECs) with a total of 10 different syntactic realizations. A FEC is a combination of different FEs of a frame together with at least one syntactic realization. For example, in Figure 3, the second FEC Agent, Air, and Depictive exhibits two distinct syntactic realizations, where the FE Agent is realized as an external noun phrase, the FE Air is syntactically incorporated, and the FE Depictive is realized as either a prepositional phrase headed by *as* or a prepositional phrase headed by *in*.

Lexical Entry

gasp.v

Frame: Breathing

Definition:

COD: catch one's breath with an open mouth, owing to pain or astonishment. strain to obtain (air) by gasping.

Incorporated FE: Air

Frame Elements and Their Syntactic Realizations

The Frame Elements for this word sense are (with realizations):

Frame Element	Number Annotated	Realization(s)
Agent	(20)	NP.Ext (20)
Air	(20)	INC.-- (20)
Circumstances	(1)	PP[in].Dep (1)
Depictive	(4)	Sabs.Dep (1) PP[as].Dep (1) PP[in].Dep (2)
External_cause	(5)	PP[at].Dep (5)
Internal_cause	(10)	PP[with].Dep (8) PP[in].Dep (2)
Manner	(1)	PP[as].Dep (1)
Place	(1)	PP[at].Dep (1)
Time	(2)	PP[as].Dep (1) AVP.Dep (1)

Figure 2. First part of LU entry of *to gasp* in the `Breathing` frame[6]

For details, see the complete lexical entry of gasp in the `Breathing` frame. For further details regarding the structure of lexical entries, the set of hierarchical frame-to-frame relations, the frame hierarchy, as well as other relevant details regarding structure and contents of the FN lexical database, see Fillmore et al. (2003), Fillmore & Baker (2010), Ruppenhofer et al. (2017), and Boas/Ruppenhofer/Baker (2024).

Since 1997, FN has compiled more than 1,200 semantic frames containing more than 10,000 frame-specific frame elements, covering more than 13,000 lexical units. The frame and LU information are based on more than 200,000 manually annotated instances of frames in naturally occurring sentences. As discussed in Boas/Ruppenhofer/Baker (2024), all of the FN data is freely available and has been downloaded more than 5,000 times from the FN website. With this brief overview of the FN database, we now turn to the impact of FN on lexicography, linguistic theory, and computational and applied linguistics.

3. Impact of FrameNet on lexicography, linguistic theory, computational and applied linguistics

3.1 From English frames to frames for other languages

The semantic frames in the Berkeley FN database are based on English. One of the many interesting questions surrounding the conceptual architecture of FN is whether the semantic

Number Annotated	Patterns			
1 TOTAL	Agent	Air	Circumstances	Depictive
(1)	NP Ext	INC --	PP[in] Dep	Sabs Dep
3 TOTAL	Agent	Air	Depictive	
(1)	NP Ext	INC --	PP[as] Dep	
(2)	NP Ext	INC --	PP[in] Dep	
4 TOTAL	Agent	Air	External_cause	
(4)	NP Ext	INC --	PP[at] Dep	
1 TOTAL	Agent	Air	External_cause	Internal_cause
(1)	NP Ext	INC --	PP[at] Dep	PP[with] Dep
8 TOTAL	Agent	Air	Internal_cause	
(2)	NP Ext	INC --	PP[in] Dep	
(6)	NP Ext	INC --	PP[with] Dep	
1 TOTAL	Agent	Air	Internal_cause	Time
(1)	NP Ext	INC --	PP[with] Dep	PP[as] Dep
1 TOTAL	Agent	Air	Manner	Time
(1)	NP Ext	INC --	PP[as] Dep	AVP Dep
1 TOTAL	Agent	Air	Place	
(1)	NP Ext	INC --	PP[at] Dep	

Figure 3. Valence table of the lexical entry of *to gasp* in the `Breathing` frame[7]

frames based on English are also applicable to other languages, i.e., whether and how it is possible to use existing FN frames for the description and analysis of other languages. Initial research by Heid (1996), Fontenelle (2000/2009), and Boas (2002/2005) explored the idea of how similar semantic frames could be applied to a variety of different languages. Given that frames in FN are defined on a semantic basis, one might expect many frames to mostly be comparable across languages and language varieties, e.g. frames such as `Communication_statement` (evoked by LUs such as *to talk*, *to speak*, *announcement*, *comment*), `Self_motion` (evoked by LUs such as *to run*, *to walk*), and `Sleep` (evoked by LUs such as *asleep*, *to doze*, *to nap*, *hibernation*, *shut-eye*). Similarly, the concept of `Commercial_transaction` should be much the same in any culture, although details may vary (see Hasegawa et al. 2010).[8] Other frames that relate more closely to specific cultural, social or economic institutions involving elaborate background knowledge, such as `Revenge` may, however, pose challenges with respect to coverage and cross-lingual or cross-cultural applicability (for details, see Boas 2020).

For instance, the stages of the criminal process modeled by FN include `Arrest`, `Arraignment` and `Trial`, the latter two of which have further subframes, such as `Notification_of_charges`, `Entering_of_plea` and `Bail_decision` which are subframes of `Arraignment`. This conceptual division reflects US criminal law. While it has much in common with criminal law systems in the rest of the English-speaking world, US criminal law also includes specific events and procedures. For instance, so-called Miranda warnings given to persons in custody – not currently represented by the Berkeley FN – are specific to US law. Additional differences, with respect to possible or common role fillers, are hidden by the level of abstraction of the analysis: for example, in the US it is normally prosecutors that make the decision to prosecute, whereas in England the police make that decision in almost all cases. More substantial differences exist between US law and civil-law countries: Germany's criminal justice system is based on the notion that the prime task of a criminal trial is to determine the material truth, rather than deciding which of the contesting parties makes the better case. Accordingly, an admission of guilt is not sufficient to convict a defendant: the defendant may confess but that only counts as evidence and has no procedural effects, unlike a guilty plea in the US.[9]

These challenges notwithstanding, over time, a substantial number of frame-semantic annotation projects have been developed for languages other than English, producing substantial amounts of frame modeling and annotation (for an earlier overview, see the contributions in Boas 2009). Among the earliest projects started were Japanese FrameNet (Ohara et al. 2004), begun in 2000, the SALSA project for German (Burchardt et al. 2006), begun in 2003, Spanish (Subirats & Petruck 2010, Subirats & Sato 2004), and Chinese FrameNet (You & Liu 2005). Later FN projects were developed for (in alphabetical order) Brazilian Portuguese (Salomão 2009, Torrent et al. 2014), Finnish (Lindén et al. 2017), French (Candito et al. 2014), German (Ziem 2020), Greek (Giouli *et al.* 2020), Hebrew (Hayoun and Elhadad 2016), Italian (Lenci et al. 2010), Latvian (Gruzitis et al., 2018), Slovenian (Lönneker-Rodman, *et al.* 2009, Može 2009), Swedish (Heppin and Gronostaj 2012), and Turkish (Marşan et al. 2021).

For the most part, these projects applied the Berkeley FN frame inventory to their respective languages; most projects created new frames only to a limited extent. While the individual FrameNets for a long time simply existed alongside each other, the recent Multilingual FN project, a cooperation between FN at ICSI (English) and FrameNet-related projects for seven other languages, has produced a database comparing the frames and lexical units of English with those of each other language using a variety of alignment methods (Baker et al. 2018; Gilardi & Baker 2018; Baker & Lorenzi 2020; Sikos & Padó 2018).[10]

The availability of multilingual FN resources and of corpora with parallel frame semantic annotations has spawned interest in contrastive and typological research and is itself to some extent a result of this interest. One prominent issue that has been investigated on frame semantic annotations is Talmy's (1985, 2000) distinction between verb-framed and satellite-framed languages. For example, Ellsworth et al. (2006) compare motion scenarios in English, German, Spanish, and Japanese on parallel annotations of a chapter of Arthur Conan Doyle's *The Hound of the Baskervilles*, while Petruck (2008) examines the language pair English and Hebrew specifically.

More recently, versions of the well-known TED Talk *Do Schools Kill Creativity?* in several different languages were annotated as part of a Multilingual FrameNet Shared Annotation Task to assess how comparable frames and constructions are across languages. In order to make comparisons possible, the texts in all languages were annotated with the English FN Release 1.7 frames. Torrent et al. (2018) discusses some preliminary results, for the English and Brazilian Portuguese versions; they found that the frames for Portuguese and English were the same about 50% of the time, and about 80% of the Portuguese lexical units would fit without problems in the Berkeley frames. More recently, Ellsworth et al. (2021) argue more broadly for frame semantic annotation as a new dimension in carrying out computational semantic typology, pointing out that FrameNet relations provide a sufficiently general framework for the study of crosslinguistic semantic differences.

The availability of FN data in multiple languages has also inspired research on the role of frame (and constructional) matches and mismatches in translation. On the theoretical side, Pado & Erk (2005) provide an early study of variability in cross-lingual frame alignment by considering frame group differences resulting from differences in how causation is expressed. Boas (2013) shows how culture-specific frames can be modeled across different languages. Czulo (2017) gives an integrated analysis of shifts in framing in the process of translation, showing that grammatical, functional and semantic factors all play a part. In a more applied vein, Czulo et al. (2019) develop a metric for the evaluation of machine translation based on frame semantics; this metric does not require the use of reference translations or human corrections, but directly compares the original and the translated output. Yong et al. (2022) report on experiments studying how well neural networks can learn to predict the sort of frame shifts discussed in Czulo (2017). One goal is to aid in the automatic creation of multilingual FrameNets through projection of annotation between parallel texts in different languages.

FrameNet is not alone in supporting such research: Other English lexical resources have been central to other efforts to compare lexical semantics across languages. One of the largest of such efforts is work on projecting English PropBank (Palmer et al. 2005) to other languages. Beginning with treebanks based on English verbs, PropBank has expanded to include nouns, adjectives, prepositions, and some multiword expressions (Pradhan et al. 2022); it has also been expanded through annotation (some manual but mostly automatic) in 23 additional languages (Jindal et al. 2022). A new release in 2017 introduced expanded "rolesets" which can include different parts of speech, increasing its similarity to FrameNet, and paving the way for the addition of a new lexical semantic resource, Abstract Meaning Representation (AMR). AMR in turn has been expanded beyond English through translations to four more languages (Damonte & Cohen 2022).

3.2 Contributions to linguistic theory

FN's primary goal has been the creation of a lexicographic database of English, thereby demonstrating, among other things, how the principles of Frame Semantics can be applied to structure the lexicon of English. However, despite its lexicographic nature, FN's data have also proven useful for research in linguistic theory, in particular in areas pertaining to the so-called syntax-semantics interface.

One of the central issues in modern syntactic theory, at least since Chomsky (1965), has been the question of how to identify and characterize verb classes. In the Chomskyan framework, which assumes a modular architecture of the language faculty, the lexicon is a distinct component of the language faculty. On this view, minimally structured lexical entries interact with syntactic rules to license sentential structure. For example, the lexical entry for a verb like *love* would specify that it requires a NP as its subject and that it subcategorizes for a direct object NP (love: [NP, NP]). In Chomsky's (1981) *Principles and Parameters* approach, the lexical entry of *to love* inserts two NPs into a phrase structure rule at Deep Structure, thereby mirroring the semantic relationship between the verb's two arguments. A series of different types of interpretive principles (each constrained by a number of so-called well-formedness constraints such as the Theta Criterion or the Case Filter (Chomsky 1981)) then apply to derive different types of surface structures such as questions, declarative clauses, relative clauses, etc. (see Boas 2008 for more details). This strict separation between lexicon and syntax has proven to be quite problematic, because it presents difficulties in accounting for semi-idiomatic constructions and other multi-word expressions that should be listed in what is called "the lexicon", but at the same time show regular syntactic properties (see Fillmore et al. 1988, Kay & Fillmore 1999).

One way to deal with issues related to a purely modular approach has been to assume a tighter connection between form and meaning, as in Levin's (1993) syntactic approach to verb classification and alternations. Levin (1993:5) proposes that "verbs that fall into classes according to shared behavior would be expected to show shared meaning components." Studying 79 different syntactic alternations leads Levin (1993) to posit 193 distinct verb classes, such as verbs of putting, verbs of communication, etc., whose members are supposed to exhibit the same syntactic behavior because of their shared meaning. Baker & Ruppenhofer (2002) compare FN to Levin's (1993) verb classes and demonstrate that the frame-based classification of verbs is more detailed concerning the semantics and syntax of the verbal arguments and that FN offers more semantically coherent categories. Moreover, FN not only covers verbs, but also applies the same semantic frames and classifications to nouns and adjectives.[11]

In related research, Boas (2010a) demonstrates how semantic frames can be applied to the contrastive analyses of grammatical constructions across pairs of languages, while Boas (2011) picks up prior proposals by Baker & Ruppenhofer (2002) to show how syntactic alternations can be accounted for in terms of semantic frames instead of syntactic criteria. These ideas are developed further by Dux (2020), who shows how frame-semantic criteria can be applied to verb classifications in English and German, allowing for verb classes of different sizes and levels of granularity.

Frame Semantics has a special relation to its syntactic sister theory Construction Grammar, whose roots can also be traced back to Fillmore's (1968) seminal paper *The Case for Case* (see Section 2.1 above and Boas & Dux 2017, Boas 2021). In Fillmore & Kay (1993), the semantic side of grammatical constructions is represented in terms of semantic frames and their semantic roles (a.k.a. frame elements). In the work of Goldberg (1995, 2006), Frame Semantics represents the lexical semantics of verbs and gives rise to what she calls participant roles. Building on Goldberg's proposals, Boas (2010b) analyzes meaning parallels between verbs capable of occurring in the ditransitive construction (e.g. *Sue baked Kim a cake*; *Sascha told her a story*) and shows how constructional meaning can be modeled in terms of semantic frames, similar to lexical meaning. In more formal work on Signed-Based Construction Grammar, Sag (2012) also uses a version of Frame Semantics, in combination with the basic approach provided by Minimal Recursion Semantics, to specify the SEM(antic) values of signs. In more recent work on constructicography, the meaning side of construction entries is also modeled in terms of semantic frames (see Fillmore et al. 2012, Lyngfelt et al. 2018, Boas et al. 2019).

Przepiórkowski (2017a, 2017b) introduces two key valency ideas of FN to Lexical Functional Grammar (LFG). Whereas traditionally LFG's notion of valency was concerned only with arguments, his proposal adopts from FN the lexical introduction of all kinds of dependents, that is adjuncts as well as arguments, and the hierarchical organization of such extended valency information. Importantly, Przepiórkowski also argues for a re-analysis of the traditional argument/adjunct distinction. On his view, both types of dependents are introduced by the same mechanism and there exists only a gradual rather than a categorical difference between them: typical adjuncts are introduced higher in the hierarchy and inherited by many different frames, whereas typical arguments are introduced closer to the leaves of the hierarchy and accordingly inherited by a smaller set of frames.[12]

Apart from its impact on (computational) lexicography and lexicology, FN's frame inventory and annotated data have facilitated and inspired significant linguistic research. For instance, while implicit arguments are also addressed in the work of Levin (1993) and of Levin & Hovav (2005), FrameNet and related work in a Construction Grammar vein have provided researchers with a broad variety of empirical, annotated data. This has enabled not only corpus-based study of zero-realizations but also computational linguistic modeling of zero-realizations and their resolution to discourse referents (Ruppenhofer et al. 2010).[13] On the theoretical side, FN's work has reinvigorated research on the factors involved in licensing zero-realizations. FN's annotations subcategorize zero-realizations into two types based on lexical licensing (indefinite and definite, following Fillmore 1986) and one based on constructional licensing.

For the lexically licensed cases, Ruppenhofer & Michaelis (2014) argue for a limited implicational regularity tying the interpretation type of an omitted argument to the frame membership of its predicate. That is, while one cannot predict whether a predicate in a given frame will allow zero-realization of a certain FE, it seems to be the case that no two predicates of the same frame will license the omission of the same role with different interpretations. With regard to constructional zero-realizations, Ruppenhofer & Michaelis (2014) drew attention to genre as a factor in the licensing of certain omissions, contributing to the recent interest in research on the relationship between genre and constructions (Hoffmann & Bergs 2018; Fischer & Aarestrup 2021; *inter alia*). Boas (2017) presents a unified frame-semantic approach for capturing the meaning of words that are implicitly understood in context.

3.3 Semantic frames for domain-specific terminology

While the FN project is mostly concerned with the general language, the FN approach to lexicography and annotations has been and continues to be used and extended to facilitate the modeling of specific domains. What makes the FN approach attractive for domain-specific modeling is that, as emphasized in particular by the work of L'Homme and colleagues on environmental terminology, Frame Semantics provides a model for dealing with events (mainly expressed by verbs), whereas terminology is traditionally focused on entities (nouns) (L'Homme & Robichaud (2014), L'Homme et al. (2014), L'Homme (2018), inter alia). In that way, lexicon-driven frame-semantic terminological resources are expected to complement (a) knowledge-driven ontologies that are typically used to represent specific relationships between entities and (b) general language frame semantic resources that lack domain-specific frames and frame variants.

Especially in the context of science and technology, the domains covered range quite widely: among the research presented at EURALEX 2020 and 2022, were papers by Pilitsidou & Giouli (2020) who constructed a parallel Greek-English lexical resource for the financial domain and by Brač & Ostroški Anić (2022), who presented a specialized lexical resource, the AirFrame database, in which aviation terminology is defined in the form of semantic frames.

In addition to the work on environmental terminology, some other topical clusters exist, for instance bio-medicine and software design. As one of the first special-domain applications, Dolbey et al. (2006) develops the BioFrameNet resource as a domain-specific FN extension with links to biomedical ontologies that captures the mapping of form and meaning in the linguistic structures that occur in biomedical text. Much more recently, Roberts et al. (2018) produced Cancer FrameNet as a resource for cancer-related information in clinical notes. Within the software domain, Kundi & Chitchya (2017) reported on eliciting software use cases with FN frames. In related work, Alhoshan et al. (2018) present a frame-based approach for annotating natural language descriptions of software requirements.

Importantly, domain-specific applications of the FN approach provide a space for extending lexical coverage and representational mechanisms. Schmidt (2008) introduced the Kicktionary as a lexical resource of football language that was from the outset conceived and constructed as a multilingual resource (for English, German and French). The resource covers 104 frames and about 2000 lexical units. Notably, in addition to what it calls the scenes-and-frames approach based on FN, Kicktionary also uses concept hierarchies inspired by WordNet (Fellbaum 1998) for hypernymy / hyponymy, holonymy / meronymy, and troponymy.

In later work on a related domain, Torrent et al. (2014) created a multilingual electronic dictionary addressing the domains of soccer, tourism and the World Cup as part of the "Copa 2014" FN Brasil project. In subsequent work, the research group expanded the earlier frame-based modeling of the domains tourism and sports to support the development of a personal travel assistant application. In terms of coverage, the modeling effort resulted in a set of 58 frames for the travel domain, of which 42 were newly created by the Brazilian project and only 16 were taken over from English FN. Similarly, the project created 29 frames in the domain of sports in addition to using 4 frames from English FN. With respect to representations, Brazilian FN introduced new relations beyond the frame-to-frame relations of English FN (Costa *et al.* 2022). The first set, the so-called "qualia" relations (inspired by Pustejovsky 1995), inter-connect LUs. For instance, a formal quale connects LUs that stand in an *is-a* relation to each other. The second set of relations connects FEs to frames so as to model the fact that participants in a frame may be defined in terms of other frames. As an example, the Tourist FE in the `Attracting_tourists` frame is linked to the People frame.

4. Efforts to automate parts of the FrameNet workflow

As manual frame creation and annotation have proved to be quite labor-intensive, research has been conducted since the early days of FN to support the work by some form of automation. Work on FN resources for languages other than English notably contributed to such efforts as newly initiated projects sought to scale their coverage.

Frame and lexical unit induction.

As in the human workflow of FN, the first stage of automation efforts usually consists of creating frames and their roles. Green et al. (2004) present a system to automatically induce frame semantic verb classes based on verb senses present in WordNet and LDOCE (Procter 1978), without using corpus data. Later research (Modi et al. 2012, Materna 2012, Ustalov et al 2018, inter alia), by contrast, has usually proceeded in a data-driven way, even though it varies widely with respect to algorithms and methods. In the recent Shared Task on Unsupervised Lexical Frame Induction (QasemiZadeh et al. 2019), the best performing systems (Arefyev et al 2019, Anwar et al. 2019, Ribeiro et al. 2019) all made use of the BERT language modeling tool (Devlin et al. 2019). The Shared Task results suggest that there continues to be room for improvement, even for the simplified setting where only core roles are considered.

Compared to frame induction, a more circumscribed way to expand FN is to add new lexical units to existing human-defined frames. Along these lines, Pennacchiotti et al. (2008) used distributional and WordNet-based models to induce lexical units. WordNet and FN represent different but complementary theories of lexical semantics (Baker & Fellbaum 2009); there has been much research on how to align them (e.g., Ferrández et al. 2010), but early hopes of populating whole frames directly from WordNet synsets were not fulfilled.

Creating annotations.

From early on, a central concern of work on the non-English FN resources has been to use the best-developed resource, Berkeley FN, to speed up development. The very first approach pursued towards this end was to project annotations from English sentences to parallel sentences in a target language (Padó & Lapata 2005; Padó & Pitel 2007, Padó & Lapata 2009). Automatic methods for creating annotations were also developed for use within a language, typically so as to expand the data available for use by ASRL systems (see section 5.1). Hartmann et al. (2016) use two types of knowledge sources to label corpus data, namely (a) integrated lexical resources that combine several resources by linking them on the sense or on the role level and (b) linguistic knowledge formalized as rules to create data labeled with FN senses and roles. Pancholy et al. (2021) propose a data augmentation approach which uses the frame-specific annotations of some lexical units to automatically annotate instances of other `sister' LUs of the same frame for which no annotations were previously available. Cui & Swayamdipta (2024) extend the work of Pancholy et al. (2021) by using large language models to better ensure the semantic consistency of automatically created annotations with the targeted frames. Anwar et al. (2024) similarly use state-of-the art transformers (but not LLMs) to generate alternative lexical realizations of lexical units and semantic roles matching the original frame definition, with the lexical units, however, not being constrained to already be included in the frames by FrameNet. Both Anwar et al. (2024) and Cui & Swayamdipta (2024) report that automatic annotation creation is more effective in low-resource settings, such as when seeding annotations for a FrameNet resource in a new language.

FrameNet lexicography and large language models.

The advent of large language models such as ChatGPT has inspired research into their "knowledge" of lexical semantics and their potential for lexicographic applications. The former aspect is the focus of Petersen & Potts (2023) who present a study centered on the English verb *break*, which is well-known to exhibit numerous senses and a wide range of syntactic frames. The authors show that LLMs capture known sense distinctions and can be used to identify new sense combinations for analysis. On a theoretical level, Petersen & Potts suggest that LLMs are aligned with lexical semantic theories in that they provide representations that are both high-dimensional and contextually modulated, but which, however, lack the discrete, highly structured features assumed by more traditional approaches to linguistic semantics.

De Schryver (2023) provides an overview of 10 papers and talks that address the impact of LLMs on lexicography, covering a broad range of lexicographic tasks including centrally (COBUILD-style) definition generation but also the selection of examples, the labeling of senses (as vulgar, derogatory, etc.) and the production of IPA pronunciations. The papers summarized address certain well-known problems associated with the use of LLMs such as their significant environmental impact, potential for transmitting stereotypes, hallucinations, lack of reproducibility (non-determinism) as well as problems of memorization/plagiarism. Of specific relevance to lexicography is that the vast majority (>90%) of the training data is in English. Prompts in any other language are answered by way of English and are thus influenced by the (linguistic) characteristics and structures of English. Further, because older dictionaries with lapsed copyright are part of the training data, ChatGPT may hold on to outdated lexicographic practices from an earlier age unless explicit prompt engineering is used to mitigate. Lastly, it is not possible to link examples back to attested sources. These issues notwithstanding, the overall outlook of de Schryver for using LLMs in lexicography is a positive one.

Yin & Skiena also come to a positive assessment when comparing definitions created by ChatGPT to ones from traditional dictionaries for about 2500 words from three frequency bands. First, the authors find that definitions from traditional dictionaries show greater surface form similarity than model-generated definitions, suggesting that LLMs do not borrow from (or plagiarize) dictionary definitions contained in their training data to a greater degree than traditional dictionaries do. Secondly, the authors find ChatGPT's definitions to be consistent with what is found in dictionaries based on various automatic measurements.

For FrameNet-style lexicography, Torrent et al. (2023) have recently suggested exploring LLMs as "copilots" assisting human linguists. However, no large-scale evaluation of LLM use for all aspects of FrameNet lexicography exists at this point. To the extent that there is overlap with the processes and goals of general lexicography, use of LLMs for FrameNet lexicography faces the same challenges as discussed by de Schryver (2023). For instance, the large skew towards English training data may degrade LLMs' usefulness for other, especially lower-resourced languages.

In addition, it is worth emphasizing the specificities of the FrameNet approach. Not only are word senses and definitions needed but so are the identification, naming and definition of frames and frame elements as well. Furthermore, example sentences per sense need to also be annotated in terms of the Frame Elements that are realized. Ideally, the construction of the "net" aspect of FrameNet, the system of relations among frames and frame elements embodied by FrameNet's frame hierarchy, would also be assisted by LLMs. While some work has been carried out evaluating the use of pre-trained language models for constructing taxonomies – for instance, Chen et al. (2021) recreate the IS-A taxonomy of English WordNet – so far no effort has targeted FrameNet's larger set of frame relations.

5. Applied research using FrameNet data

5.1. Computational linguistics

Automatic semantic role labeling.

FrameNet has had a significant impact on the field of computational linguistics. Above all, its annotations enabled automatic semantic role labeling (ASRL) as a novel task through the seminal work of Gildea & Jurafsky (2002). ASRL systems have evolved continuously over the years spurred on by community-driven evaluation campaigns (Litkowski 2004, Baker et al. 2007, 2010) and the development of novel algorithms and tools by the NLP community. Among the systems developed, SEMAFOR (Das et al. 2014) represents the culmination of feature engineering approaches. More recently, frame-semantic ASRL has seen improvements through the adoption of neural word representations and transformer models (Roth & Woodsend 2014, Swayamdipta et al. 2018, Kalyanpur et al. 2020). Since the largest amount of FN annotation is available for English, ASRL systems are most advanced for that language. Typically, ASRL systems are language specific. However, often such language-specific systems involve some cross-lingual transfer of knowledge from one language (typically English) to another in order to enlarge the amount of data for training the system in the target language.While ASRL represents the most natural and "intended" use of FN's annotations for automatic semantic analysis, the majority of research in computational linguistics has made use of FN's frame inventory and annotations in a more partial way. At the same time, FN data has been used in a variety of applied tasks so large and varied that it cannot easily be summarized here.[14] So rather than attempt such a summary, we briefly illustrate the two main motivations behind "partial" uses of FN information.

One central recurring idea behind the use of FN in applied contexts is to use its grouping of lexical units into frames as a way to allow for the identification of lexical units with certain **shared features**, which may but need not amount to the recognition of (near-)paraphrases. A very narrow use of frames and their lexical units was made in research on automatically ranking sentiment-bearing LUs by their intensity (Ruppenhofer et al. 2014, Sharma et al. 2017). Here, the LU membership in FN was used to identify which lemmas evoked the same semantic scale and therefore needed to be ordered relative to each other (e.g. *good* <

excellent).[15] Note that the only candidate lemmas considered in that research were adjectives. Similarly, Wiegand et al. (2018) use the frame-memberships of words as features in training a classifier that separates negative polar expressions (of all open lexical classes) into abusive and non-abusive categories. The stated intuition underlying the use of FN was that abusive and non-abusive words would occur in separate frames. Wider use of FN information was made by Liu et al. (2016) who explore the use of FN frames for the purpose of event detection, that is the task of extracting information on pre-defined event types (such as `Attack`, `Fine` or `Execute`) from text. While only the information on frame-evoking elements (FEEs) and the frames they evoke is used and no use is made of FEs, the authors do consider frame-to-frame relations to map LUs in FN frames to predefined event types.[16]

Another type of use of FrameNet data is interested in the **predicate-argument relationships between FEEs and FEs**. One applied task where FE information has been made use of is noun compound interpretation, which Ponkiya et al. (2021) cast as semantic role labeling within noun compounds. That is, their system assigns a FN frame to the compound head and determines the FE role that the compound modifier bears to the frame evoking head noun. Fuller use has been made of FN in work on the textual entailment task. For instance, Burchardt & Frank (2006) approximated textual entailment by degrees of structural and semantic overlap between a (short) text and a hypothesis it potentially entails. The semantic representation used for this purpose consisted of automatically assigned frame and role annotations. (Note that, as is often the case in applied contexts, strict correctness of the automatic frame semantic analysis was not necessary: the entailment task might be solved correctly even if the frame semantic analysis is less than perfect). A more specialized but comparable use of FN was made in work by Zhang et al. (2018) on identifying duplicate questions in the context of community question answering on sites such as Quora or Stack Exchange. The specific interest in using FN lay in the fact that it establishes relations between FEEs and FEs. While modern neural networks can easily learn semantic similarity between words and address the problem of unknown words, they may not readily recognize the syntactic-semantic relationships between predicates and their arguments. Accordingly, they may fail to consider questions that feature high word overlap but have a single crucial difference in FE fillers as non-identical (non-duplicate). To counteract this, frame-semantic parses were integrated with neural networks.

5.2 Language education / pedagogy

Although Fillmore had connected frames to pedagogy in work on reading comprehension (Fillmore 1982b), the pedagogical potential of Frame Semantics (see Fillmore 1990) and its sister theory, Construction Grammar, received growing attention only with some delay after these theories had been adopted in theoretical or descriptive work on native speakers' productions and first language acquisition. Early research on applied questions involving constructions includes Liang (2002), Gries & Wulff (2005, 2009), and Valenzuela Manzanares & Rojo López (2008), who study constructions among foreign learners of English. Wee (2007) and Holme (2010a, b) investigate the use of Construction Grammar in the classroom. Beginning in 2013, the conference series "Constructionist Approaches to Language Pedagogy" (CALP) established a forum for researchers with an interest in applying insights from Construction Grammar and Frame Semantics to improving language teaching and learning.

While much of the recent research addresses constructions, there is also significant work on semantic frames in an L2 context. Boas et al. (2016) demonstrate how the German Frame-based Online Lexicon (G-FOL) uses the principles of FN to solve certain didactic challenges in foreign language pedagogy that result from the disconnect between the types of information presented by lexical resources such as dictionaries and syntactic resources such as grammars (see also Boas & Dux 2013 and Lorenz et al. 2020). In subsequent research, Gemmel Hudson (2022) shows how the G-FOL lexicon can be used to structure the curriculum of a second-year university level German course. Law (2022) proposes a frame-centered approach to French vocabulary instruction, using a case study on teaching metonymic uses of Place for Institution. Most recently, Dalpanagioti (2023) argues more generally for the importance of applying frame semantic insights to task - based lesson planning as both share a usage-based perspective on learning.

5.3 Practical NLP applications

Many of the thousands of downloads of the FrameNet data were due to requests from companies offering "text mining" and summarization services. In most cases, the companies regard their algorithms as proprietary commercial assets and the FrameNet team cannot determine how they are using FN data. Thanks to personal communications, the FN team is aware that IBM's Watson question answering system incorporated FrameNet data along with much other NLP research; they also believe that Google's search engine depends in some small part on Frame Semantics. The collaboration with DAC also gave the team insight into how FN data was being used to analyze texts for the Department of Defense. With the current tidal wave of large language models (LLMs), it has become even harder to determine what part FrameNet plays in commercial systems.

However, the team at FrameNet Brazil is currently building an NLP system for a very practical purpose in which FrameNet data plays an important part: They are trying to reduce gender-based violence (GBV) by detecting instances of GBV which were not reported to the authorities by workers in the national public health system, even though such reporting is legally required. Since the records of interactions of patients with healthcare workers contain notes from each interaction, some of these will offer clues to instances of GBV, many of which are not being reported for a variety of cultural and political reasons. If these clues can be followed up, patterns of underreported GBV can be detected and local authorities will be able to take action to improve the reporting rate and reduce the violence. The data for the project was anonymized medical records from Recife, Brazil, combining records of visits to public health clinics (including both structured data and free-form text), coroner's reports of deaths, and records from a system for reporting violence against women. The first steps were an analysis of the language of the text fields to gather the medical terminology, abbreviations, slang, and general vocabulary, and to cluster them and define the necessary FrameNet frames. The study was based on 17 existing FN frames in the medical domain, but required creating two new healthcare domains, 28 new frames (and the relations between them), 4,459 new Portuguese lexical units in these frames, and 4,698 new qualia relations between the frames and lexical units. Students were then trained to annotate the anonymized text with the FrameNet labels. The resulting frame analysis was combined with demographic and violence metadata to train a local instance of the LOME frame-based information extraction system (Xia et al 2021), which was run against the collection of all the public health records from the city of Recife (population estimated at 3.7 million), generating more than 24 million annotation sets. These automatically generated annotations combined with the structured healthcare data were used to train a classifier to identify possible instances of gender-based violence. The FrameNet-based semantic model greatly outperformed two other systems, one built on a standard LLM (SGPT BLOOM 7B) and the other built on the structured data alone: the F1 scores were 0.77, 0.46, and 0.30 respectively (Tiago Torrent p.c.) The results of the project are being used both for interventions in the local healthcare system and for decisions about healthcare policy. (cf. Torrent 2024 for more information).

6. Past, current and future challenges

6.1 Funding and other support

FrameNet I

The ICSI FN project in Berkeley enjoyed seven years of support from the National Science Foundation.[17] FrameNet I: The FN Project started officially in 1997, with NSF grant IRI

#9618838, "Tools for Lexicon Building" (PIs Fillmore and Dan Jurafsky), which funded frame semantic research at ICSI from 1997-2000. As discussed in Boas/Ruppenhofer/Baker (2024), Charles Fillmore and Sue Atkins had published papers on Frame Semantics and mapped out the rough outlines of a project to create a "super dictionary" while collaborating on the DELIS project (Heid 1994) with Uli Heid. The proposal sought funding for a proof-of-concept phase, to answer the basic questions: Could the theory of Frame Semantics, as expounded in articles published over several decades, each with a handful of examples, be applied to lexical semantics in general? The theory predicts that most, if not all, open-class lexical items derive much of their meaning and syntactic behavior from the semantic frames they evoke (Fillmore & Baker 2010: 317-320). Could the team develop software and hire and train annotators so as to produce the annotation needed to test these general principles? The annotation would have to be sufficient both in quantity and quality to show that the examples in the papers are representative of larger classes and that useful syntactic patterns could be extracted from annotating them. Given the centrality of the concept of the semantic frame, it was decided that the lexicon would be created frame-by-frame rather than word-by-word.

In the original proposal, the team committed to create a highly relational "starter" lexicon containing 5,000 entries covering major semantic domains and make it freely available to researchers. Each database entry would be associated with the semantic frame in which it participates, and annotated "with respect to how it constellates with the elements of that frame, both morpho-syntactically and semantically". Entries would also "list examples taken from a corpus showing the range of the word's use, including relative frequency data." These objectives were accomplished during FrameNet I, except that (1) far fewer LUs were created than planned and (2) after discussion with NLP colleagues, the team realized that the selection of texts for annotation under FN policies would not result in a statistically representative sample of English, so that any frequencies derived from it would not be generally useful.

The researchers initially selected twelve semantic domains, deliberately chosen to be extremely varied, so as to test whether Frame Semantic theory would be applicable and appropriate and would lead to useful annotations in all of them. The domains were: `Causation`, `Cognition`, `Communication`, `Commerce`, `Emotion`, `Health and Medicine`, `Judgement`, `Life and Death`, `Locative relations`, `Motion`, `Perception`, and `Time`. The proposal also committed to deliver "a set of high-performance computational tools for corpus research, annotation, and analysis (…) which will be made available to the research community (…) exploring natural language processing, speech recognition, and the complex problems of language understanding."

FrameNet II

In 2000, the FN project received its largest grant, ITR/HCI #0086132, "FrameNet ++: An On-Line Lexical Semantic Resource and its Application to Speech and Language Technology" of $2.2 million dollars for the period from 2000-2004, with PIs Charles Fillmore, Dan Jurafsky, Srini Narayanan, and Mark Gawron. The applications given in the proposal were: word sense disambiguation, speech recognition and understanding, machine translation (English to Japanese), open domain information extraction, and large-scale knowledge acquisition. The team promised to deliver both the lexical semantic resource and the tools needed to build it. The lexical resource would include (1) frame descriptions with relations between frames such as inheritance, frame composition, and frame blending, (2) a lexicon based on these frames, and (3) a collection of sentences annotated using these frames. The software would include tools for handling and searching text corpora, manual annotation, automatic semantic role labeling, and statistical summaries. These goals were accomplished thanks to this grant, and FN began distributing copies of the lexical resource.

In addition to the basic support for building the FN lexical database mentioned above, the project also received NSF funding in the form of a subcontract from grant IIS-0325646 (Dan Jurafsky, PI) for providing full-text FN-style annotation of texts also annotated in the PropBank project. The FN team annotated five such texts, which marked the beginning of FN "full-text" annotation (see Section 3.3 above).

As Table 1 indicates, the years 1997-2000 were essentially a proof-of-concept period, which demonstrated that it was possible to build a lexical resource based on Frame Semantics, and exposed some weaknesses in the design of the database and the software. The major new award in 2000 enabled the team to hire a new programmer to build an improved software suite and switch to a relational database.[18] The following years (2001-2003) saw the most rapid increase both in new frames and new LUs.

Between 2003-2014, development continued with a lower level of funding from NSF and a variety of other sources[19], and at a correspondingly lower speed. FN also benefited from subcontracts with other NSF researchers as well as a research fellowship from Google, Inc. The basic principles of Frame Semantics underpinned all this research, but the content of the text being annotated varied with the funding source. For example, a collaboration with Profs. Nancy Ide and Christiane Fellbaum led the FN team to annotate example sentences containing certain polysemous words from the American National Corpus (de Melo et al. 2012). A SBIR subcontract with Decisive Analytics, Inc., working on military text, prompted the creation of several frames related to improvised explosive devices (IEDs).

Figure 4 shows the progress of the work of FrameNet, as measured by the definition of frames and lexical units and the annotation of instances of LUs in text. Because the counts for these differ by two orders of magnitude (~1,000 frames ~10,000 LUs, ~200,000 annotation sets), we display the progress in terms of percent of the final totals for each category. Aside from the general shape, showing rapid progress in the first decade which slows down later, we can see that the growth of lexical units was faster than that of frames in the first phase, while the converse is true in later years. This is in keeping with the original objective of working on everyday language at first and NSF funding with relative freedom to choose the domains. Later years involved more collaboration with industry, requiring a narrower focus on particular frames. The FrameNet team also moved toward more abstract frames such as those containing lexical units for spatial relations (e.g. *above, in front (of),* see Petruck & Ellsworth 2018), which contain a very limited set of high-frequency lexical units.

By 2003, even though the lexical database fell short of the original goal of 5,000 lexical units, the FN team felt that it was important to start releasing the data, so that other computational linguistics researchers could use it and give the team feedback. FN has had a consistent policy that all the results of the research will be made freely available, including the text itself. This requires that the texts selected for annotation be free of copyright or distributed by permission of the copyright holders. The lexical database has gone through six releases, each with accompanying technical documentation of the database structure and a

Table 1. Summary of frame and lexical unit development in the FrameNet project

Years	Lexical Units	Frames	LUs/year
1997-2000 (FN 1)	1,401	81	350
2001-2003	6,187	399	2,062
2003-2014	5,461	708	546
2014-2023	1,112	65	124
Totals	14,161	1,253	545

copy of a document (also gradually revised) which serves both as a manual for annotators and as an explanation of the principles behind the annotation.

The data generated by FN over 25 years has been of interest to a broad variety of researchers. Table 2 shows the number of requests for download of FN's lexical database from 2003-2023. The request form asks the user about how they intend to use the data, which allows the team some insight into the wide range of uses for FN data. (The names, institutions, and intended purpose of users who grant permission are also listed on the FN web pages at https://framenet.icsi.berkeley.edu/framenet_users.) The largest group of users are computational linguistics/NLP researchers, many of whom want to add FN to an existing NLP system as an additional source of information. In some cases, the only information extracted from FN is whether or not two words are in the same frame, i.e. only as a measure of semantic similarity. Others make use of more of the rich semantics of FN, such as implications from frame Inheritance relations, event structure from Precedes relations, etc.

The death of Prof. Fillmore in 2014 was, of course, a major blow to the project, and made it harder to attract graduate students and postdocs to the project. However, the team has persisted with Frame Semantic research until the present (2023), and student participation has been vital to this research. Although Dr. Baker, the project manager of FN since

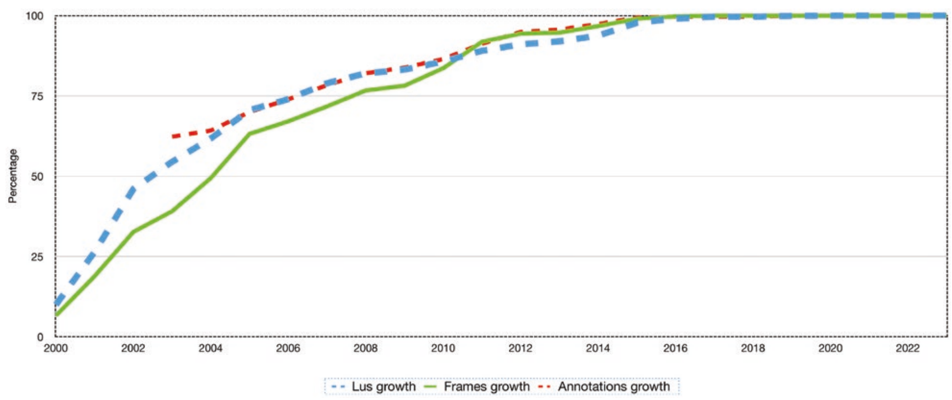

Figure 4. The Growth of FrameNet data 2000-2023[20]

Table 2. Requests to download FrameNet data, by year.

Year	Requests	Year	Requests
2003	2	2013	326
2004	401	2014	303
2005	346	2015	285
2006	263	2016	306
2007	229	2017	621
2008	236	2018	633
2009	251	2019	538
2010	358	2020	459
2011	484	2021	432
2012	313	2022	366
		2023	154

2000, was not on the Berkeley faculty, he led a series of small research projects through the UC Berkeley Undergraduate Research Apprenticeship Program (URAP) between 2016 and 2022, under the sponsorship of Prof. Terry Regier of the UC Berkeley Linguistics Department. In this program, the students were able to earn credits for their work, which also contributed to the development of FN more generally. Examples of these projects include: installing and testing the Open Sesame Frame Semantic parser (Swayamdipta et al 2018) and development of scripts to make its output more readable; some early efforts at cross-linguistic alignment of FrameNets; predicting missing frame relations on the basis of the existing hierarchy; and a study of frames and framing in the domain of politics, with application to the California state-wide propositions in 2020.

Crowdsourcing and games

Given the alternatives of expensive manual annotation of texts or automatic semantic role labeling by systems which offer few insights into how humans understand sentences, the FN team regarded crowdsourcing as a practical compromise for data collection. Crowdsourcing has been widely used for linguistic data collection for more than a decade (Callison-Burch & Dredze 2010). In 2008, the FrameNet team submitted an NSF proposal to collect data through a game interface, a technique that had proven useful in previous linguistic data collection projects (e.g., Poesio et al. 2008), but it was not funded.

In 2009, FN received an NSF award (#0947841) for a more "traditional" type of crowdsourcing: the team used Mechanical Turk (Snow et al. 2008) as the mechanism for paying annotators and constructed their own web-based system for presenting the items to the annotators running at ICSI. The task was frame disambiguation; the results (Hong & Baker 2011) showed that untrained annotators could provide useful data on the frame disambiguation task, but also that building the presentation system from scratch was a fairly difficult task. A second experiment with crowdsourcing was carried out in cooperation with several Google staff members, and with the support of a Google Faculty Research Fellowship for Dr. Baker. The FN team chose a set of lemmas that occur in more than one frame, and the Google staff created a slick user interface to present them for disambiguation. The Google staff also arranged for the task to be carried out by workers who already had experience annotating for Google, and set up A-B testing to refine the interface. The outcome, reported in Chang et al. (2015), confirmed that such techniques could produce high-quality data for FN and that the user interface design was crucial. However, when the experiment ended, Google retained ownership of the presentation software, and FN was not able to use it again.

Finally, under the NSF-funded Summer Undergraduate Program in Engineering Research at Berkeley, a CMU undergrad was able to devote two months to writing an online data collection game for FN (unimaginatively called "Frame Game") using the Unity game programming framework. The game prompts users to write a short story using lexical units from FN, and then to annotate frame elements in the text they have created. This was only a proof of concept, and was not actually published on the web, but the student and Dr. Miriam Petruck jointly wrote a conference paper on it (Amspoker & Petruck 2022).

6.2. Organizational issues

The history and success of FN over the past 25 years depended on a number of different factors. To better understand the evolution of FN since 1997, this section discusses some of the organizational, financial, institutional, and personal factors. Charles Fillmore and Paul Kay had been teaching in the Linguistics Department at UC Berkeley for several decades; during the early 1990's they co-taught a course there in which the principles of Construction Grammar (including Frame Semantics) were worked out week by week in the classroom. However, they moved to the International Computer Science Institute (ICSI), only a few blocks away from the UC campus, soon thereafter, in part because their research was increasingly computational (Kay was returning to the study of color terms across languages, as well as continuing to work on Construction Grammar, and Fillmore was seeking more computing support for corpus-based lexicology). Another advantage of moving to ICSI was that, since ICSI is a much smaller organization than UC Berkeley and has been supported entirely by grants and contracts, it is able to act more quickly and efficiently on grant applications.

At ICSI, as noted above, Fillmore received two NSF grants for the first six years of FrameNet, but support was far from steady thereafter. The same was true of ICSI as a whole; the Institute went through years of feast and famine depending on the funding of the current grant situation. Two research groups which had brought major funding to ICSI, the speech group and a group working on computer system security, were spun off into start-ups, and outside funding for their research ended.

From 2012 to 2015, ICSI put together a research team which participated along with several other teams in a large research project funded by the Intelligence Advanced Research Projects Activity (IARPA) on creating systems for automatically detecting and classifying metaphorical expressions in four languages (English, Spanish, Russian, and Farsi). The ICSI-administered project, called MetaNet (Dodge et al. 2015), brought major funding to ICSI, and involved hiring Linguistics professors, graduate students, subject matter experts, and programmers at ICSI, Berkeley, and other UC campuses. It had been hoped that the existing FN frames would be used as the basis for the metaphor research. However, the linguists leading the ICSI team decided to define metaphors based on existing research on metaphor (e.g. Lakoff & Johnson 1980, 1999; Sullivan 2013). Although that research treats metaphors as relations between frames, the metaphor team found that existing FrameNet frames did not match those from metaphor research and that creating the new full-blown FN frames would be too time-consuming. In practice, they created and used a data structure based on frames derived from metaphor research (although links to FrameNet frames were often included in their frame definitions). FrameNet, WordNet, and Wiktionary were used mainly to expand the search for the most relevant frame in their system (Dodge et al. 2015. 44). The entire metaphor project (including the teams at other centers) was abruptly canceled in 2015; research on representations of metaphors is continuing at the University of British Columbia.[21] Dodge (2016) is a detailed case study which clarifies the MetaNet methodology. Although the ICSI FN group has created a frame-to-frame relation for metaphor, the results of the MetaNet project would not be easy to integrate into ICSI FrameNet.

The FrameNet team has come to believe that both NSF and NIH are increasingly unwilling to fund any project that involves large-scale manual, expert annotation. For computer scientists in general, the preferred approach to any classification problem, including those involved in natural language understanding, has been to run a small manual annotation task and then train software to make the same discriminations automatically as soon as possible. Obviously, the rapid progress in creating large language models (LLMs) trained on massive amounts of data means that pressure to automate all NLP tasks is only increasing. However, given the fact that LLMs are basically opaque, and that the task generative LLMs are trained on is basically to predict the next word in a sequence, we feel it is somewhat misleading to equate progress on LLMs with progress on natural language understanding by computers.

The fluctuations in funding for FN development over the years, the different objectives of different grants, and the need to hire students for software development meant that many different programmers created the FN software, often with little or no overlap for handover from one to the next. Despite the project manager's efforts to require thorough documentation of all code, new programmers often had to spend considerable time learning about existing software. Furthermore, different individuals preferred programming in different languages, so the FN software became a mixture of code in Python, Java, PHP, JavaScript, Perl, Haskell, Scala, and shell scripts, linking to a variety of frameworks for corpus manipulation and low-level processing.[22] A constant background throughout this period was the booming tech industry centered in nearby Silicon Valley; many FN employees (both programmers and annotators) left the project for more exciting (and higher paid) jobs at Google, Apple, Microsoft, Amazon or a startup. This process can be seen from different points of view: By working for FN for a short period, they received valuable training, which enabled them to enter the tech workforce, fulfilling one of NSF's objectives and benefiting them individually. However, from the point of view of the FN project, the turnover of employees made it difficult to maintain high skill levels and consistent policies for both programming and annotation.

Another important background factor was the relationship between ICSI and UC Berkeley. ICSI has never been part of UC Berkeley, or received any funding from it, but most leaders of research groups at ICSI have had a position at Berkeley. Prof. Fillmore's long tenure in the Berkeley Linguistics department meant that he was often able to recruit students from his courses to participate in developing frames and annotating sentences for FN. Even after his retirement from full-time teaching in 1995, his reputation attracted students and postdocs from Berkeley and around the world to ICSI and FN.

Notable among these were postdocs from Germany supported by generous year-long fellowships from the German Academic Exchange Service (Deutscher Akademischer Austauschdienst– DAAD). The questions they have asked have repeatedly helped us think more deeply about Frame Semantic theory and most of them published FrameNet-related papers while at ICSI. Notable among them are Hans C. Boas (at ICSI 2000-2001), Professor of Germanic Linguistics, University of Texas at Austin; Petra Steiner (2002-2003), Senior Researcher at Technische Universität Darmstadt; Thomas Schmidt (2005-2006), Chief Computational Poetry Officer at Musicalbits.de; Jan Scheffczyck (2005-2006); Birte Lönneker-Rodman (2006-2008), Head of Professional Services, semantha®; Martin Hilpert (2007), Professor of English Linguistics, University of Neuchâtel; Oliver Czulo (2011-2012), Professor of Translation Studies at the University of Leipzig; Prof. Gerard de Melo (2011-2013) Chair of Artificial Intelligence and Intelligent Systems, Hasso Plattner Institute / University of Potsdam; and Alexander Ziem (2013-2014), Professor of Germanic Linguistics, Heinrich Heine University, Düsseldorf. Most of the members of the new Global FrameNet Association founded in Düsseldorf in 2023 were once DAAD fellows at ICSI.

7. Conclusions

In this paper, we first provided in Section 2 a brief summary of the structure and content of the FN database (for details, see Boas/Ruppenhofer/Baker 2024). In Section 3, we discussed the impact of FN on lexicography, linguistic theory, computational and applied linguistics (with a special emphasis on translation studies, linguistic typology, and linguistic theory) and also showed how the concepts and ideas of English FN were eventually extended to allow for the creation of FrameNets for other languages and to domain-specific terminology such as biomedical or soccer language. Subsequently, we discussed how insights from FN have been applied to computational linguistics and the teaching and learning of foreign languages and we reviewed a number of past, current, and future challenges for FN, mainly in terms of workflow, funding, and organization.

In Section 4 we discussed several efforts to automate central aspects of the workflow of FN that to date have been carried out manually. More specifically, we reviewed several efforts to automate the development of semantic frames and the annotation of corpus examples and we pointed out significant issues with both efforts that do date have hindered an automation of these aspects of the FN workflow. Section 5 provided an overview of the applications of FrameNet data to research in two specific domains, namely computational linguistics and language pedagogy and foreign language education. In Section 6, we discussed a number of past, current, and future challenges for FN. More specifically, in Section

6.1 we summarized the various types of financial support that FN received from different funding agencies over the past 25 years and we addressed the problem of finding continuous financial support for FN, whose ultimate outcome, a frame-based online lexicon of English, is an ambitious and challenging long-term project. In Section 6.2, we discussed various organizational and institutional challenges faced by FN since 1997, including the changing infrastructure provided by FN's host institution, the International Computer Science Institute, the difficulty of maintaining lexicographic researchers at FN because of better paid jobs in nearby Silicon Valley, and technical issues related to changing software standards, databases, and scripting languages over the years.

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Notes

1 We dedicate this paper to the memory of our colleague Miriam R.L. Petruck who passed away in the interval since the first part of this paper was published last year. She began work on Frame Semantics as part of her PhD research at UC Berkeley and later become an integral part and driving force of the Berkeley FrameNet project and the global FrameNet community.

2 The frames can be found from the Frame Index at https://framenet.icsi.berkeley.edu/frameIndex, the lexical units index is at https://framenet.icsi.berkeley.edu/luIndex. As discussed in Ruppenhofer et al. (2016), FrameNet distinguishes between core roles and peripheral as well as extra-thematic roles. The core roles are those that instantiate conceptually necessary components of a frame, while making the frame unique and different from other frames. Metaphorical relations are captured in FrameNet by a frame-to-frame metaphor relation.

3 Lexical units are typically words, but roughly 1,000 are multi-word expressions like *make out* (several senses), *ramp up*, *on the run*, *lose* (one's) *head*, *seal* (one's) *lips*, etc. Each lexical unit is mapped to one frame; polysemy is represented by mapping the same word form(s) to multiple frames, constituting multiple lexical units.

4 For a concise overview of the terminology associated with FrameNet, we refer the reader to Fillmore & Petruck's (2003) glossary. For a more general overview of FrameNet, see Ruppenhofer et al. (2017).

5 See https://framenet.icsi.berkeley.edu/fnReports/data/frameIndex.xml?frame=Breathing

6 See https://framenet.icsi.berkeley.edu/fnReports/data/lu/lu4961.xml?mode=lexentry

7 See https://framenet.icsi.berkeley.edu/fnReports/data/lu/lu4961.xml?mode=lexentry

8 For the first cross-linguistic applications of semantic frames, see Fillmore (1982a) on Japanese *nurui* vs. English *cool*. Fillmore and his students published on the topic soon thereafter (for example, Fillmore 1985, Petruck 1986).

9 For a discussion of how different polysemy patterns affect cross-linguistic analysis using semantic frames, see Boas (2011).

10 See https://www.globalframenet.org/. The FN team at ICSI received a small NSF grant in 2014 to hold a workshop in 2015 to assess the level of support for a research project that would connect the projects across languages. Based on generally positive feedback, the team then applied for and received a grant of $600k over four years to build "Multilingual FrameNet" (NSF #1629989). However, it proved impossible to collect and redistribute the annotation data from multiple FrameNets, due to a combination of copyright restrictions, government regulations (in some countries), and reluctance of some projects to share annotation data without compensation. However, most projects were happy to share their frame data and lexical units. Ultimately, the project produced a database of alignments between frames in English and frames in Japanese, Portuguese, Chinese, and Spanish. The alignment data and a visualization tool which allows users to interactively view parallel frames across pairs of languages are now available at https://github.com/icsi-berkeley/framenet-multilingual-alignment/releases/tag/1.0.3-2. For details, see Gilardi and Baker (2018), Baker & Lorenzi (2020), and Baker et al. (2022).

11 VerbNet (Kipper-Schuler 2005) is a computational lexical resource for English that, following Levin's (1993) work, defines verb classes based on semantic and syntactic similarities, paying particular

attention to shared diathesis alternations. For each class of verbs, VerbNet provides common semantic roles, selectional restrictions, typical syntactic patterns and a set of semantic predicates. For the most recent extension of VerbNet's semantic representation, refer to Brown et. al. (2022).

12 Dowty (2003) discusses the adjunct vs. complement distinction within a categorial grammar approach, arguing that within CG many of the semantic properties of the distinction follow directly from the syntactic characterization of adjuncts and complements. Despite the differing framework, Dowty's proposal comes to similar results as FrameNet and Przepiórkowski do. For instance, he notes cases where prototypical adjunct categories such as adverbs and adjectives are in fact subcategorized by certain verbs.

13 Close in time and in a similar vein, Gerber & Chai, 2010 used VerbNet (Kipper, 2005) rather than FrameNet to reduce data sparsity for groups of similar nouns in the context of recognizing implicit arguments of nominal predicates that are not covered by NomBank (Meyers et al. 2004) annotations.

14 A query for "FrameNet" in the ACL anthology returns more than 6200 papers (last access: October 31, 2023).

15 FN does not capture information on the relative intensity ranking of scalar predicates in the same frame.

16 The same authors later combined FN, Wikipedia, and Freebase with better results (Chen et al. 2017); a related group aligned FN and Wikidata, creating an event ontology (Guo et al. 2023).

17 First under grant IRI #9618838, March 1997 - February 2000; then under grant ITR/HCI #0086132, September 2000 - August 2003 and a small but much appreciated supplement in 2004. We refer to the period from 1997-2000 as FrameNet I and 2000-2004 as FrameNet II, respectively.

18 During FrameNet I, all data was stored in the form of SGML files, containing the sentence text with labels inserted, but with this format (1) across-the-board changes (such as renaming a frame element) in hundreds of separate SGML files were tedious and error-prone, and (2) there was no support for transactions to avoid collisions or allow data sharing among simultaneous users. At the start of the second stage of the project, FN completely changed its software system by storing the data in a relational database (implemented in MySQL) and creating a Java GUI for it. This architecture allowed us to combine the vanguarding operations (creating new frames, FEs and LUs) and the annotation operations (applying labels to some of the extracted sentences). With this system, one can annotate a sentence, find that one needs another FE, add the FE to the frame, and return to annotate using the new FE, all in the same interface. The use of a relational database means that frames, FEs, and LUs can be renamed as needed without causing any data integrity problems. All users have access to current data all the time. The data from FrameNet I was imported into the new database, and we were finally able to implement some long-awaited concepts, notably that semantic frames are related to each other in a hierarchy, and that some are elaborations or specifications of others.

19 Other funding was provided by DARPA 2003- 2005 (FA8750-04-2-0026), ARDA AQUAINT 2005-2006, and DTRA (HDTRA1-17-1-0042).

20 Data for annotation sets between 2000 and 2003 is unavailable because of changes in the database resulting in the loss of the date of creation for annotation sets before 2003.

21 https://metanet.arts.ubc.ca/

22 The team investigated external frameworks such as GATE (Cunningham et al. 2002) and UIMA (Ferrucci & Lally 2004) but none of them provided all the needed functionality.

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