# 2

# The Rich Event Ontology

## Ontological Hub for Event Representations

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**Abstract.** This chapter reviews the current landscape of ontological and lexical resources that motivated the development of the Rich Event Ontology (REO). Aimed at a whole that is greater than the sum of its parts, REO functions as a conceptual organization of event types that facilitates mapping between FrameNet, VerbNet, and the Entities, Relations, and Events corpus annotation from the Linguistic Data Consortium.

## 2.1 Introduction

Lexical resources are the foundation of many natural language processing (NLP) tasks, such as word sense disambiguation, semantic role labeling, and question answering. Manually crafted resources such as WordNet (Fellbaum, 1998), VerbNet (Kipper et al., 2008), and FrameNet (Baker et al., 1998) and their accompanying annotated corpora have required a great deal of time and resources to construct, reflecting their value to NLP but also making it intractable to meet the demand for such resources on a large scale in a variety of languages. Somewhat independently, there has been an explosion of efforts in the construction of ontologies as part of the Semantic Web (Berners-Lee et al., 2001). These ontologies facilitate machine reasoning over data that were previously only available for human consumption. Unfortunately, the progress to integrate computational lexical resources into the Semantic Web (e.g., Eckle-Kohler et al., 2015) has been somewhat slow and difficult, given that conversion of resources like FrameNet, with its complex ontological relations, into the minimalist Resource Descriptive Framework (RDF) schema used in the Semantic Web is not trivial (Scheffczyk et al., 2006). Despite the challenges, there is tremendous value to bringing ontological and lexical resources together—much as WordNet's incorporation of structuring relations into a lexical resource was a tremendous boon to NLP, further integration of these two fields can lead to major contributions.

In this chapter, we survey work that demonstrates the variety of ways and extents to which lexical resources and ontologies can be integrated beneficially, and we provide our own case study illustrating these benefits in the development of the Rich Event Ontology (REO). First, we focus on ontologies—related work marrying ontologies to lexical resources as well as a description of the basic structure and organizing principles of REO, which offers a novel hierarchy of event concepts capable of linking disparate semantic role labeling (SRL) resources and adds typical temporal and causal relations between events. We then turn our focus to SRL resources and describe both related work and the SRL resources leveraged in REO. We demonstrate how bringing together SRL resources into an ontological hub like REO can greatly expand the conceptual coverage of events beyond any single resource and facilitate deeper reasoning about events, such as script or storyline extraction.[1] We close with a discussion of future work in which we further leverage ontologies and linguistic resources together.

## 2.2 Ontologies

Ontology is traditionally a subfield of philosophy, defined as the science of what is—the various types and categories of objects and relations in existence. Aristotle was one of the most prominent early ontologists, whose ideas laid out in *Categories* and *Metaphysics* clearly influence the distinctions made in many of the ontologies described herein.[2] Within computational efforts, an ontology can be defined as a computer-readable vocabulary of a particular domain. Thus, there is some overlap with lexical resources such as dictionaries; however, ontologies are *structured* to demonstrate various relationships between words, including the common *is-a* subclass relations that indicate the type or category of an ontology entry (WordNet stands out as a lexical resource with ontological structuring). This structure facilitates a computer system's understanding of type relationships and, in combination with other relations, can enable more complex querying and reasoning over the ontological concepts.

Many of the ongoing efforts to create large, computer-readable ontologies, such as YAGO (Suchanek et al., 2007), FreeBase (Bollacker et al., 2008), and

[1] Events in REO are "perdurants" defined in Section 2.2.2.
[2] For a clear summary of Aristotle's ideas and how they have been adapted in a modern ontology, see Smith (2000).

DBpedia (Bizer et al., 2009), focus on things or objects, especially named entities, as opposed to events or qualities. Here, we focus on ontological resources that include or concentrate on events. These are numerous and growing, because ontologies often need to be tuned to a particular domain and end goal. Thus, we highlight the ontologies that were most relevant to the development of the type of ontology we sought to create with REO. For each resource, we attempt to briefly describe how it uniquely brings together lexical and ontological information, as well as the high-level category distinctions, principles behind category distinctions, and basic relations it encompasses.

### 2.2.1 Related Work: Ontologies

#### Manually Crafted

**WordNet** (Fellbaum, 1998) is a large electronic database of English words with ontological structure; it represents one of the first large-scale efforts to add such structure to a dictionary-like resource. WordNet is divided firstly into syntactic categories – nouns, verbs, adjectives, and adverbs – and secondly by semantic relations, including synonymy (given in the form of "synsets"), antonymy, hyponymy (e.g., *tree* is a hypernym of *maple*), and meronymy (part–whole relations). These relations make up a complex network of associations that is both useful for computational linguistics and NLP and also informative in situating a word's meaning with respect to others. The highest-level semantic distinction made is between concrete entities and abstract entities, with events falling under abstract entity.

**The Suggested Upper Merged Ontology (SUMO**; Pease et al., 2002) is a formal ontology that maps to the WordNet lexicon. SUMO serves as the upper-level ontology for a variety of domain ontologies, varying in focus from emotions to weapons of mass destruction. Like WordNet, SUMO also makes a primary distinction between physical entities and abstract entities. However, SUMO's next distinction for physical entities is between objects and processes, such that most events are represented as physical, as opposed to abstract, entities. SUMO's extensive documentation and relations, including logical axioms, were leveraged for efficient expansion of the coverage of nonevent concepts in REO (see Section 2.2.2), as well as semi-automatic extraction of qualia relations currently being integrated into REO (see Kazeminejad et al., 2018).

**The Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE**; Masolo et al., 2003; Gangemi et al., 2002) is the first module of the WonderWeb Foundational Ontologies effort, the goal of which is to provide a library of ontologies that facilitate mutual understanding. DOLCE

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aims to model the conceptual categories underlying natural language and common sense, but, because it is intended to be one module in a library of ontologies, it does not itself include lexical mappings. Within DOLCE, a primary distinction is made between ENDURANT and PERDURANT (also sometimes called "continuants" and "occurrents," respectively), which we have adopted for REO. When present, endurants are wholly present, whereas perdurants extend in time by accumulating different temporal parts, so they are only partially present.

**The Basic Formal Ontology (BFO**; Smith et al., 2014) is intended to be an upper-level ontology to support the creation of lower-level domain ontologies; therefore, it is designed to be neutral with regard to the domains to which it is applied. BFO and DOLCE share many goals and properties, including an initial split between CONTINUANT (entities that can be sliced to yield parts only along spatial dimensions; e.g., *table*) and OCCURRENT (entities that can be sliced along spatial and temporal dimensions to yield parts; e.g., events—*childhood, throwing*).

**The Event and Implied Situation Ontology (ESO)** focuses on pre- and postsituations with respect to some event type, making explicit how a participant's pre- and poststates change in an event (Segers et al., 2015). ESO was developed as part of the NewsReader project (Vossen et al., 2016), which exploits SRL technology to process millions of English news articles on the global automotive industry from 2003 to 2013. It is another excellent case study in bringing together lexical and ontological resources. The 59 event types included (in version 1) are those relevant to the automotive domain – CHANGE OF POSSESSION, MOTION, etc. Mappings between FrameNet frames and frame elements (see Section 2.3 for more details on FrameNet) and the ESO event types and roles are needed to translate role annotations provided by an SRL module to ontology vocabulary. ESO leverages SUMO to derive the hierarchical structure of events.

**The Brandeis Semantic Ontology (BSO)** was developed to provide a resource capturing the Generative Lexicon theory of linguistic semantics, a basic tenet of which is the distributed nature of compositionality in language—spreading the semantic load across all constituents as opposed to verb-based approaches (Pustejovsky et al., 2006). Qualia relations are at the heart of this theory and are a primary piece of lexical information represented for each entry in the ontology. The ontology structure makes a basic category distinction between ENTITY, EVENT, and PROPERTY. Each of these, in turn, is divided into the subtypes NATURAL, ARTIFACTUAL, and COMPLEX, which are characterized by the presence or absence of particular qualia relations. The value of qualia relations has been demonstrated for a variety of NLP applications, including furnishing world knowledge for artificial agents (e.g., McDonald and Pustejovsky, 2013; Pustejovsky et al., 2017; Narayana et al., 2018). This motivated us to integrate qualia relations into REO (see Section 2.2.3).

**The Rochester Interactive Planning System (TRIPS) LF Ontology** was developed to serve as a lexicon for deep syntactic and semantic parsing with the TRIPS parser—a dialogue assistant applied to a variety of different application domains (Dzikovska et al., 2004). This ontology was built by manually combining features from different lexical resources. FrameNet was leveraged for semantic predicates in the system and was the basis for generalized roles, VerbNet was used for the syntax–semantics mapping included in each frame/lexicon entry, and EuroWordNet (Vossen, 1997) was used to gather selectional restrictions on roles. The ontology top level consists of two artificial, empty top nodes that serve as parents for the contentful entries starting at the second level.

### Automatically Induced

There are a growing number of automatically induced ontologies, which may rely to a greater or lesser extent on manual resources for seed structure and/or content. Although we focus on manually created resources, assuming they can be leveraged for mappings to automatically induced ontologies that incorporate them, we would like to note the Predicate Matrix (De Lacalle et al., 2014), BabelNet (Navigli and Ponzetto, 2012), ConceptNet (Speer and Havasi, 2013), and the Never-ending Language Learner (NELL) system (Betteridge et al., 2009) as automatically derived resources that also showcase the merits of leveraging lexical resources and ontologies together.

### Ontologies for Annotation Schema Interoperability

Two existing efforts that deserve special attention are UBY (Gurevych et al., 2012) and the Ontologies for Linguistic Annotation (OLiA; Chiarcos and Sukhareva, 2015). Like our goal of facilitating mapping among different SRL resources, both UBY and OLiA share a primary goal of bringing together the disparate labeling schemas of lexical resources into one, interoperable ontological resource.

**UBY** is a lexical–semantic resource combining information from expert and collaboratively constructed resources for both English and German – for example, English WordNet and German Wiktionary. The structure of UBY reflects the intention to capture lexical–semantic information, as opposed to world knowledge. Thus, a Lexicon node has direct subclasses such as

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LexicalEntry, Synset, SemanticPredicate, etc. UBY also provides sense alignments across the included resources by converting existing alignments and automatically inferring additional alignments both within resources of the same language and across languages.

**OLiA** was developed to provide a terminological backbone between several prominent repositories of annotation terminology. The architecture of OLiA consists of (i) a main reference model that specifies the common terminology that different annotation schemas can refer to in order to facilitate interoperability; (ii) multiple external reference models with their own annotation terminologies, such as GOLD; and (iii) multiple annotation models (32 models for about 70 different languages), which capture both the annotation tag and concrete individuals instantiating that tag. For each of the external reference and annotation models there is a linking model that specifies the relationship between that model and the reference model. The categories in the OLiA reference model and the annotation models included are largely morphological and syntactic in nature, with only a few semantic categories.

We find the architecture of OLiA to be uniquely valuable because, unlike many resources that provide a direct mapping between resources, providing the pivot of a reference model enables recovery of information about sources and the extent or types of mismatches between models. Furthermore, it introduces a clear distinction between the externally provided information and the ontology engineer's interpretation of that information. Given the value of this architecture, we adopt it for our own ontology structure, described in the next section.

### 2.2.2 The Rich Event Ontology

As we have seen, many existing ontological resources focus on representing world knowledge, in the philosophical tradition of ontology, and may or may not include lexical resources mapping to those concepts. In contrast, WordNet, UBY, and OLiA focus on representing lexical and morpho-syntactic information. The REO aims to represent lexical event semantic information; thus, we hope to capture both commonsense world knowledge about events and their participants, as well as lexical information on how these concepts are realized and tagged in various English annotation schemas.

REO unifies the existing SRL schemas FrameNet, VerbNet, Automatic Content Extraction (ACE; Doddington et al., 2004), and its spinoff, the Rich Entities, Relations and Events (ERE; Song et al., 2015). REO unifies the disparate schemas by providing an independent conceptual backbone through which they can be associated, and it augments the schemas with event-to-event causal and temporal relations. The ontology was developed, in part, in response to unsuccessful efforts to map directly between FrameNet and the small set of disparate event types in (ERE). The difficulty was mainly due to differences in the granularity of events described by the FrameNet frames and ERE event types and inconsistencies in how the resources divided the semantic space.

FrameNet (FN), ERE, and VerbNet (VN) have wide-coverage lexicons of events, and they contribute annotated corpora and additional semantic and syntactic information that can be crucial to identifying events and their participants. REO serves as a shared hub for the disparate annotation schemas and therefore enables the combination of SRL training data into a larger, more diverse corpus, as well as expanding the set of lexical items associated with each event type. By adding temporal and causal relational information, the ontology also facilitates reasoning on and across documents, revealing relationships between events that come together in temporal and causal chains to build more complex scenarios.

After considering the somewhat unique purposes and structures of each of the existing ontologies described in Subsection 2.2.1, we have selected a top-level concept, ENTITY, with an initial distinction between ENDURANT and PERDURANT entities (inspired by DOLCE and BFO). We define ENTITY as a unique thing or set of things in the world. We define ENDURANTS as those entities that can be observed/perceived as a complete concept, no matter which given snapshot of time; that is, were we to freeze time, we would still be able to perceive the entire endurant—for instance, a specific person, place, or organization—that typically functions as a participant. We define PERDURANTS as those entities for which only a part exists if we look at them at any given snapshot in time. Variously called events, processes, activities, and states, perdurants have temporal or spatial parts and participants. Beyond this primary distinction, our ontology makes secondary distinctions between PHYSICAL and NONPHYSICAL endurants, as well as EVENTIVE and STATIVE perdurants. Below this level, the semantic space was divided with an eye toward sub-event structures and event participants to facilitate the linking of event types to SRL resources.

The structure of REO, illustrated in Figure 2.1, consists of a main "reference" ontology of generic event types and individual OWL (Web Ontology Language) "resource" ontologies. The relationships between the generic event types in the reference ontology and the event designations made in a particular annotated data resource are spelled out in various "linking models" that import both the reference ontology and a resource ontology. In the example shown in Figure 2.1, REO DISCHARGE events map to the Releasing frame in FN and the

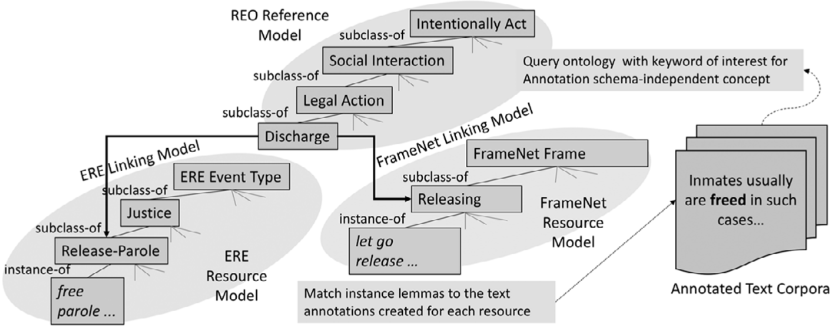


Figure 2.1 OWL resource models are linked to REO reference model in linking models (ACE and VN linking models not shown).

Release-Parole event type in ERE.[3] Additional indirect mappings are detailed in Brown et al. (2017). Individual words within the resource classes can be detected in text to find a wide variety of mentions of each event type, or one can query the ontology for words associated with an event of interest to view its participants and its relations to other events that are independent of the various lexical resource schemas.

As an ontology meant to provide a shared vocabulary of SRL annotation resources, the development of REO has focused on how to structure ontological relations between the events and states included in these resources (ACE, ERE, VN, FN). Although our intention has never been to create a detailed ontology of the endurant entities that serve as the participants in these events/states, such information is needed to generalize and map it across resources, as well as provide some insights into selectional restrictions generally and qualia relations specifically (see Section 2.2.3). Thus, we opted to integrate REO with an existing ontology containing the type of information on participants that we were interested in. Given the detailed information on objects and accompanying information such as HASPURPOSE in SUMO, we decided that it was best suited to our needs and elected to leverage SUMO to extend our coverage of endurant entities and facilitate the addition of qualia relations between endurant and perdurant entities.

PERDURANTS largely map to what SUMO deems PROCESSES, and, although many ENDURANTS map to what SUMO deems OBJECTS, there were also

[3] Other mappings between ERE and FN are necessarily more indirect; for example, with respect to the COMMUNICATION node in REO, ERE, and ACE (as related projects, ERE and ACE share similar event classes) only map to Instrument communication and Statement, whereas FN has mappings to nearly all daughters, as does VN, and VN maps to the mother Communication node as well.

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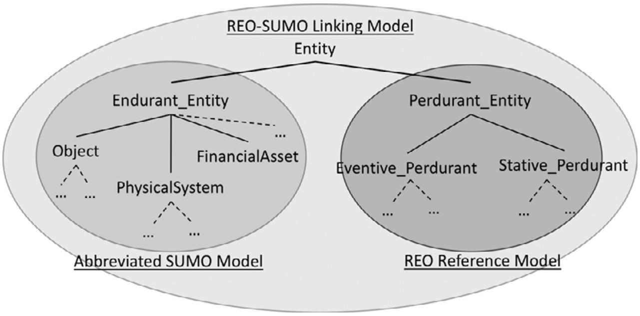


Figure 2.2 REO-SUMO linking model: REO specifies the PERDURANTS of the model, and SUMO specifies the ENDURANTS.

a variety of useful concepts in SUMO that seemed to fit the definition of an ENDURANT, including FINANCIALASSET, GRAPH, and PHYSICALSYSTEM, among others. To flesh out the ENDURANT portion of REO, we opted to integrate from SUMO all daughters of OBJECT and the classes just mentioned as daughters of our ENDURANT class. Specifically, this was done in a linking model like those described earlier. The linking model imports an abbreviated OWL version of SUMO (containing only the ENDURANT-compatible classes, their documentation that provides a description of what they are, and their associated WordNet sense keys) and the REO OWL reference model. The resulting model has all of the REO event ontology nested under PERDURANT and the extracted SUMO content nested under ENDURANT (see Figure 2.2). In Section 2.2.3 we describe how qualia relations are integrated to relate the objects and events, or endurants and perdurants, in the ontology.

REO remains under development; currently the suite of ontologies together encompass over 7,000 classes with over 27,000 unique individuals, which are the resource class members, such as verb types from VerbNet. Presently, there are 18 different annotation properties in the ontology, including REO definitions and WN sense key mappings. There are 60 object properties, which include the HAS_REFERENCE_GROUP relation that maps classes in the reference ontology to classes in the resource models, as well as the temporal and causal relations, such as TYPICALLY_PRECEDES and HAS_SUBEVENT.

### 2.2.3 Qualia in REO

Generative Lexicon qualia relations include an entity's function, origin, parts, and type (Pustejovsky, 1995). As part of our world knowledge, qualia relations represent our familiarity with the essence of entities and relations between

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them. For instance, we know that the prototypical function of a desk is "to sit at while reading or writing." Hence, when someone is sitting at a desk, we naturally infer that she or he is reading or writing. Such inferences are an essential part of a natural language understanding system. Thus, we sought to incorporate qualia relations in REO, but we wanted to do this efficiently by leveraging the kind of information encompassed in qualia relations already implicitly captured in other ontological resources. After evaluating several machine-readable ontologies (as mentioned in Section 2.2.1) as a resource to semiautomatically extract qualia relations, we found SUMO (Niles and Pease, 2001) to have the highest potential for achieving our purpose. In SUMO, we used two types of data for extracting qualia relations, including logical and textual data. First, we used the higher-order logical axioms embedded in SUMO. Each axiom is a conjunction of smaller logical relations that are connected via other relations or logical operators and represents the semantics of each entity. We used a number of SUMO relations to extract qualia relations from these axioms (Kazeminejad et al., 2018). Second, we performed regular expression searches in each entity's documentation, employing textual clues such as "purpose is," "intended to," or "designed for," which could indicate the telic quale.

Before implementing the extracted qualia relations in REO, we did a sanity check on the results using human judges. An online annotation system was developed and linguists annotated each extracted relation with their judgment (Kazeminejad et al., 2018). After validation, the extracted qualia relations were integrated into REO, enabling their use in knowledge representation and reasoning.

## 2.3 Semantic Role Labeling

Semantic roles, also called "thematic roles," refers to general classes of participants in a sentence and attempt to define the relation of the participant to the event. In the sentence *Fred gave Maria a book*, we must know which thing in the world *Fred* refers to and also that he is the agent of the action. We must know that the book is the gift and Maria the recipient instead of the other way around. Participants in an eventuality have a particular semantic role regardless of the syntactic format of the sentence. For example, in *Fred gave a book to Maria*, *Maria* is still the recipient, even though *Maria* is syntactically now an object of a preposition instead of a direct object.

Identifying the semantic roles of the participants is part of the more general task of understanding the semantics of the event, which has certain semantic components regardless of the specific verb used. Whether a speaker talks of *giving*, *handing*, or *passing*, there is always a transfer of an entity from the giver to a recipient. Grouping verbs with similar semantics allows us to refer to their shared semantic components and participant types.

In addition to furthering our understanding of how language communicates meaning, these theories of semantic roles and classes of semantically related verbs have improved several important NLP tasks. By labeling the semantic roles of participants in large amounts of text, machine learning models have improved information extraction (Bastianelli et al., 2013), question-answering systems (Yih et al., 2016), and machine translation (Xiong et al., 2012), among others.

### 2.3.1 Theories of Semantic Roles

Although the idea of semantic roles has fairly widespread acceptance in linguistics, an exact definition and a canonical list of the roles have never been agreed upon. Fillmore (1968) introduced the notion of "deep" cases as verb arguments with semantic types, such as agentive, instrumental, and locative, and set off a debate as to what the categories are and how to identify an entity's type. In largely contemporaneous work, Jackendoff (1987) explored thematic roles as an important aspect of the interface between semantics and syntax.

As linguists put these theories into practice, a loose set of 10 to 20 roles emerged, with Agent, Patient, Instrument, Theme, and a few others as the most widely accepted roles. However, using a strict set to label participants in actual text proved difficult to do consistently. Often, a participant did not "fit" the criteria for a certain role or it would have characteristics that partially fit multiple roles.

Over the next couple of decades, Baker et al. (1998) developed the influential theory of Frame Semantics, which describes the conceptual structure of events in terms of frames or schemas, with specific roles, or "frame elements," defined for each frame. Rather than focusing on generalizations about roles across event types, he moved away from a small set of roles to develop a large, unbounded set of richly described, specific relations between participants in event types. Fillmore's theory served as the basis for the lexical resource FrameNet (see Section 2.3.2).

Dowty (1991) took the opposite approach, instead defining the characteristics of a prototypical Agent and a prototypical Patient. This influential theory informed the argument labels in the widely used SRL resource, PropBank (Palmer et al., 2005), which we are integrating into REO currently.

Levin (1993) circumvented strict categories of roles by instead focusing on the syntactic alternations that characterized classes of verbs with similar semantics. She pointed out that meaning is largely preserved across syntactic alternations. For example, *Fred gave Maria the book* means much the same thing as *Fred gave the book to Maria*. Levin does not call out *Maria* as a Recipient, but the implication is that she has the same relation to the event in both sentences, regardless of labeling. In this work, Levin categorized thousands of English verbs into classes based on their participation in syntactic alternations. These classes all demonstrate some amount of semantic similarity, from very general (e.g., verbs of changes of state) to very specific (e.g., verbs of cutting). These classes form the core of the lexical resource VerbNet (see Section 2.3.2).

### 2.3.2 Semantic Role Labeling Resources in REO

These linguistic resources attempt to apply these theories of semantic roles and verb classes to large numbers of English predicates. The resources described here differ in the semantic granularity of their semantic role types. They also differ in the focus of their groupings: FrameNet groups verbs purely on semantics, VerbNet on the semantics as reflected in syntactic variation, and ERE/ACE on predetermined domains of interest. The resources have been widely used for the NLP task of SRL, which requires large amounts of annotated data. These particular SRL resources were selected for inclusion in REO because of the extant large-scale corpora manually annotated with each SRL schema. The desire to increase the data available without expensive and time-consuming annotation has led to efforts to map from the classes and roles of one resource to another. As described in Section 2.2, the difficulty of one-to-one mappings between resources such as ERE and FrameNet motivated linking them via an ontology in REO (see Figure 2.3). REO offers conceptual levels that abstract away from low-level, resource-specific differences. In this section, we describe and compare the resources included in REO.

**FrameNet**, based on Fillmore's frame semantics (Baker et al., 1998), groups verbs, nouns, and adjectives into "frames" based on "frame elements" that evoke the same semantic frame: a description of a type of event, relation, or entity and the participants in it. For example, the APPLY_HEAT frame includes the frame elements COOK, FOOD, HEATING_INSTRUMENT, TEMPERATURE_SETTING, etc. The resource currently has over 1,224 frames that connect over 13,000 lexical units (i.e., word senses). These frame elements have been used as semantic role labels in NLP. The "net" of frames makes up a rather

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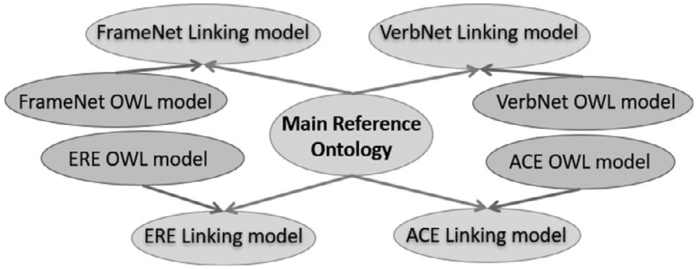


Figure 2.3 Modular architecture of REO showing the lexical resource models.

complex network, including simple *is-a* inheritance relations as well as more complex relations such as *Precedes* and *PerspectiveOn.*

These relations highlight important aspects of many frames; for example, the APPLY_HEAT frame is *UsedBy* the COOKING_CREATION frame. Often, however, the frames involved are not anchored to the main *is-a* hierarchy. In addition, the automatic reasoning capabilities of ontologies implemented in OWL are restricted to strictly logical relationships between classes. The complexity of FN precludes complete representation in OWL, as others have found (e.g., Scheffczyk et al., 2006).

**VerbNet**, based on Levin (1993), groups verbs into "classes" using their compatibility with certain syntactic alternations (e.g., "the causative–inchoative alternation"—*She rolled the ball down the hill* vs. *The ball rolled down the hill*). Although the groupings are primarily syntactic, the classes do share semantic features as well, because, as Levin posited, the syntactic behavior of a verb is largely determined by its meaning. Each VN class specifies its member verbs and their typical participants (i.e., semantic roles), lists the syntactic patterns, or subcategorization frames, they are all compatible with, and connects those patterns to semantic representations (Kipper et al., 2008).

By linking to VN, the ontology gains valuable syntactic information about how events are expressed in English. Generally, a VN class is linked in a one-to-one relation to one of the main reference ontology classes. A class's syntactic alternations, however, sometimes cut across semantic distinctions made by the main ontology. For example, events expressible with causative–inchoative alternations are grouped in the same VN class but are divided in the main ontology (because the main ontology makes distinctions based on the number and types of event participants). For these VN classes, we link an ontology class to specific subcategorization frames in a class, using VN thematic roles to distinguish the appropriate frames. These cases coincide with places where

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VN's semantic representation also differs for a particular frame, indicating that the reference ontology is consistent with VN semantic distinctions.

In (1) and (2) we compare VN and FN semantic role schemas.

(1) a. *Fred gave Maria a book.*
b. Agent Recipient Theme (VN)
c. Donor Recipient Theme (FN)

(2) a. *Fred told Maria about a book.*
b. Agent Recipient Topic (VN)
c. Speaker Addressee Message (FN)

Using broad VN roles, the arguments in each sentence have largely the same roles, whereas the FN labels place the arguments in different and much more specific categories. Both approaches have their advantages: broad labels allow generalization, whereas more specific labels can be associated with fine-grained inferences. They also each have their disadvantages. Because not all arguments fall neatly into a small set of roles, the VN set can lead to inconsistencies when it is used to annotate text. Very specific roles are easier to apply consistently, but the large number of specific FN roles leads to few labeled instances of each role, a major detriment to machine learning techniques. REO facilitates leveraging the strengths of both sets of roles together and can potentially allow for "backoff" from a finer-grained role label to a coarser-grained label to overcome data sparsity issues.

**ERE** is a slight expansion of the **ACE** project's semantic role annotation schema. The goal of the ERE and ACE projects is to provide a shallow representation of the meaning of the text by marking up events, the entities involved in them, and any coreference between these. Annotated events are limited to certain types of interest to the defense community, with top-level types of Life, Movement, Transaction, Business, Conflict, Manufacture, Contact, Personnel, and Justice events.

Within REO, both the FN and VN resource ontologies model lexical units and class members, respectively, as individuals that represent lemmas, which may be used as references for particular event concepts. Because ERE and ACE are resources developed specifically for annotating training data, they do not predefine the lexical "triggers" of event types. Instead, these are always discovered in context. Thus, ACE and ERE provide a data-driven, bottom-up perspective on event semantics that is distinct from the other resources. Their models in REO include as individuals English lemmas that have been annotated either in the freely available ACE 2005 Multilingual Training Corpus (Walker et al., 2006) or the as-of-yet-unreleased ERE corpus, respectively.

### 2.3.3 Evaluation: Expanding Event Detection

As a preliminary evaluation of how linking these lexical resources via an ontology can improve NLP tasks, we looked at leveraging REO to support event detection in information extraction (IE) systems (Brown et al., 2017). For various reasons, many existing IE systems are limited to the detection of events marked up in the ACE data. To avoid the need for additional manually annotated data, REO and its associated lexical resources can be used in backoff techniques to augment the trigger words associated with certain event types, thus expanding the domain of application. We tested this idea by examining the reference groups associated with the LEGAL ACTION portion of the ontology. LEGAL ACTION is the parent class of several subclasses, including ARREST, SUE, and DECLARE BANKRUPTCY. We first established a baseline of what a typical system, trained on ACE, might recognize as triggers associated with LEGAL ACTION event concepts. We followed all ACE types and subtypes linked to the subclasses of LEGAL ACTION via the HASREFERENCEGROUP relation and extracted the individuals that had been tagged as triggers for them, finding 102 lexemes in total. Presumably, systems trained on ACE data have the potential to recognize these lexemes as triggers of the LEGAL ACTION events.

To determine how the ontology may help to move beyond this baseline, we accessed the lexemes in the reference groups associated with LEGAL ACTION in ERE, FN, and VN, which added groups of 204, 69, and 14 lexemes, respectively. Thus, we were able to expand the LEGAL ACTION vocabulary from 102 words to 389. In addition, the resources seem to be making unique contributions: only 17 of the 389 lexemes are duplicated from one resource to another. This expansion highlights the potential for the ontology to overcome data sparsity by combining resources. Although word embeddings have the potential to expand IE vocabulary as well, they lack the frame relations we get from FN or the syntactic alternations from VN.

## 2.4 Conclusions, Gaps, and Future Work

This chapter describes existing ontologies and lexical resources that play prominent roles in NLP. It presents REO as a rich event ontology specifically designed to provide a conceptual bridge between informative semantic role labeling resources, such as FrameNet, VerbNet, and the Linguistic Data Consortium's Entities, Relations, and Events. Thus, REO supports mapping between specific event types of different resources and enables the merging of associated annotated corpora and expanding sets of related event triggers.

There are clear benefits to this marriage of ontological and lexical resources. However, by itself, this is still insufficient. To truly leverage the information in these resources and harness it to modern NLP, the next step is a much closer interweaving of these types of symbolic resources with the current plethora of large-scale continuous vector representations that are transforming the field, such as Devlin et al. (2019). Exciting results are already being demonstrated by effective integration of neural net techniques and resources such as WordNet (Kumar et al., 2019), to name just one. Our goal of natural language understanding is elusive enough that we cannot ignore any tools at our disposal but instead must marshal a diverse and coordinated effort.

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