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Modeling Events on the Semantic Web

Modelování událostí na sémantickém webu

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Prohlášení

Prohlašuji, že jsem vypracoval samostatně diplomovou práci na téma *Modeling Events on the Semantic Web*. Použitou literaturu a další podkladové materiály uvádím v přiloženém seznamu literatury.

V Praze dne ....

Tomáš Hanzal

Abstract

There are many ontologies and datasets on the semantic web that mention *events*. Events are important in our perception of the world and in our descriptions of it, therefore also on the semantic web. There is however not one best way to model them. This is connected to the fact that even the question what events *are* can be approached in different ways. Our aim is to better understand how events are represented on the semantic web and how it could be improved. To this end we first turn to the ways events are treated in philosophy and in foundational ontologies. We ask questions such as what sorts of "things" we call "events", what ontological status we assign to events and if and how can events be distiguished from other entities such as *situations*. Then we move on to an empirical analysis of particular semantic web ontologies for events. In this analysis we find what kinds of things are usually called "events" on the semantic web (and what "kinds of events" there are). We use the findings from the philosophy of events to critically assess these ontologies, show their problems and indicate possible paths to their solution.

Keywords Events, Semantic web, Ontologies, Conceptual modeling, Philosophy

Abstrakt

Na sémantickém webu je mnoho ontologií a datasetů, které se zmiňují o *událostech*. Události jsou důležité pro naše vnímání světa i jeho popisování, a proto i pro sémantický web. Přitom není jediný nejlepší způsob jak je modelovat. To souvisí s tím, že i k otázce, co to události *jsou*, lze přistupovat různě. Naším cílem je lépe porozumět tomu, jak jsou události na sémantickém webu reprezentovány a co by na tom bylo možné vylepšit. Kvůli tomu se nejprve zabýváme způsoby, kterými jsou události pojímány ve filosofii a v obecných (*foundational*) ontologiích. Ptáme se mimo jiné na to, co nazýváme "událostmi", jaký ontologický statut událostem přisuzujeme a zda a jak lze události odlišit od jiných entit jako jsou *situace*. Poté se přesuneme k empirické analýze jednotlivých ontologií pro modelování událostí na sémantickém webu. V této analýze zjistíme, co se obvykle na sémantickém webu nazývá událostmi (a jaké "druhy událostí" se zde vyskytují). Pro kritické zhodnocení těchto ontologií využíváme poznatky z filosofie událostí. Ukazujeme jejich problémy a naznačujeme cesty k jejich řešení.

Klíčová slova Události, sémantický web, ontologie, konceptuální modelování, filosofie

Contents

Introduction

There are many ontologies and datasets on the semantic web that mention *events*. For example the famous John Peel sessions dataset from BBC[1]. This dataset uses (among others) the Music Ontology [19] and features thousands of *performances* and *recordings*, which are classes defined in this ontology, and subclasses of the class *Event* from the Event Ontology.[2] Another example can be taken from the well known DBpedia, whose ontology also contains a class of events[3] that includes sporting, natural, personal and other events.[4]

This of course reflects the fact that there are many things that *happen* in our world and that we often need to represent them on the semantic web. Many semantic web vocabularies are of course meant to describe *static* things and relationships between them; but once the things we are describing cannot be represented as static and the time factor comes in we have to take events into account (every *change* is actually an event).

So, there is need to model events on the semantic web and there are many things already present on the semantic web labeled as events. The problems thus arising are that events can be modeled, like other things, in different ways and that it is not exactly clear what events *are* and if events in general are a homogeneous and clearly defined set of "entities". Our aim is to better understand how events are represented on the semantic web and how it could possibly be improved. But we think that before considering how to model events in semantic web ontologies it is important to understand them in the natural language and to get acquainted with the ways they are usually treated in philosophy. This can provide us, if not full understanding of the "nature" of events, some inspiration for semantic modeling.

Thus we should ask questions like these:

[1] `http://dbtune.org/bbc/peel/`

[2] `http://motools.sourceforge.net/event/event.html`

[3] `http://dbpedia.org/ontology/Event`

[4] We can look for examples on the DBpedia's SPARQL endpoint (`http://dbpedia.org/sparql`), e.g. in this way: SELECT ?event
WHERE ?event a <http://dbpedia.org/ontology/Event>
LIMIT 100

- What sorts of “things” on the semantic web are called “events”?
- What sorts of “things” we call “events” in our natural language?
- What sorts of “things” should we call “events” according to our ontology? (What *ontological status* we want to assign to events?)
- And also: What *significance* does it have to call a thing an “event” on the semantic web?

The last question aims at the fact that there are many things labeled as events (subsumed under a *class* of events) on the semantic web. The problem is what does this mean. We think that there is more to semantics on the semantic web than just the structure of the ontologies, OWL restrictions and names of classes and properties. How these classes and properties are defined (in the natural language) is also significant. As we will see, there can be different notions of events. From that follows there can be different “event” classes based on different ontological views. We have to keep in mind that on the semantic web, there are non-unique names of entities and “anyone can say anything about anything”. Therefore there can be lots of classes called “Event” and lots of things can be said about these classes and relationships between them. But to keep the body of data consistent, we have to pay close attention to what the entities are actually supposed to mean (that requires at least reading their *labels*). Same name does not ensure same meaning. The event class from the Event Ontology is not the same as the event class from *schema.org*.

Same structure does not ensure same meaning either. Are events the same as *situations*? Or even *reified relationships*? They all look like some “constellations of objects”. What are the relationships of events to situations and reified relationships is one of the things we cannot ignore in our study.

So, to sum up, our aims here are to explore the ways events are currently usually modeled on the semantic web and how it could be improved; to do a representative survey of semantic web vocabularies for events; to find what “kinds of events” are represented on the semantic web, and what are the ontological commitments and concepts of events of the ontologies in use. This demands a better understanding of what events are or what we suppose them to be. That is why we, before moving to the semantic web ontologies themselves, occupy ourselves with philosophical conceptualizations of events and foundational ontologies.

Chapter 1 is mostly technical; it briefly deals with the notions of the semantic web and semantic modeling. In Chapter 2 we jump to event philosophy; in number 3 we return to computer science but with strong foundations is philosophy (the foundational ontologies). Chapter 4 is an empirical analysis but it also draws on what we’ve learned in the previous chapters; it contains several studies of existing ontologies that make use of the explored notions. Chapter 5 shows how *PURO*, a language for "ontological background" models, can help us in the practice but also re-introduces and emphasizes the importance of philosophical considerations in conceptual modeling.

Chapter 1

The Semantic Web and Ontologies

1.1 The semantic web

The information presented on typical World Wide Web pages is basically tied together with its presentation – they are "interwoven" in the page (typically a HTML document). What is connected on the classical web (by hypertext links) are these pages. The main idea behind the semantic web (or *linked data*) is to make links "at the level of the data rather than at the level of the presentation" [1, p. 6]. So, while classical web connects documents, the semantic web connects data items (or entities) across the web, creating a distributed data infrastructure which "allows the data to drive the presentation so that various web pages (presentations) can provide views into a consistent body of information" (*ibid.*).

1.1.1 RDF

Information on the semantic web should be machine-readable. This is ensured at the basic level by a common data model, the *Resource Description Framework* (RDF) which is a W3C standard.[1] The basic abstract[2] structure of RDF is a *triple* consisting of *subject*, *predicate* and *object*. A set of such triples forms a graph with subjects and objects as *nodes* and predicates as directed *arcs*. A node in such graph can be an IRI[3] (ensuring that the data are *linked*), a *literal* or a *blank node*.[4]

[1] See `http://www.w3.org/standards/techs/rdf#w3c_all` for RDF and related standards.

[2] There are various kinds of RDF *serialization* syntaxes. In the following chapters we will be using mainly the *Turtle* syntax which is another W3C standard [16].

[3] *Internationalized resource identifier*, generalized URI.

[4] For more details see [20, 5].

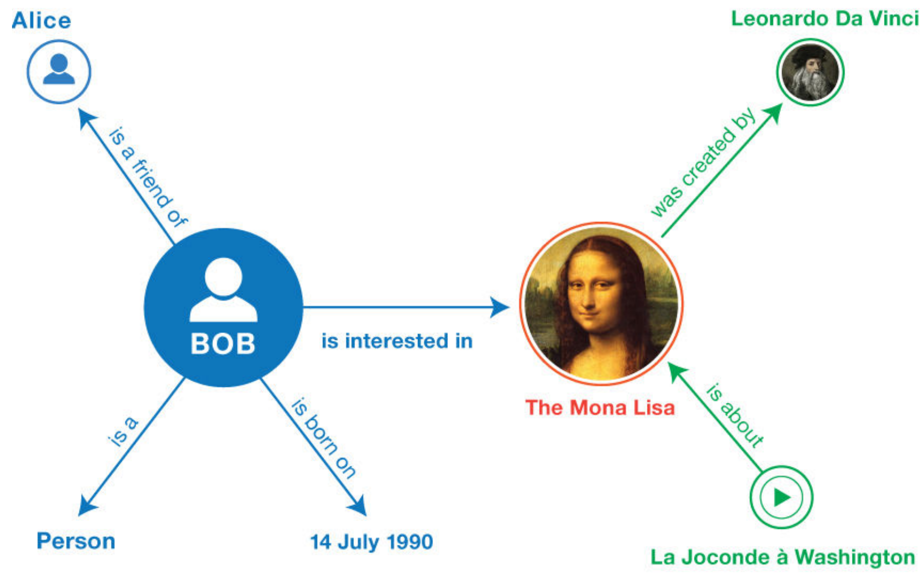

Figure 1.1: Graph representation of the example triples. Source: [20]

Example of a set of RDF triples, informally expressed, can look something like this (borrowed from [20]):

```
<Bob> <is a> <person>.
<Bob> <is a friend of> <Alice>.
<Bob> <is born on> <the 4th of July 1990>.
<Bob> <is interested in> <the Mona Lisa>.
<the Mona Lisa> <was created by> <Leonardo da Vinci>.
<the video 'La Joconde à Washington'> <is about> <the Mona Lisa>.
```

These triples are visualized as a graph in figure 1.1.

We can see that RDF is an abstract framework, maybe we can say a *form*, that we need to express anything on the semantic web. But it is not sufficient on its own to really *say something*. We can introduce IRIs for entities like Bob and The Mona Lisa, but we also need (besides other things) the predicates, like "is interested in", "is a . . . " etc. This is where semantic modeling and ontologies come in.

1.1.2 Fundamental characteristics of the semantic web

But before we move on to semantic modeling, there are five fundamantal concepts about the semantic web we should keep in mind:

The AAA slogan Anyone can say Anything about Any topic

Open world "A consequence of the AAA slogan is that there could always be something new that someone will say; this means that we must assume that there is always more information that could be known."

Nonunique naming

The network effect "The property of a web that makes it grow organically. The value of joining in increases with the number of people who have joined, resulting in a virtuous cycle of participation. . . "

The data wilderness "The condition of most data on the web. It contains valuable information, but there is no guarantee that it will be orderly or readily understandable." [1, ch. 1, particularly p. 11–12]

1.2 Semantic modeling and ontologies

The example above is basically a *model* of "a part of reality". It is *abstract*; that means it focuses on some details while ignoring others that are not relevant for us (in the given context). It says, for example, that "Bob is interested in Mona Lisa" but it does not say how much, from when etc., which are things that can be said in our language but not necessarily in this particular model.

By *semantic modeling* we basically understand designing *ontologies* in the sense this word has in computer science (or information science). The word "ontology" has its home in philosophy; being usually understood as a synonym of "metaphysics", it can be defined roughly as "an account of being in the abstract", or a classification of all entities there *are* (see [21, p. 155]). In computer science, designing of ontologies is not (usually) so ambitious and it has more directly practical aims. An ontology in this sense is more often than as a comprehensive and accurate description of reality as a whole understood as *a conceptualization* or *a conceptual model* which is

> an abstract, simplified view of the world that we wish to represent for some purpose. Every knowledge base, knowledge-based system, or knowledge-level agent is committed to some conceptualization, explicitly or implicitly. (Gruber; cited in [21, p. 161])

In this sense, even the simple model introduced by RDF is a conceptualization; it presupposes there are some "things" (corresponding to the nodes in the RDF graph, and to the *subjects* and *objects* in the triples) and relationships between them (arcs in the graph, *predicates* in the triples). The cited example builds on top of this and brings new elements into the conceptualization, e.g. the types of relationships between things like "is interested in" and types of things like "person". Such entities (if we subordinate both "things" and "relationships" under "entities") are defined in ontologies.

Ontologies for the semantic web are often called also semantic web *vocabularies* but we will continue to use primarily the term "ontology" in the course of the following chapters.

1.2.1 RDFS and OWL

If we want to design a semantic web ontology that would allow us to express things such as in the example cited above (figure 1.1), we need one more "layer" on top of the basic structure of RDF. If we are to e.g. define classes like "person" and relationships like "is a friend of", we need the concepts of classes and relationships first. These notions as well as notions of relationships between them are provided partially by RDF vocabulary itself, and also by RDFS and OWL (which are actually semantic web ontologies themselves, too).

RDF and RDFS We have already described the basic form of RDF, the triples that together make up the *graph* (graphs) of semantic web. But the RDF vocabulary also defines some concepts that are important for semantic modeling. Other important concepts are contained in its extension, RDF Schema [2]. Let's take a look at the most important of them. But first, we have to define their *namespaces*:[5]

```
@prefix rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
```

Now we can list some selected RDF triples about some terms from these two namespaces. They can be found, along with their full context, at the two listed IRIs.[6]

```
rdf:type a rdf:Property .
rdf:Property a rdfs:Class .
rdfs:Class a rdfs:Class .
```

[5]Here, like in the rest of this work, we use the *Turtle* syntax [16]. For the explanation of the use of IRIs and namespaces on the semantic web, see e.g. [10, chapter 2].

[6]Note that: "The token 'a' in the predicate position of a Turtle triple represents the IRI http://www.w3.org/1999/02/22-rdf-syntax-ns#type ." [16, 2.3], i.e. `rdf:type`.

```
rdfs:subClassOf a rdf:Property .
rdfs:subPropertyOf a rdf:Property .
rdfs:domain a rdf:Property ;
    rdfs:range rdfs:Class ;
    rdfs:domain rdf:Property .
rdfs:range a rdf:Property .
rdfs:Literal a rdfs:Class .
```

We can see that there are defined important concepts like *class* and *property*, relationships like *subclass of*, *type* (meaning "the *subject* is an instance of *object*") and *domain* and *range* of a given property. Interesting thing that we can notice is that some notions are defined using themselves: `rdf:type` has `rdf:type rdf:Property`. Class is a class. Domain and range have domains and ranges themselves.

OWL Web Ontology Language 2 [11] is a language for expressing ontologies. It is designed to capture more complex "knowledge" than simple RDF with RDF Syntax and RDF Schema vocabularies. Concepts introduced by OWL include: equivalent classes, property restrictions, property cardinality restrictions, property characteristics (e.g. inverse property) etc.

Because full OWL is a very expressive language, reasoning above it could be in some cases too computationally complex. This is why there are different *profiles* defined as subsets of OWL 2 Full. For details see the cited documentation.

Most ontologies discussed in this thesis are written in OWL.

Chapter 2

Philosophical Conceptualizations of Events

Events have become a topic of high interest in the philosophical debates in the last few decades. It seems that an ontology[1] of *objects* (whether just physical or also "intangible", just particular or also abstract) does not suffice to account for our world because there *are* also "things" that *happen*, like walks, weddings, performances, births and deaths and so on; that is: *events*. In one way or another, we arguably must take events into our ontological considerations. If events are frequently characterized as "things that happen", does that mean they are a kind of "things"? Well, at least we often refer to them in a similar way as to objects ("*This* performance is really amusing."). Sure, they are usually in some sense dependent on (physical) objects. But that doesn't eliminate the need to account for them in our ontology. Besides, couldn't objects be dependent on events at the same time? We could say: We can imagine objects insulated from events but not events insulated from objects. Is that the right criterion for assessing dependence? And if so, *can we*, really? Maybe we can imagine a set of static objects in a place without any interactions, without time. Of course nothing like that *exists* but at least we can imagine it. That would be an argument to support the claim that our world consist essentially of objects and that events are something ontologically inferior. But an interesting thing is that even if we are *imagining* objects without events there is always at least the event of our imagining, for example. It seems that we can't really escape from events.

[1] In the previous chapter we introduced the term "ontology" in its computer science sense and we noted that it comes from philosophy. In this chapter it has obviously its philosophical meaning but starting with the next chapter we will talk about computer ontologies again.

Casati and Varzi list some facts that indicate that our language and thought contain some sort of "ontological commitment" to events:

> Pre-linguistic infants appear to be able to discriminate and "count" events, and the content of adult perception, especially in the auditory realm, endorses the discrimination and recognition as events of some aspects of the perceived scene.
>
> Humans (and, arguably, other animals) appear to form the intention to plan and execute actions, and to bring about changes in the world.
>
> Dedicated linguistic devices [...] are tuned to events and event structures, as opposed to entities and structures of other sorts.
>
> Thinking about the temporal and causal aspects of the world seems to require parsing those aspects in terms of events and their descriptions. [4]

There are several different ways to account for events and their "ontological status". In this chapter we will briefly try to show some of them. Our main source for the outline is the cited text by Casati and Varzi along with some other, both primary and secondary, philosophical texts. We also try to develop some of the considerations with respect to their application in the following chapters.

2.1 Events and objects

If we contrast events with *objects* we can take note of some distinctions that are more or less commonplace in the philosophical literature. While objects are said to *exist*, events are usually said to *happen* or *take place*. Objects are taken as *continuants*, i.e. they persist through time as wholes, while events are taken as *occurrents*, meaning they have "temporal parts" and therefore are not wholly present at every moment (this dichotomy is incorporated into several "foundational ontologies" – see below). This distinction is however controversial, as there are philosophers who take objects as four-dimensional entities. This assumption in effect diminishes the distinction between objects and events; in this interpretation they both have both spatial and temporal parts.

Another distinction between objects and events could be that objects have *crisp* spatial boundaries and *vague* temporal, while events have vague spatial and crisp temporal boundaries. This distinctions looks elegant, but it is certainly problematic, too. For example, it seems to us that the "spatial boundaries" of events are actually as crisp as we define them. If we take them to be (which is one of the possible approaches) aligned with the spatial boundaries of the event's participant, then will the boundaries be crisp in the same way as the boundaries of the objects. It is also not exactly clear why would the temporal boundaries of events be crisp and of objects vague. It may be more appropriate to speak about more or less vague, but that would of course spoil the definition of the distinction.

Another thing related to space an time is that it is generally allowed for two events to be at the same time in the same place, while we usually deny this when speaking about objects. But this again depends on what we take the place of an event to be.

Besides the distinction between events and objects, there is also the question of their relations, especially of *dependence*. We have already touched this question above. Events cannot be (at least usually) without objects, but also objects cannot actually be without events. There have of course been conceptualization granting primary role to objects and others granting it to events. They can also be given an equal ontological status, but one of them taken as primary *in the order of thought* [4]. It has been however argued by Strawson that a *pure event-based ontology* would have not been sufficient as our "re-identifying practices" require a stable frame of reference, which needs objects [23]. But Davidson maintains that there is a symmetry in conceptual dependence between substances (i.e. objects) and their changes (i.e. events) [6, p. 175].

These conceptions emphasize the differences between events and objects, but they also presuppose that they have some important features in common: both events and objects are situated in space and time, they are individuals (*particulars*), can be counted, referred to, and quantified over.

2.2 Facts, situations, states of affairs

If events are particular temporal "entities", they should be distinguished from *a*-temporal *facts*. If we talk about concrete temporal events, we can also talk about their corresponding facts which are abstract and a-temporal. For example, the event of Caesar's death that took place in Rome in 44 BC have a corresponding fact *that* Caesar died in Rome in 44 BC (facts expressed in English are usually syntactically distinguished by the "*that*-clause"). This approach takes events and facts as two distinct categories while admitting their close connection. The question would be if there are good enough reasons for keeping both these categories in our ontology.

Another category often taken to be in some way related to events is *situation*. We are assured that "[t]here is no consensus about what situations are, just as there is no consensus about what possible worlds or events are," but: "According to some, situations are structured entities consisting of relations and individuals standing in those relations." [13]

Situations were discussed often with connection to J. Barwise's work on situations in direct perception reports where sentences like:

> Beryl saw Meryl feed the animals.

Are analyzed in this way:

> There is an actual past situation s that Beryl saw, and s supports the truth of *Meryl feed the animals.* [13]

Other related theories follow the considerations of *situation semantics* and develop a general theory of information content with the key notion of *states of affairs* (see *ibid.*). From all the notions we have considered so far in this section, states of affairs and situations are two that are closest to each other; in fact so close that we can use them interchangeably. There is of course extensive literature elaborating these notions, but for our understanding of them, we will very briefly turn to a classic, namely Wittgenstein's *Tractatus Logico-Philosophicus*.

2.2.1 Wittgenstein's Sachverhalte

According to Wittgenstein's early metaphysics as presented in *Tractatus Logico-Philosophicus*, the world is "the totality of facts, not of things." [24, 1.1][2] A *fact* is the existence (or non-existence) of a *Sachverhalt* (2). *Sachverhalt* is the key notion we are now looking for. Ogden translates it as "atomic fact" but the more influential translation is the second one: *state of affairs*. A fact can be positive, meaning it is the existence of a state of affairs, or negative, non-existence of a state of affairs (2.06). A state of affairs is a combination (connection, configuration) of objects, things (2.01). It has a *structure*, which is the way the objects are connected in it (2.032).

This conception roughly corresponds to the above cited characterization of situations ("situations are structured entities consisting of relations and individuals standing in those relations") except for the rather strong word "entities".

Now, what can we make of "states of affairs" in connection with events? They seem to be two different kinds of "things" (if we can use this term). Events *happen*, while states of affair *exist*. Except they do not exist in the same sense as objects, obviously. They are not

[2] We use an edition containing the German original as well as two English translations (Ogden and Pears/McGuinness) which differ in key terminology, so it will be necessary to refer to both of them. In this particular sentence they, probably by accident, don't differ at all.

“substances” (substances are things, objects; states of affair are just configurations of them). Wittgenstein’s approach to states of affairs seem to be a-temporal. But if we interpret the objects which enter into the states of affairs as the kind of objects we daily encounter then it is obvious that the states of affairs, these configurations, *start and cease to exist*, therefore are temporal, just like events. Look again at the cited example of analysis in situation semantics:

> There is an actual past situation *s* that Beryl saw, and *s* supports the truth of *Meryl feed the animals.* [13]

The situation *s* here *referred to* corresponds to such conception of states of affairs: it could surely be interpreted as a configuration of objects (Meryl, animals, food etc.) and it is *past* which means it “existed” for some time but does not exist anymore.

So we can see that situations or states of affairs understood as configurations (structures of relations) of things in time can be used to interpret what we in natural language call events.

2.3 Davidson’s analysis of “action sentences”

Another approach to events can be found in Donald Davidson’s analysis of “action sentences”, i.e. sentences about *somebody doing something.* The analysis aims at establishing the *logical form* (expressible in predicate logic) of this type of sentences. In an essay entitled *The Logical Form of Action Sentences*, Davidson analyzes this sentence:

> (1) Jones buttered the toast in the bathroom with a knife at midnight. [6, p. 107]

The first take on establishing the logical form of such a sentence would be to treat “buttered” as a five-place predicate and the sentence as this predicate with its places filled with Jones, toast, bathroom, knife and midnight. The problem is that if we take another sentence, say:

> (2) Jones buttered the toast,

then we would analyze it in the same manner as a sentence containing a two-place predicate “buttered”. But the two sentences have obviously the element of the predicate in common and this analysis fails to take in into account as the two predicates (five-place “buttered” and two-place “buttered”) are distinct.

According to Davidson, our usual talk about actions suggest there are such *things* as actions, which can be described in various ways while retaining their identity; it is the same “buttering” even if we describe in one case as in (1), in another case as in (2). Roughly these considerations lead Davidson to treat actions (and more generally events) as entities, of which can be a lot of things predicated, and giving the corresponding predicates an "event-place" in the analysis (see [6, p. 118]). For example the sentence:

> Shem kicked Shaun,

would be thus analyzed:

> $(\exists x)(\mathit{Kicked}(\mathit{Shem}, \mathit{Shaun}, x))$

Where x is the action (event) of the "kicking". We can then say something more about this x, for example that Shem kicked Shawn *vigorously* (by adding something like $\mathit{Vigorously}(x)$) without needing to alter the number of places of the predicate.

So, Davidson thinks that there are good enough reasons to treat actions and events as particulars: we quantify over them "in much of our ordinary talk" [6, p. 166].

Davidson also proposes a *criterion of identity* of events: "events are identical if and only if they have exactly the same causes and effects" [6, p. 179].

It has been pointed out that:

> Situations and events seem to be the same kinds of things. If situations are particulars, so are events. If situations are built from relations and individuals standing in those relations, so are events. We don't seem to need both of those things. We don't seem to need both situation semantics and Davidsonian event semantics. [13, section 9]

Well, it is quite possible that we don't need both situation semantics and Davidsonian event semantics. But can we from the observations that events and situations have many features in common and lots of sentences can be interpreted both as referring to events and to situations infer that they *are* one and the same kind of things? That depends on our willingness to accept the implications of conflating these two categories. Namely, do we want to call for example *the "standing" of this house in this street for a hundred years* an event? Or, on the contrary, *its collapse last week* a situation? Both is of course possible. If we want, on the other hand, to keep both of these categories we need some criteria to distinguish between them.

2.4 Events and other categories

Besides objects, situations, and facts, events can be contrasted also with other ontological categories:

Properties Events can be viewed also as properties, or, as we are now talking about *particular* events, as *tropes* (i.e. *abstract particulars*). That means that we could construe particular events as properties e.g. of some “space-time region”. Taking events as tropes instead of “things” arguably implies a weaker ontological commitment; in this view they are “accidents” rather than “substances”

Times Another, even “more reductionist”, approach is to take events to be be *times* (temporal intervals) *cum description*. Events would be in this view identified by ordered pairs of time periods and sentences describing the event; for example “The sun rises.” [4, section 1.4]. But also the inversion of this approach is possible; instead of reducing events to descriptions of times, some philosophers reduce, on the opposite, times (instants or intervals) to relations between events (simultaneous or consecutive) taken as primitives (see *ibid.*).

2.5 Types of events

There is a classic typology distinguishing between four kinds of events [4, section 2.1]:

- activities
- accomplishments
- achievements
- states

These types of events are characterized in terms of *homogeneity* and *culmination*. Both activities and states are homogeneous (meaning their sub-events satisfy the same description as the events themselves) and have no culmination. Accomplishments may have culmination and are not homogeneous and achievements are always culminating events, which also means they are instantaneous.

Interesting is the inclusion of *states* (e.g. *my knowing that* $1 + 1 = 2$), which most of us arguably would not in usual discourse call events (this problem amounts to distinction between events and situations – see above, p. 19).

Other distinctions of types of events include: static vs. dynamic events and mental vs. physical events (see [4]).

Actions are naturally understood as a distinctive subclass of events.

2.6 Events as universals

Until now, we have treated events basically as particulars. But they can be understood also, as Casati and Varzi put it, "as abstract, timeless universals, i.e., as repeatable entities that may be said to recur many times and in many places" [3]. But if we take events as abstract universals, we still need to account for their *recurring* in particular cases. Christholm, for example, proposes to construct the universal, recurring events (e.g. "my dropping of a saucer of mud") as classes and the recurrences of them as their instances (see [6, p. 183]). Davidson, on the other hand, proposes to treat the instances (my particular droppings of a saucer of mud, yesterday and today) as *parts* of another *particular* event which is their *sum*, is discontinuous, but has the same ontological status.

Chapter 3

Events in the Foundational Ontologies

Foundational ontologies, often called also *top-level* ontologies or *upper-level* ontologies (see [21]), are ontologies that are not focused on a specific domain but rather include very general concepts that can be applied in various (in an ideal case all) domain ontologies. Their aim is to use formal ontological theories to provide sound theoretical foundation for conceptual modeling. We can imagine a typical use of a foundational ontology in designing of a particular domain ontology basically (in the simplest case) as subordinating the concepts from our domain under the general ones from the foundational ontology.

In this chapter, we are concerned not with foundational ontologies in general but more specifically with their treatment of events. We will look at several examples of notable upper-level ontologies with events in mind. A comprehensive survey of foundational ontologies or analyses of their utility or possible inconsistencies etc. are not our goals here.

Notable upper-level ontologies that are *not* mentioned in the following include: SUMO[1], GFO[2], Cyc[3] and the core module of CIDOC-CRM.[4]

[1] `http://www.adampease.org/OP/`

[2] `http://www.onto-med.de/ontologies/gfo/`

[3] `http://sw.opencyc.org`

[4] `http://www.cidoc-crm.org`

3.1 KR Ontology

KR (Knowledge Representation) Ontology by J. F. Sowa was influenced mainly by the philosophers Charles Sanders Peirce and Alfred North Whitehead.[5] It is not based on a "fixed hierarchy of categories, but on a framework of distinctions, from which the hierarchy is generated automatically". There are twelve central categories based on three basic distinctions, that can be arranged into a matrix:[6]

	Physical		**Abstract**	
	Continuant	**Occurrent**	**Continuant**	**Occurrent**
Independent	Object	Process	Schema	Script
Relative	Juncture	Participation	Description	History
Mediating	Structure	Situation	Reason	Purpose

The most interesting for us out of these distinctions is that of *continuants* on one the hand and *occurrents* on the other.[7] They are defined as follows:[8]

> **Continuant.** An entity whose identity continues to be recognizable over some extended interval of time. [...]
>
> A continuant x has only spatial parts and no temporal parts. At any time t when x exists, all of x exists at the same time t. [...]
>
> The identity conditions for a continuant are independent of time. [...]
>
> **Occurrent.** An entity that does not have a stable identity during any interval of time. [...]
>
> The temporal parts of an occurrent, which are called stages, exist at different times.
>
> The spatial parts of an occurrent, which are called participants, may exist at the same time, but an occurrent may have different participants at different stages.
>
> There are no identity conditions that can be used to identify two occurrents that are observed in nonoverlapping space-time regions.

It is obvious that events belong to occurrents. But, as we can see in the matrix, there are still other distinctions that can be applied to occurrents. We can tell that events are *physical*, because that means in the KR Ontology: "An entity that has a location in space-time". That

[5] `http://www.jfsowa.com/ontology/`

[6] `http://www.jfsowa.com/ontology/toplevel.htm`

[7] We have mentioned this distinction already in the previous chapter.

[8] `http://www.jfsowa.com/ontology/toplevel.htm`

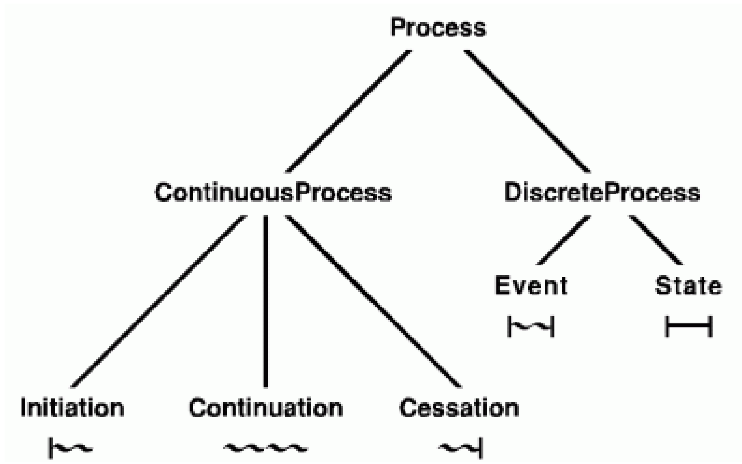

Figure 3.1: Types of Processes in KR Ontology. Source: `http://www.jfsowa.com/ontology/process.htm`

leaves us with three basic categories under which can be subsumed that what we call events: *process*, *participation* and *situation*; these categories are in turn *independent*, *relative* and *mediating*. These terms can be briefly explained thus: "An independent entity need not have any relationship to anything else, a relative entity must have some relationship to something else, and a mediating entity creates a relationship between two other entities" (*ibid.*). These categories are themselves subjects to further distinctions. *Process*, for example, has several further types including *event* in sense of a discrete (as opposed to continuous) change. But this category does not necessarily include everything we call events in all contexts. One of the reasons would be that process is, as we have seen, defined as an *independent* physical occurrent. And independence of events can be of course questioned. What we can tell is that events can be conceived as a kind (or several kinds) of *occurrents* as opposed to continuants.

Note also that the other categories of physical occurrents besides process are *participation* and *situation*. We have already encountered situations in the previous chapter and will encounter briefly both situations and participations in the next. It is often not quite clear what is their relationship to events or if they are events too.

3.2 DOLCE

DOLCE (a Descriptive Ontology for Linguistic and Cognitive Engineering)[9] uses a basic distinction between *endurants* and *perdurants* which actually correspond to continuants and occurrents.[10] The following definition may therefore look familiar.

> Endurants are wholly present (i.e., all their proper parts are present) at any time they are present. Perdurants, on the other hand, just extend in time by accumulating different temporal parts, so that, at any time they are present, they are only partially present, in the sense that some of their proper temporal parts (e.g., their previous or future phases) may be not present. [14, p. 10]

There are various kinds of perdurants, distinguished by notions of *homeomericity* and *cumulativity* [14, p. 17]. In effect, the class of perdurants breaks up like this:

- Event
  - Accomplishment
  - Achievement
- Stative
  - Process (e.g. running)
  - State (e.g. sitting)

Again, not everything we could call event is subsumed under the *event* class. A comparison with the KR Ontology might be interesting: there was "event" along with "state" subsumed under (discrete) "process"; now we have similarly "event" standing against "stative"; but "process" is here a kind of stative (along with "state").

3.3 UFO-B

UFO-B is a foundational ontology *for events* based on UFO (Unified Foundational Ontology) [8]. UFO works with the already familiar distinction between enduring and perduring entities but here the perduring entities are explicitly called *events* (we have seen in the previously discussed foundational ontologies that "events" there were just *some* of the perdurants (occurrents). That means that the notion of event is here somewhat more general and therefore probably closer to the concept elaborated in the previous chapter. Examples of events

[9] `http://www.loa.istc.cnr.it/old/DOLCE.html`

[10] Endurants and perdurants are, along with *qualities*, "spatio-temporal particulars" in DOLCE. Besides spatio-temporal DOLCE includes also abstract particulars.

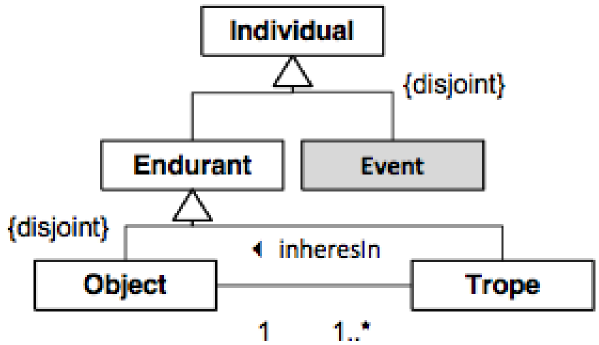

Figure 3.2: "A fragment of the Unified Foundational Ontology (UFO)". Source: [8]

(i.e. perdurants) given are fairly intuitive: "a conversation, a football game, a symphony execution, a birthday party, or a particular business process" [8]. As we can see in figure 3.2, inside the category of endurants, there is a distinction between *objects* and *tropes*. Objects are existentially independent while tropes (which include both qualities and dispositions) are dependent on other entities – they *inhere* in objects (*ibid.*).

Events in UFO-B can be composed of other events. Depending on their structure from this point of view they can be *atomic* (i.e. having no parts) or *complex* (i.e. aggregations of at least two events). Between a complex event and its parts there are relations "has-part".[11] It is understandable that the notion of atomic events was introduced for theoretical reasons. The problem is what corresponds to these atomic events in the "real world"; what are the atomic events constituting for example a birthday party?

"Events are ontologically dependent entities in the sense that they existentially depend on objects in order to exist." [8] We have discussed the issue of dependence of events briefly in the previous chapter. This is arguably the most intuitive way how to conceive it. Atomic events are dependent *directly* on objects, complex events are dependent on their parts and *indirectly* on the objects these parts are dependent on.

"[S]patial properties of events are defined in terms of the spatial properties of their participants. In contrast, all temporal properties of objects are defined in terms of the events they participate in" (*ibid.*). This is interesting because, as we have seen, events are *existentially* dependent on objects. This relationship is asymmetrical. But events and objects have also this more symmetrical relationship of dependence of their spatial or temporal properties

[11] UFO-B is fully axiomatized in the standard predicate calculus.

respectively. That means that although objects are (ontologically) independent on events, without them they would probably be "a-temporal".

"Events are transformations from a portion of reality to another, i.e., they may change reality by changing the state of affairs from one situation to another" (*ibid.*). So, we have both *events* and *situations*. Both have specified temporal properties. They have relationships of these kinds:

- a situation *s* *triggers* an event *e*
- an event *e* *brings about* a situation *s*

This leads to the following picture: Situations follow events and events follow situations. If a situation fulfills all conditions for an event to happen, it *triggers* this event. The event *brings about* a new situation. And so on. Here is the distinction between events and situations meaningful.

But let's consider this sentence:

> A *triggers* relation between situation *s* and event *e* captures the notion that s exemplifies a state of the world that satisfies all the sufficient and necessary conditions for the manifestation of *e*. (*ibid.*)

That means that if an event *e* brings about a situation which is sufficient to triggers another event *e'*, it triggers it "immediately" (*e* is said to *cause* *e'* in this circumstances). From this follows that situations don't have time extension, they obtain in one "point" of time. It is not clear from the cited paper what situations *are*. They are certainly not events (which is the same as perdurants in UFO-B). So what are they? It seems that they have somewhat lesser ontological status compared to events.

Chapter 4

Semantic Web Ontologies for Events

In this chapter we survey selected semantic web ontologies that are designed for modeling events. Our starting point and main source of these ontologies is the *Linked Open Vocabularies* portal, especially its event section.[1] We start with ontologies utilizing a very general notion of event, of which the *Event ontology* seems to be the most prominent. Subsequently we move to the standard ways of modeling temporality, which is an essential feature of events. Next step will be looking (using the LOV's SPARQL endpoint) for ontologies that build on top of the general Event Ontology and specialize its notion of event for specific domains and purposes. This will allow us to see what "kinds of events" we can encounter on the semantic web.

These parts of the chapter are focused mainly on the Event Ontology, which we conceive to be the most prominent ontology in the semantic web ecosystem for modeling events, and ontologies that are similar to it and/or connected with it. To this we add a section about *mappings* between the mentioned ontologies as well as others, including some upper-level ontologies.

Then we supplement two short analyses related to modeling events on the semantic web. They concern:

- Use of ontology design patterns involving events and situations in ontologies from the SPAR ontology suite, and
- the *Stories Ontology*, which views "stories" as sequences of events.

4.1 The Event Ontology

```
@prefix event: <http://purl.org/NET/c4dm/event.owl#>.
```

[1] `http://lov.okfn.org/dataset/lov/vocabs?tag=Events`

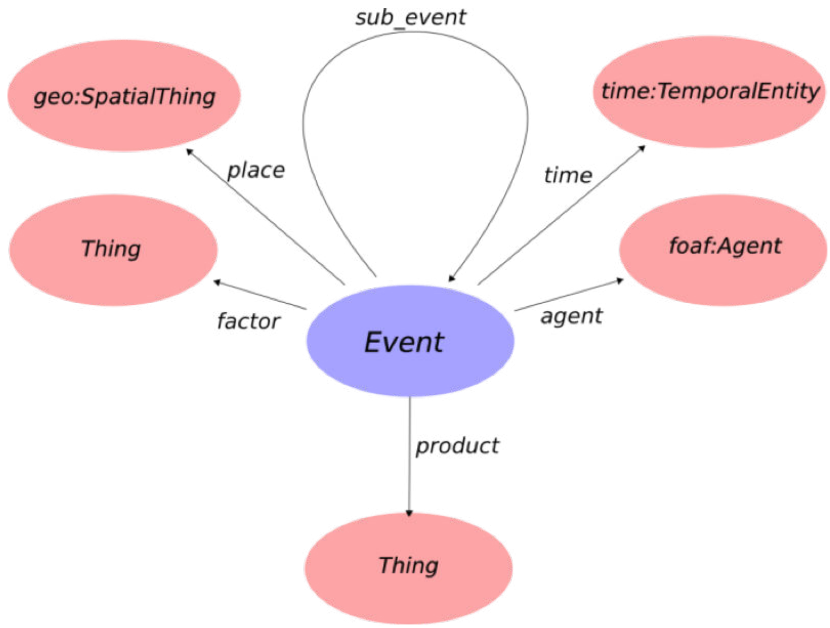

Figure 4.1: The *Event Ontology*. Source: `http://motools.sourceforge.net/event/event.html`

The *Event Ontology* was developed in the Centre for Digital Music in Queen Mary, University of London. Its core notion is *reified* event. In this ontology, events are seen as "the way by which cognitive agents classify arbitrary time/space regions".[2] They can have place, time, factors, agents and products. Events may also be composed of sub-events.

The following example is given in the ontology specifications. It deals with a "performance event, involving one performer and an instrument (the Santur) in London, the 15th of October 2007 at noon, and lasting an hour":[3]

```
@prefix event: <http://purl.org/NET/c4dm/event.owl#>.
@prefix mit: <http://purl.org/ontology/mo/mit#>.
@prefix foaf: <http://xmlns.com/foaf/0.1/>.
@prefix tl: <http://purl.org/NET/c4dm/timeline.owl#>.
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>.

:performance
```

[2] `http://motools.sourceforge.net/event/event.html`
[3] `http://motools.sourceforge.net/event/event.html`

```
a event:Event;
event:factor mit:Santur;
event:agent [
    a foaf:Person;
    foaf:name "P. H.";
];
event:place <http://sws.geonames.org/2643744/>;
event:time [
    a tl:Interval;
    tl:at "2007-10-15T12:00:00"^^xsd:dateTime;
    tl:duration "PT1H"^^xsd:duration;
] .
```

From such entries we can tell *when* and *where* the event took place, *who acted* in the event, what *factors* were used and what *products* produced. What we cannot tell (at least not directly) is what kind of event or action it was. This could be done using subclasses of the *Event* class. There are vocabularies specializing the Event Ontology for specific domains, which have such subclasses. We will show examples of those later. Also, we cannot tell what the agent *did*. This could be specified using specialized subproperties of the *agent* property.

The ontology can thus be seen as a general framework for modeling events which should be made more specific (or *specialized* – see below, section 4.4) for use with different "types of events".

Important feature of events and therefore also of modeling them is the temporal dimension; a (*particular*) event has to happen in time. In the range of `event:time` is `time:TemporalEntity` which could be either instant or interval. In the example above the *Timeline Ontology* is used for specifying the time. We will take a closer look at these ontologies in a dedicated section below.

We have already mentioned above that *events* are understood by the *Event Ontology* to be *reifications*. From that follows that they are not considered to be *in the background* some kind of entities; they are just "arbitrary time/space regions" so classified by "cognitive agents". This seems to partially undermine the natural language meaning of "event" because even if we admitted that we use the term for "time/space regions", we would hardly call them arbitrary.

4.2 Other structurally similar ontologies

There are other ontologies for describing events that have structure similar to that of the *Event Ontology*. That means there is a central “event” class and several properties for linking its instances to the event’s “constituents”. Let us look at some of these ontologies.

4.2.1 Simple Event Model

```
@prefix sem: <http://semanticweb.cs.vu.nl/2009/11/sem/>.
```

SEM (The Simple Event Model Ontology) [9][4] has “core” classes and corresponding properties that allow us to model the basic facts in a similar fashion as in the Event Ontology. These basic classes are: *Event*, *Actor*, *Place* and *Time*. It has also means to express some constraints related to different viewpoints, namely: “(1) Event bounded roles, (2) time bounded validity of facts (e.g. time dependent type or role), and (3) attribution of the authoritative source of a statement”. There are also classes of types of the entities from the “core” classes and properties with these classes in their range. Types of events, for example, are therefore modeled as instances of class *EventType*, while in the ontologies specializing the *Event Ontology* they are modeled as subclasses of the main class entitled *Event*.[5]

Unlike the Event Ontology, SEM has its own way of modeling the time aspect of events (see section 4.3.3).

4.2.2 Linking Open Descriptions of Events

```
@prefix lode: <http://linkedevents.org/ontology/>.
```

LODE (Linking Open Descriptions of Events)[6] is explicitly focused on describing *historical* events and “mapping between other event-related vocabularies and ontologies” (see section 4.5). It defines only one class which is called, not surprisingly, *Event*. There are properties for defining the usual aspects of events (place, time, involved agents and objects) and an interesting property *illustrate* for linking things (“typically media objects”) to events which they illustrate.

Like in the Event Ontology, time is specified using `time:TemporalEntity` which is in this case in range of `lode:atTime`.

[4] `http://semanticweb.cs.vu.nl/2009/11/sem/`

[5] We could talk about different “modeling styles”.

[6] `http://linkedevents.org/ontology/`

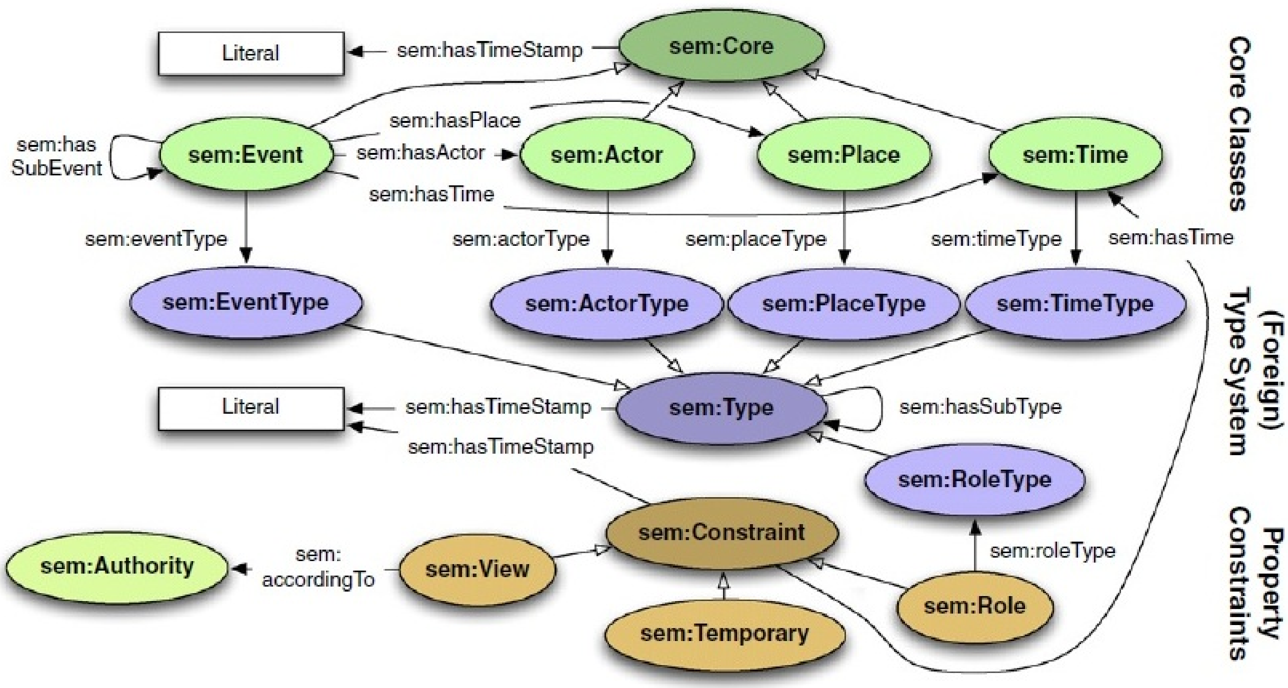

Figure 4.2: The *Simple Event Model* Ontology. Source: `http://semanticweb.cs.vu.nl/2009/11/sem/`

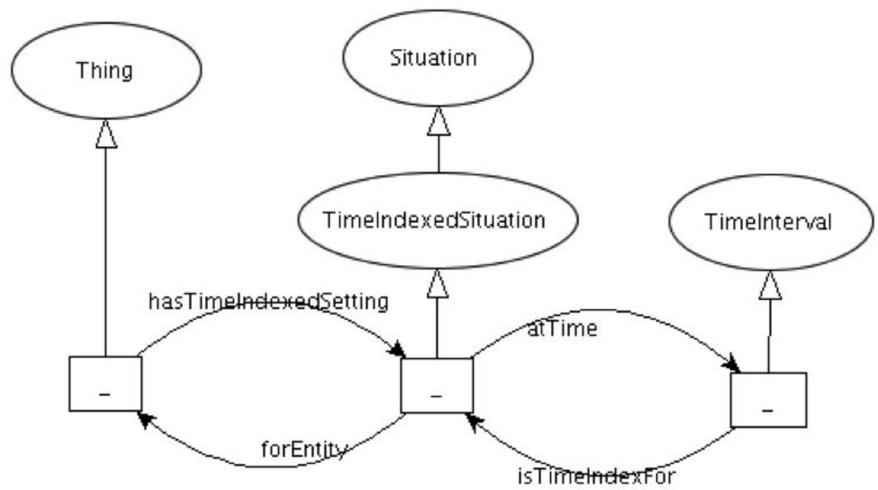

Figure 4.3: Time Indexed Situation pattern

Event is in the ontology's documentation defined thus: "An event consists of some temporal and spatial boundaries subjectively imposed on the flux of reality or imagination, that we wish to treat as an entity for the purposes of making statements about it." This definition reminds us of that one used in the description of the Event Ontology. "Boundaries" of events are "subjective" (at least this time not "arbitrary"), while what is "objective" is arguably just some spatio-temporal "flux" lacking all boundaries.

4.2.3 Time Indexed Situation design pattern

```
@prefix tis: <http://www.ontologydesignpatterns.org/cp/owl/timeindexedsituation.owl#>.
```

Basically the same structure as the mentioned ontologies has also the *Time-indexed situation pattern*,[7] which is an extension of the *Situation pattern*.[8]

Properties `atTime` and `forEntity` have a common super-property from the situation pattern (`isSettingFor`), like, analogously, their inverse properties. Therefore, more specific properties can be added to distinguish between various kinds of things for which (or: ways in which) the situation "is setting", similarly to agents, products etc. in the Event Ontology.

[7] `http://www.ontologydesignpatterns.org/cp/owl/timeindexedsituation.owl`

[8] `http://www.ontologydesignpatterns.org/cp/owl/situation.owl`

Time is specified using the *Time Interval* pattern[9] with class `TimeInterval` and its two datatype properties: `hasIntervalStartDate` and `hasIntervalEndDate`.

Time-indexed situation and the *Event Ontology* have (in the foreground) the same basic structure. There is of course difference in their central notions (*event* vs. *situation*), but these notions are very similar and therefore both could be used to represent more or less the same "real-world" facts (see p. 19). The differences of the two notions may be too subtle for the world of semantic web; but using the terms interchageably, or together without specifying their difference may cause confusion.

4.2.4 schema.org

```
@prefix schema: <http://schema.org/>.
```

schema.org has also a class called *Event*.[10] But in this case, "event" is something more specific compared to the notion of event in the previously mentioned ontologies. As *schema.org* defines it: "An event happening at a certain time and location, such as a concert, lecture, or festival."

Thus *schema.org*'s notion of events is not meant (at least primarily) to model events in the broad sense like the Event Ontology and others. And being focused on concerts, lectures, festival etc. it contains some specific properties that are useful for describing such events, prominently:

- `attendee`
- `doorTime`
- `eventStatus`
- `performer`
- `workPerformed`

There are also several more specific types of events defined, for example *BusinessEvent*, *LiteraryEvent*, *SportsEvent* etc.

For specifying time, (datatype) properties `doorTime`, `duration`, `startDate` and `endDate` with conjunction with date/time in ISO 8601 format can be used.

4.2.5 DBpedia Ontology

```
@prefix dbo: <http://dbpedia.org/ontology/>.
```

[9] `http://www.ontologydesignpatterns.org/cp/owl/timeinterval.owl`
[10] `http://schema.org/Event`

The *DBpedia* ontology "is generated from the manually created specifications in the DBpedia Mappings Wiki".[11] That means it can change in dependence on what data are extracted from Wikipedia and added to DBpedia. Therefore, the conditions of its origin are significantly different from those of the other ontologies mentioned in this chapter. It is however still very interesting for us because it is actually used on the semantic web to represent large amounts of data.

DBpedia's ontology contains, like the others, a class called *Event*.[12] There are several properties connected with it that we should notice, namely:

- datatype properties with `Event` in their domain: `participant`, `numberOfPeopleAttending`, `startDate` and others,
- properties with `Event` in both domain and range: `followingEvent`, `nextEvent`, `previousEvent`.

This ontology contains a taxonomy of events which were the aforementioned ontologies (say, except for schema.org) missing. There are four subclasses of the event class on the top level:[13]

- Competition
- LifeCycleEvent
- NaturalEvent
- SocietalEvent

The most of the hierarchy falls under *SportsEvent* which is one of the subclasses of *SocietalEvent*. This shows us that the hierarchy origins from the need of converting particular Wikipedia articles to DBpedia and not from some thorough considerations regarding all thinkable types of events.

4.3 Modeling temporality

In this section, we survey the ways in which temporality is modeled in the aforementioned ontologies. A more comprehensive overview of different approaches to capturing temporality in linked data can be found in [15].

4.3.1 The Time Ontology

```
@prefix time: <http://www.w3.org/2006/time#>.
```

[11] `http://dbpedia.org/ontology/`

[12] `http://dbpedia.org/ontology/Event`

[13] For the whole hierararchy, see `http://mappings.dbpedia.org/server/ontology/classes/#Event`

The OWL-Time[14] ontology specifies the class `TemporalEntity` with subclasses for both *instants* and *intervals*. It can specify their relationships using properties such as `after` and `before`. These core entities basically have `DateTimeDescription` or `DurationDescription` which in turn have the date/time or duration specified with a set of datatype properties.

The usage of the ontology can look for example like this:[15]

```
:meetingStart
    a time:Instant ;
    :inDateTime :meetingStartDescription ;
    :inXSDDateTime 2006-01-01T10:30:00-5:00 .

:meetingStartDescription
    a time:DateTimeDescription ;
    time:unitType time:unitMinute ;
    time:minute 30 ;
    time:hour 10 ;
    time:day 1 ;
    time:dayOfWeek time:Sunday ;
    time:dayOfYear 1 ;
    time:week 1 ;
    time:month 1 ;
    time:timeZone tz-us:EST ;
    time:year 2006 .
```

4.3.2 The Timeline Ontology

```
@prefix tl: <http://purl.org/NET/c4dm/timeline.owl#>.
```

The *Timeline Ontology*[16] was developed (like the Event Ontology and the Music Ontology) in the Centre for Digital Music in Queen Mary, University of London. While the Time Ontology is centered around the notion of *temporal entities*, the Timeline ontology is focused on, as the name suggest, *timelines* (instants and intervals can be "placed" on the timelines). The

[14] `http://www.w3.org/TR/owl-time/`

[15] This example is adapted from the cited web page of OWL-Time. It specifies the time using both Time ontology and XML DateTime.

[16] `http://motools.sourceforge.net/timeline/timeline.html`

main difference is that the Time ontology works just with the "absolute" timeline, while the Timeline ontology allows for multiple timelines which can be *relative*. The Timeline Ontology is designed with musical and multimedia use-case in mind and its original aim is to describe "temporal objects" like a signal, a score or a musical work, which can be said to be spread on a timeline on which some *events* can be marked. For example:[17]

- "In this song, the first chorus is before the second verse," or
- "A new structural segment starts at 2 minutes and 43 seconds, on this signal."

The ontology allows us to specify relationships between multiple timelines, for example the relationship between a discrete timeline of a digital record to a continuous timeline of its analog counterpart to the "universal" timeline with date and time of performance etc.

4.3.3 Simple Event Model

SEM includes seven *time stamp* data properties that can be used to specify time "boundaries" not just of events but also of constraints like roles and views held in time. These properties are:

- `hasTimeStamp` for specifying a single (*instant*) time value,
- `hasBeginTimeStamp` and `hasEndTimeStamp` for specifying intervals (open-ended intervals can be also expressed using just one of the properties),
- `hasEarliestBeginTimeStamp`, `hasLatestBeginTimeStamp`, `hasEarliestEndTimeStamp`, and `hasLatestEndTimeStamp` for uncertain intervals.

4.4 Domain-specific ontologies built using the Event Ontology

The Event Ontology has more than thirty "incoming links" documented in LOV.[18] Most of them are from vocabularies that "specialize" it.[19] The following table shows these specializing vocabularies.[20]

[17] *Ibid.*

[18] see `http://lov.okfn.org/dataset/lov/vocabs/event`

[19] `voaf:specializes`; that "[i]ndicates that the subject vocabulary defines some subclasses or subproperties of the object vocabulary, or local restrictions on those" (`http://lov.okfn.org/vocommons/voaf/v2.3/#specializes`).

[20] Obtained from the LOV SPARQL endpoint (`http://lov.okfn.org/dataset/lov/sparql` [May 2015]) using the following query:

Prefix	Name	URI
af	Audio Features Ontology	http://purl.org/ontology/af/
ao	Association Ontology	http://purl.org/ontology/ao/core#
bibo	The Bibliographic Ontology	http://purl.org/ontology/bibo/
bio	BIO: A vocab. for biographical info.	http://purl.org/vocab/bio/0.1/
blt	British Library Terms RDF schema	http://www.bl.uk/schemas/bibliographic/blterms
cco	Cognitive Characteristics Ontology	http://purl.org/ontology/cco/core#
chord	The OMRAS2 Chord Ontology	http://purl.org/ontology/chord/
co	Counter Ontology	http://purl.org/ontology/co/core#
elec	Vocabulary for Vote Results	http://purl.org/ctic/sector-publico/elecciones
geosp	GeoSpecies Ontology	http://rdf.geospecies.org/ont/geospecies
igeo	Ontologie géographique de l'INSEE	http://rdf.insee.fr/def/geo
locah	The LOCAH RDF Vocabulary	http://data.archiveshub.ac.uk/def/
mo	Music Ontology	http://purl.org/ontology/mo/
opo	Online Presence Ontology	http://online-presence.net/opo/ns#
ov	OpenVocab	http://open.vocab.org/terms
pbo	Play Back Ontology	http://purl.org/ontology/pbo/core#
pne	Press.net Event Ontology	http://data.press.net/ontology/event/
po	Programmes ontology	http://purl.org/ontology/po/
sem	The SEM Ontology	http://semanticweb.cs.vu.nl/2009/11/sem/
sport	BBC Sport Ontology	http://www.bbc.co.uk/ontologies/sport
theatre	Theatre Ontology	http://purl.org/theatre#
txn	TaxonConcept Ontology	http://lod.taxonconcept.org/ontology/txn.owl
vivo	VIVO Core Ontology	http://vivoweb.org/ontology/core
wi	The Weighted Interests Vocabulary	http://purl.org/ontology/wi/core#
wo	Weighting Ontology	http://purl.org/ontology/wo/core#

If we take a look at some of these vocabularies, we can get an idea for what "kinds of

PREFIX voaf:<http://purl.org/vocommons/voaf#>
PREFIX dcterms:<http://purl.org/dc/terms/>
SELECT DISTINCT ?prefix ?title ?vocab { GRAPH <http://lov.okfn.org/dataset/lov> {
?vocabversion voaf:specializes <http://purl.org/NET/c4dm/event.owl> .
?vocab <http://www.w3.org/ns/dcat#distribution> ?vocabversion .
?vocab dcterms:title ?title ; <http://purl.org/vocab/vann/preferredNamespacePrefix> ?prefix . }} ORDER BY ?prefix

events" can be and is the *Event* class and the general structure provided by the *Event Ontology* used.

Audio Features Ontology contains a small taxonomy of "events" for representing structural segments of audio signals (music or speech). They are organized in two main groups: *Point* and *Segment* (point are instantaneous, while segments last for an interval of time). They include, for example, *KeyChange* (point) and *Laugh* (segment).

The Bibliographic Ontology contains several subclasses of *Event*: *Conference*, *Hearing*, *Interview*, *Performance*, *PersonalCommunication* and *Workshop* and a subproperty of *product* named *presents* (with *Document* in its range)

BIO vocabulary contains a rich classification of personal events, both "group" and "individual", for example *Marriage*, *Divorce*, *Birth*, *Death* (with other subclasses including *Murder*), *Graduation* etc., and several properties with *Event* in their range and/or domain.

British Library Terms schema contains class *PublicationEvent*.[21] (In our analysis of modeling styles and local coverage, we treated this particular "kind of events" as a reified relationship.[22])

In the Music Ontology [19] there are *Event* subclasses: *Activity*, *Arrangement*, *Composition*, *Festival*, *Performance*, *Recording*, *Show* and others.

BBC Programmes Ontology contains (among others) a *Broadcast* event class for modeling a particular broadcast of a programme at a certain time.

BBC Sport Ontology class *Competition* is another example of subclass of `event:Event`. "Competition" here means "a competitive sporting event". Interesting feature of this ontology is that an event of this kind "usually appears as an occurrence of a recurring competition"[23], such as "Summer Olympics". For this purpose there is a class called *RecurringCompetition* which is not itself subclass of `event:Event`, but its instances could be viewed as "event universals" if we wanted to admit such entities.

Taxon Concept Ontology defines *Identification* and *Occurrence* [of a specimen] and also several properties with these classes in their domain (but without stating their subproperty relationship to the properties from the Event Ontology), e.g. `identifiedBy`, `occurrenceHasIndividual`, `occurrenceInContinent` or `occurrenceInCounty`[24]

[21] Along with *PublicationStartEvent* and *PublicationEndEvent*

[22] See `http://tomhanzal.github.io/owl-modeling-styles/`.

[23] According to the `rdfs:comment` of the class.

[24] The last two cited properties seem to be intended as subproperties of `event:place`. But it might be better if they were properties of the place of the event, not the event itself.

These examples demonstrate that several different things are called *events*; and not just called – in consequence of using the Event Ontology they are subsumed under a common class.

They include structural components of temporal entities like audio recordings (point, segment), there are "social" events that are organized by people (conference, workshop, festival, performance, sporting competition etc.), there are *actions*, i.e. "somebody did something" (like marriage[25], publication, composition, broadcast, identification etc.) and also events in the sense that "something happened" (e.g. birth, death, occurrence).

4.5 Mapping between ontologies

Some ontologies for modeling events contain statements about equivalences or similarities between their *Event* classes and classes from other ontologies. To find examples of such statements we used again the SPARQL endpoint of Linked Open Vocabularies. We were looking for classes called "Event" that are connected to other classes with certain predicates indicating desired relations. The selected results are shown in the table below.[26]

[25] In a different sense, marriage can also be a social event.

[26] Obtained from the LOV SPARQL endpoint (`http://lov.okfn.org/dataset/lov/sparql` [September 2015]) using the following query:

PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX skos: <http://www.w3.org/2004/02/skos/core#>
PREFIX event: <http://purl.org/NET/c4dm/event.owl#>
PREFIX sem: <http://semanticweb.cs.vu.nl/2009/11/sem/>
PREFIX lode: <http://linkedevents.org/ontology/>
PREFIX edm: <http://www.europeana.eu/schemas/edm/>
PREFIX dbo: <http://dbpedia.org/ontology/>
SELECT ?c1 ?p ?c2 { GRAPH ?graph {
?c1 ?p ?c2 .
?c1 a owl:Class .
FILTER regex(str(?c1), "Event")
FILTER (isIRI(?c2))
FILTER (?p = owl:equivalentClass || ?p = skos:closeMatch || ?p = skos:broadMatch)}}

Class 1		Class 2
dbo:Event	EC	http://schema.org/Event
dbo:SportsEvent	EC	http://schema.org/SportsEvent
edm:Event	EC	http://www.cidoc-crm.org/rdfs/cidoc-crm#E4.Period
edm:Event	EC	http://purl.org/vocab/frbr/core#Event
edm:Event	EC	http://metadata.net/harmony/abc#Temporality
lode:Event	EC	event:Event
lode:Event	EC	http://www.loa-cnr.it/ontologies/DUL.owl#Event
sem:Event	CM	http://www.loa-cnr.it/ontologies/DOLCE-Lite.owl#perdurant
sem:Event	CM	http://sw.opencyc.org/2009/04/07/concept/en/Situation
sem:Event	CM	http://purl.org/dc/dcmitype/Event
sem:Event	CM	http://www.ontologyportal.org/translations/SUMO.owl.txt#Process
sem:Event	BM	event:Event
sem:Event	BM	lode:Event

EC = `owl:equivalentClass`

CM = `skos:closeMatch`

BM = `skos:broadMatch`

We can see that the event class defined by the BDpedia ontology is said to be equivalent with the event class from schema.org. This actually cannot be the case because the first evidently subsumes more than the second class; its subclasses include *LifeCycleEvent* and *NaturalEvent*, which do not fit the definition of event in schema.org.

The event class from *Europeana Data Model*[27] is equal with the class *Period* from CIDOC-CRM (and, surprisingly, not with the class *Event* from the same ontology even though the textual definition of the EDM event class implies this) on the one hand and with FRBR event class "whose members are an action or occurrence"[28] on the other. This effectively equals a class of historical periods with a class of "actions or occurrences". This could possibly lead to inconsistencies.

Further, we can see here equivalence between event classes of the Event Ontology and LODE. As we've seen, LODE is focused on historical events, while the notion of event in the Event ontology is more general. Therefore these classes probably *shouldn't* be said to be equivalent (as there arguably can be instances of `event:Event` which are not instances of

[27] `http://pro.europeana.eu/page/edm-documentation`

[28] `http://vocab.org/frbr/core.html#Event`

`lode:Event`). There is also stated a *broad match* between the SEM event class and both of these two event classes.

Especially interesting are the "close matches" of `sem:Event`. One is with the DOLCE class *perdurant* (see above, section 3.2). As we have seen, in DOLCE this class subsumes also a class called "event" but it has a narrower meaning than "event" in some of the discussed ontologies, presumably including SEM. Another close match is with *situation* from OpenCyc, which have "notable specializations": *Event* and *StaticSituation*.[29] This shows us that the notion of event in SEM encompasses both events and situations, which can, but don't have to, be taken as different concepts (see page 19).

4.6 Events vs. situations in Semantic Publishing and Referencing (SPAR)

To further illustrate the principles and concepts discussed above (in chapters about philosophy of events and foundational ontologies) we may look at examples of ontologies which use notions of both situations and events. Two such ontologies are *Publishing Status Ontology* (PSO) and *Publishing Workflow Ontology* (PWO), which are members of a suite of ontologies entitled *Semantic Publishing and Referencing* (SPAR), that focuses on various aspects of semantic publishing.[30]

SPAR consists of eight ontologies written in OWL 2 DL which import various *ontology design patterns*.[31] Both PSO and PWO use (among others) the *Time-indexed situation* pattern (see above, section 4.2.3) which introduces the notion of *situation*, and *Participation* pattern which introduces the notion of *event*. We have argued that the Time-indexed situation pattern corresponds structurally to the Event ontology (and similar ontologies) and therefore could be used to model the same "real-world facts". But we also know that in some cases there *is* a distinction between situations and events (see page 19 and section 3.3). So if these ontologies import design patterns containing both of these notions, there ought to be a relevant distinction between them. Otherwise this would be, if not outright faulty modeling, a mess. Let's now take a look at these ontologies to see how the notions of events and situations are incorporated into them.

[29] `http://sw.opencyc.org/2009/04/07/concept/en/Situation`
[30] `http://sempublishing.sourceforge.net`
[31] `http://ontologydesignpatterns.org/`

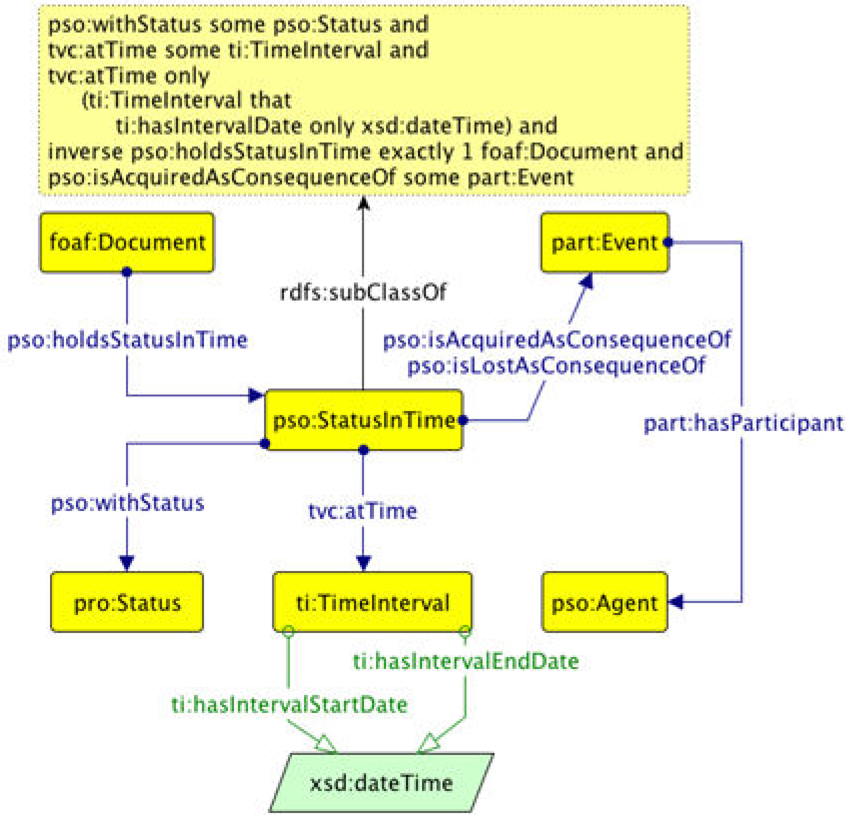

Figure 4.4: The Publishing Status Ontology. Source: `http://purl.org/spar/pso`

4.6.1 PSO

```
@prefix pso:  <http://purl.org/spar/pso/>.
@prefix ti:   <http://www.ontologydesignpatterns.org/cp/owl/timeinterval.owl#>.
@prefix tvc:  <http://www.essepuntato.it/2012/04/tvc/>.
@prefix part: <http://www.ontologydesignpatterns.org/cp/owl/participation.owl#>.
```

The Publishing Status Ontology "is an ontology for describing the status held by a bibliographic document or other publication entity at each of the various stages in the publishing process."[32] The key notions for describing these stages are *status* of a document *in time* and *event* which changes the status. The mentioned Time-indexed situation pattern isn't imported directly, but it serves as a foundation for the *Time-indexed Value in Context* pattern which is

[32] `http://purl.org/spar/pso`

here used. The *status in time* is a "value" valid at a certain time interval and therefore a kind of "situation". The notion of event is introduced by the Participation pattern (which basically talks about events and objects which *participate* in them). Between the status in time (i.e. the situation) and the event is a relationship described as `pso:isAcquiredAsConsequenceOf` or `pso:isLostAsConsequenceOf`. This reminds us of the logic we have seen in UFO-B: an *event* "brings about" a *situation*. There are of course differences. These "statuses in time" doesn't seem to "trigger" events by themselves. And they are extended over time intervals while the situations in UFO-B seem to be instantaneous (see above, section 3.3).

This leads us to another concern which are the temporal properties of the entities in question. The status in time obtains at a time interval which is modeled using the Time interval pattern (as we can see in the figure 4.4). The event on the other hand doesn't have its time specified. It of course happened at some time, but the ontology doesn't specify it; and from the ontology alone we just cannot infer that the event occurred at some time. We can infer this if we take into account our general notion of events which (presumably) says that every *particular* event must happen at some time. Then we can even infer the time of an event from the time of the status connected with it. For example if we know that a document was *in press* from January to March, that John put it in press, and that the situation of its being in press was "acquired as a consequence of" John's putting it in press, we can determine that he put it in press in January. But it would still be arguably better for the ontology to specify the time of the event.

4.6.2 PWO

```
@prefix pwo:   <http://purl.org/spar/pwo/>.
```

The Publishing Workflow Ontology "is an ontology for describing the workflow associated with the publication of a document."[33] At the heart of this ontology (see figure 4.5) lies a *workflow* which consists of *steps*. These steps involve *actions*. Now, what are these actions? According to the textual description, they are *events* (which coincides also with the common assumption that actions are a kind of events). But if we look at *action*'s super-classes defined in the ontology we can see that they include both event from the Participation pattern *and* Time-indexed situation from the corresponding pattern.

So, while in PSO there is a distinction between events and situations (exemplified as "values in time"), in PWO the are *actions* which are said (in consequence of using certain

[33]`http://purl.org/spar/pwo`. We worked with version 2.2 from 18/06/2015.

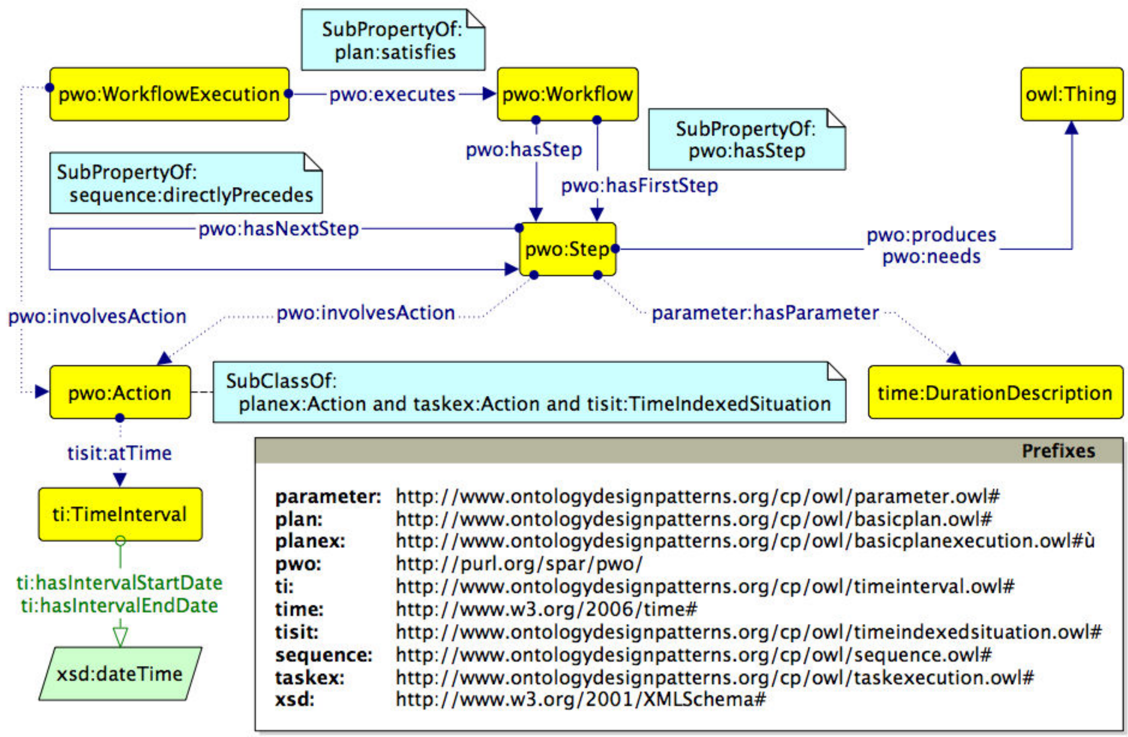

Figure 4.5: The Publishing Workflow Ontology. Source: `http://purl.org/spar/pwo`

ontology design patterns) to be events and situations at the same time, which is very difficult to make sense of.

4.7 The Stories Ontology

```
@prefix stories: <http://contextus.net/stories>.
```

The *Stories Ontology*[34] was developed by Michael O. Jewell, Paul Rissen and Toby Harris in collaboration with BBC. It uses previously mentioned *Event* and *Timeline* ontologies.

The primary class of this ontology is *Story*. A story is here basically understood as an *ordered list of events*; not necessarily temporally ordered but rather in the order of telling the story, for example in a TV series episode.[35] The ontology allows also for sub-stories, description of individual views of the events (using the *Interpretation* and *Assertion* classes), stating *subject*s of the story and indication by which "item" is the story told (TV programme, book etc.).

The web page of the ontology provides the following example of an episode of *Doctor Who* (adapted and shortened):

```
@prefix stories: <http://contextus.net/stories>.
@prefix event:   <http://purl.org/NET/c4dm/event.owl#>.
@prefix olo:     <http://purl.org/ontology/olo/core#>.
@prefix dcterms: <http://purl.org/dc/terms/>.
@prefix tl:      <http://purl.org/NET/c4dm/timeline.owl#>.

:world_war_ii { :s01e09_ev12 dcterms:subject
    <http://dbpedia.org/resource/Category:World_War_II>. }

<http://www.bbc.co.uk/programmes/b0074ds9#programme> stories:tells :s01e09.

:s01e09 a stories:Story;
    dcterms:subject <http://dbpedia.org/resource/Category:World_War_II>;
    stories:events :s01e09_events;
    stories:contextualises :s01e09_int12.
```

[34] http://www.contextus.net/stories/

[35] The *Ordered List Ontology* (http://smiy.sourceforge.net/olo/spec/orderedlistontology.html) is used for representing the list.

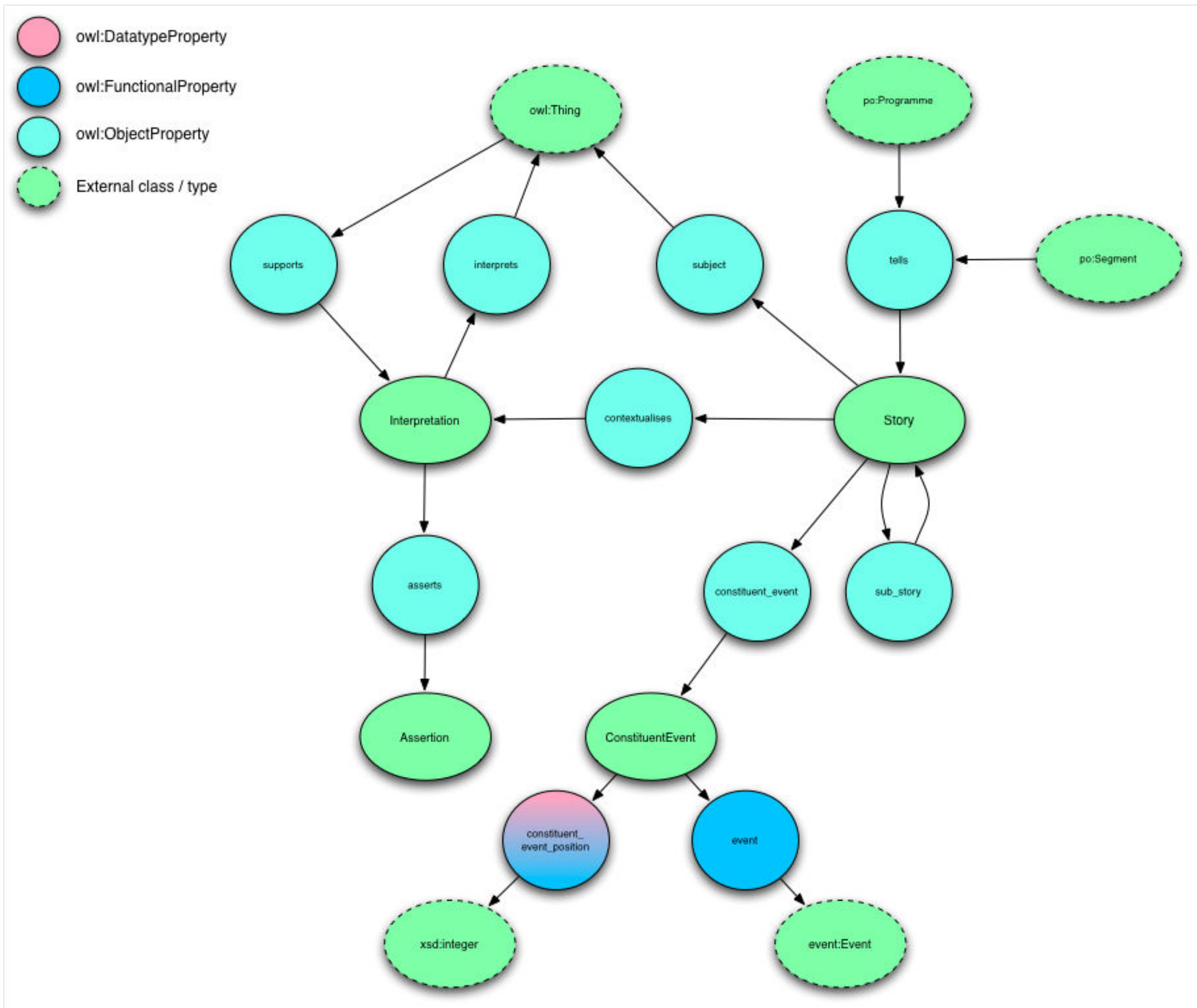

Figure 4.6: The Stories Ontology. Source: `http://www.contextus.net/stories/` (This diagram actually doesn't exactly correspond to the specifications and the example cited and should be therefore taken as an approximation only.)

```
# Event list
:s01e09_events a stories:EventList;
    stories:slot [
        olo:index 1;
        stories:item :s01e09_ev1 ];
    stories:slot [
        olo:index 2;
        stories:item :s01e09_ev2 ];
    # ...
    stories:slot [
        olo:index 12;
        stories:item :s01e09_ev12 ];
    # ...

# Events
:s01e09_ev1 a event:Event;
    event:place :space;
    event:factor :tardis;
    event:time [ tl:before :s01e09_ev2 ].
:s01e09_ev2 a event:Event;
    event:place :tardis;
    event:agent :doctor;
    event:agent :rose_tyler;
    event:time [ tl:after :s01e09_ev1; tl:before :s01e09_ev3 ].
# ...
:s01e09_ev12 a event:Event;
    event:place :drinking_den;
    event:agent :doctor;
    event:time [ tl:after :s01e09_ev11; tl:before :s01e09_ev13 ].

# Interpretations
:s01e09_int12 a stories:Interpretation;
    stories:interprets :s01e09_ev12;
    stories:asserts [ stories:facts :world_war_ii ].
```

This example tells us that a particular BBC programme tells a *story* which consists of several *events*. These events are formally ordered in *slots* with index numbers of an *event list*. The index numbers indicate the order of the events in the context of the story, which is not necessarily their temporal order (although in this example we can see that the individual events have time specified using the *Timeline ontology* properties `before` and `after` in the same order as they appear in the story). The events are modeled using the Event ontology in the way we are already acquainted with. That means that apart from time there are also places, agents and factors defined. So we know where, when, involving who and what something happened (the only thing we cannot tell is, unluckily, *what* happened).

Another thing taken into account in the example is an *interpretation*. We can see that the story *contextualises* the interpretation, while it, in turn, *interprets* one of the events of the story and *asserts* an (unnamed) assertion, which consist of *facts* contained in a separate graph (`:world_war_ii`). Namely that the event has World War II as its *subject*. In other words: According to this particular interpretation, the "subject" of "event 12" is World War II.

4.7.1 Stories vs. events with sub-events

As we have seen, events as they are perceived in the Event Ontology can have *sub-events* as their parts. That suggest that we could possibly model a "story" using the Event Ontology as an event with sub-events that would correspond to the story's constituent events. This implies the question what are the differences between modeling a story using the Stories ontology and using the Event ontology as an event with sub-events. Because if there weren't any essential differences, we wouldn't need the Stories ontology.

First of all, there is an obvious difference at the level of the structure of the model. Events in a story are organized in *slots* of an ordered list while sub-events of an event lack such ordering; the Event Ontology cannot express it. The sub-events can be obviously ordered on a *timeline* but that applies to the events in the story too, of course. As we've already pointed out, in the Stories Ontology these two orders are independent. The Stories ontology therefore allows us to say more, to express facts such as: "In the story (as told by this book/TV programme etc.), the events were presented in such-and-such order."

The Event Ontology's documentation also says about the property `sub_event` the following:[36]

> This property provides a way to split a complex event (for example, a performance involving several musicians) into simpler ones (one event per musician).

[36] `http://motools.sourceforge.net/event/event.html#term_sub_event`

That implies that the property is not meant (at least not primarily) to point out temporal *parts* of an events, but rather its "structural" parts.

4.8 Summary

We have described a few ontologies for modeling events that generally share the basic structure (although they differ in certain details – certain things are modeled using different "modeling styles"). What is always central is the class of *events* whose instances have time properties and are connected to other entities – place, agents etc. using dedicated properties. In some cases there are additions to this basic model, for example modeling of different views (SEM).

At first sight, this structure seems to copy the structure of Davidson's analysis of action sentences (see section 2.3), i.e. it speaks about events as entities which can be quantified over and about which many different things can be said (in predicate logic, or, in this case, in RDF/OWL). But the views of at least some of the authors of the discussed ontologies concerning the ontological status of events differ from Davidson's. While Davidson argues that there are good enough reasons to admit events as entities, authors of the Event Ontology and LODE see them as "reified events", "the way by which cognitive agents classify arbitrary time/space regions" or "temporal and spatial boundaries subjectively imposed on the flux of reality or imagination". That means they don't count events as "real" entities, like physical objects, along with *space* and *time*. So, the foreground model of e.g. the Event Ontology is practically the same as would be a semantic web ontology for events based on Davidson's account of events although the ontological considerations are quite different; there are differences *in the background* (Davidson wouldn't probably say that, for example, *Shem's kick* – see above – is an "arbitrary time/space region"). The question now is: does it matter? Are these "background" ontological considerations relevant for modeling on the semantic web, or, on the contrary, is it so that we can say, along with Quine, "Save the structure and you save all" [18, p. 8]?

We have already argued that for example the Time-indexed situation pattern can be used to model the same facts as the Event Ontology because it has the same structure and (more or less) equivalent means for expressing the relevant relations. The difference is that we talk about *situations* instead of events but we effectively *refer to the same entities* (if the reader permits me such an expression, for now). It is not a problem as long as we don't need to distinguish between events and situations (and we have seen that many philosophical conceptions do not use or need this distinction). But if we deny "substantiality" to events and talk about "reified" events, like the authors of the Event Ontology, we effectively approximate events to *reified relationships*.[37] That could even mean that we believe that events are actually *relationships* between things, places and times and they are reified in the OWL ontologies in the same way as any n-ary relations. And that the class `event:Event` is just a class of a special kind of reified relations. This is actually no problem for the modeling, as long as the arity of these relations remains indeterminate (otherwise we would encounter the very same difficulties Davidson wanted to remove with his analysis). Of course, we should treat various event and situation classes as equivalent, if they both are relations between people, things and places that have time coordinates and therefore there is nothing to distinguish between them.

So, what *does it mean* to call something on the semantic web for example `a event:Event`? There are actually no relevant OWL restrictions defined in the Event Ontology to help us with this, so we have to work with the textual definition we have already quoted:

> An arbitrary classification of a space/time region, by a cognitive agent. An event may have actively participating agents, passive factors, products, and a location in space/time.

None of the things an event "may have" is explicitly made obligatory but we can infer that it *must* have location in space and time (at least implicitly) because it is, according to the definition, a "space/time region". The definition implies that the "place" of events isn't in ontology (in the philosophical sense) but in epistemology. But it goes even further: it says that the classification of something (to be exact: some "space/time region") as an event is *arbitrary*. It depends, of course, on how we understand the notion of "arbitrariness". If we understand is as in the sentence "it *could* be just as well some other way", like if we say, for example, that dogs could be called "cats" instead and therefore the connection of the word "dog" with dogs is arbitrary. If it was meant in this way in the definition of `event:Event`, we can agree that classification of something as an event is arbitrary. But it doesn't seem that the classification of "space/time regions" (or anything else) as *objects* is any less arbitrary; calling *this* a house is arbitrary because we could just as well classify *it*[38] as an aggregate of "parts of wall", a roof etc.

If the arbitrariness is to be understood in the way that individuals arbitrarily classify something as events but the classification of objects is not arbitrary (and I think that this was meant by the definition), then the definition seems to conflict with our common-sense notion

[37] More than binary relationships have to be reified in the RDF/OWL ontologies because of the basic form of triples.

[38] What is it before classification?

of events. That we classify "something" as a death, a walk or a wedding is not somebody's caprice. It reflects the "fact" that somebody died, somebody took a walk etc. So, although the definition of `event:Event` can be said to make sense, it can hardly be understood as a definition of what we usually understand events to be.

The reason for undertaking this scrutiny is that, as we have seen above, a lot of ontologies specialize the Event Ontology by defining subclasses of `event:Event`. And we suppose that when some ontology uses the notion of event from the Event Ontology, *it agrees with its definition of events*. The question now would be if the authors of all the mentioned ontologies really agree that performances, births, publication etc. are "arbitrarily classified space/time regions". Maybe it is not just the structure and names what we should take into account when reusing semantic web ontologies. The meaning of the terms which goes beyond RDF and OWL is an important factor too. And maybe some ontology for events that would admit that events are something real and not wholly arbitrary would be useful for modeling on the semantic web.

One thing that we cannot tell using only the Event Ontology (or other similar ontologies we were describing) is *what happened*, what kind of action was it that somebody did etc. The arguably most intuitive solution to this is to introduce subclasses of the event class. We have seen examples of those in the ontologies *specializing* the Event Ontology. So, when preparing a dataset from a certain subject field we can use these subclasses of events. The "kinds of events" (as we've tentatively entitled them) are of course universal, and therefore it seems appropriate to define them in the ontologies. But there is also another way to model the kinds of events; the SEM ontology (section 4.2.1) defines them as instances of a separate class called *EventType*.

In our survey of the ontologies specializing the Event Ontology, we came to a conclusion that there are classes of many different "things" subsumed under a common class of "events", which effectively creates a relatively flat hierarchy which would be difficult to make sense of. The solution would be to create another level between the class of all events and these more particular classes. There are of course such hierarchies under *occurrents* or *perdurants* in the foundational ontologies. What we have in mind is however something more comprehensible and therefore (more) suitable for use on the semantic web.

A very tentative classification of kinds of events that we have briefly suggested above would look roughly like this:

1. actions,

2. happenings (in the sense that "something happened"),
3. "social"/planned "events" and
4. "structural components of temporal entities".[39]

This classification differs from those offered by the foundational ontologies in that it is not drawn from *a priori* metaphysical distinctions but it springs from an empirical survey concerning what we usually call "events", especially on the semantic web. This is also the reason why it cannot be taken as a finalized system to which nothing can be added. There are of course also "metaphysical" considerations behind distinguishing these "kinds of events" but they are more or less implicit, left "in the background".

One more topic I'd like to cover in this summary is that of *universal events*. We have already encountered this topic, first in the chapter about philosophy of events (section 2.6) and then again in this chapter. BBC Sport Ontology has a class of "recurring competitions", which are not themselves *events* but are connected by a dedicated property to particular events (for example *Summer Olympics* are a recurring event with a particular associated event *Olympics 2012*). In this case, the universal event is modeled as an instance of a class independent on the class of particular events. But the various subclasses of `event:Event` we were talking about can be understood as representing universal events as well. For example a birth is a universal event which has births of particular people for its ocurrences. But if we take the example of "my dropping of a saucer of mud" (see the referenced section), we can see that this universal event is more determined (and therefore less general) than birth; it can have various times and places but has already determined the "who" and "what". To express such universal events in the Event Ontology, for example, would be a problem – we would have to either model them as classes which would be problematic in several aspects, or as instances but then we couldn't tell, if they are universals or particulars.

So, the need of modeling both particular and universal (repeated) events is another thing that should be addressed when developing a more appropriate general semantic web ontology for events. (This section can be taken as notes for such a development while keeping in mind that it doesn't cover all the issues that should be taken into account.)

[39] This type was inspired by the Audio Features Ontology (see above) which has a common creator with the Event Ontology (Yves Raimond) and the subclasses of `event:Event` it defines are closer to and, interestingly enough, in a sense also more far away from the definition of events offered by the Event Ontology. They are maybe more *arbitrarily* classified than the other kinds of events but they are not spatio-temporal regions, just temporal.

Chapter 5

Events in PURO

5.1 PURO overview

PURO [22] is a language for creating *ontological background models* (OBM). The idea is that there can be the same facts expressed in different ways (using different "modeling styles") in the *foreground* model (typically in OWL) and therefore there can be some use for a language that expresses them unequivocally; one background model in PURO can correspond to several different foreground models in OWL.

PURO is not a language for use directly in data representation or applications but rather a tool for ontological engineers that can serve for creating background models (or model fragments) from which several different foreground models (for different use-cases) in OWL can subsequently be generated. Another possible use of PURO OBMs is comparing existing ontologies, their modeling styles and expressivity. The background models in PURO can be designed either "from scratch" (actually from description of the target domain and some, often implicit, metaphysical considerations), or as a model of the "ontological background" of an existing ontology (or a set of ontologies).

The acronym "PURO" signifies the two basic distinctions incorporated into the language: *Particular* vs. *Universal* and *Relationship* vs. *Object*. There is actually a third possibility added to the relationship/object distinction – a *valuation* which is an assignment of a quantitative value to an individual. The combination of these two distinctions determines the six basic PURO terms:[1]

- $\mathcal{B}$-object (particular object),
- $\mathcal{B}$-type ("universal object", i.e. type of objects; there are also types of types),

[1] The "$\mathcal{B}$" stands for "background".

- $\mathcal{B}$-relationship (particular relationship),
- $\mathcal{B}$-relation (type of relationships),
- $\mathcal{B}$-valuation (particular assertion of quantitative value) and
- $\mathcal{B}$-attribute (type of valuations).

A PURO OBM is composed of instances of these six primitives and relationships *subTypeOf* and *instanceOf*.

PURO is in many ways similar to OWL. It can roughly be said that $\mathcal{B}$-object corresponds to OWL individual, $\mathcal{B}$-type to class and $\mathcal{B}$-relation to property. But there are differences that allow PURO to abstract from modeling style choices that are necessary in OWL. PURO allows for higher-order classes and, as it is not limited by the data model of RDF, does not have the arity of relationships limited to two.

5.2 OBM for events

Whether we want to design PURO OBM for events from scratch or from existing ontologies, we need to make clear to ourselves what "event" means for us. Particularly, there is a fundamental question *whether events in general* (i.e. everything we call "events" in natural language *and* in semantic web ontologies) *can and should be treated either as B-objects or B-relationships.*[2] When trying to answer this question, we should consider whether we can make a general (domain-agnostic) OBM for events (and whether it would be useful). Such general OBM presupposes a coherent notion of event applicable on anything that anybody calls an "event". But is the "class" of everything we call "event" really so coherent that we could make a universal background-modeling decision in favour of one of these options? It might be the case that it would be better to distinguish between two or more "kinds of events" (e.g. in the way we indicated in section 4.8). Some "events" might be better understood as relationships, some as "objects". Let's consider this for a moment.

It has already been stated that the distinction between $\mathcal{B}$-relationships and $\mathcal{B}$-objects is not always sharp:

> The boundary between relationships and objects may not be as sharp in some situations. Due to absence of n-ary relations, LD vocabularies often feature reifying individuals, e.g., the instances of mo:Composition in MO (relation between

[2] We are again speaking primarily about *particular* events. If we had in mind events as universals, we would of course classify them as background universals but the second distinction would still be open: $\mathcal{B}$-type or $\mathcal{B}$-relation?

> musical work, its composer, place, and time) or gr:Offering in GR (relation between a seller, offered items, eligible regions, etc.). Such objects can be viewed as B-relationships but often also as regular B-objects — the event of composition, an abstract information record. The distinction is often a modeling decision (even at the background level) and it should be based on the criterion whether the (reifying) object would be meaningful even without explicitly considering the other participants in the relationship. In these terms, a composition event is clearly incomplete without knowing what was composed, similarly a business offering is incomplete without knowing the seller or the items offered.[22, p. 10]

(The case with `mo:Composition` is similar to that with *PublicationEvent* in the aforementioned British Library vocabulary, which we have analyzed as a B-relationship too.)

Could be everything we call an "event" taken as an n-ary relationship in this sense? Composition of a musical piece or publication of a book can. What about the other examples of kinds of events (subclasses of `event:Event`) gathered above? Personal events like birth or marriage arguably can, occurrence of a specimen of a given taxon too. But what about events like conferences, festivals etc.? Here we feel a difference. When talking about publication of a book or a marriage (as a personal event, like it's probably meant in the BIO vocabulary), we can easily reformulate our sentences in such a way to avoid talking about "reified" events and thus we have no problem modeling the fact as a relationship. For example: "John and Mary's marriage took place at 11 o'clock." can be transformed into "John married Mary at 11 o'clock." It is hard to imagine something similar when talking about conferences or festivals. But why? Are these "events" qualitatively different, or is there just a difference in degree? Is it so that if we feel this difference, we should just do a modeling decision, and in consequence model (in the ontological background) e.g. the marriage as an *n-ary relation* between Mary, John and the time (and maybe also place) of the marriage but the conference or festival as an *object*? If we used the criterion proposed in the quotation above ("whether the [...] object would be meaningful even without explicitly considering the other participants in the relationship"), the result would be similar.

The marriage in this example was meant as a personal event between two people. But marriages are also (planned) social events with many participants. If we take it in this way, they may be more like a festival. What if we apply our tentative criteria for distinguishing between *events as relationships* and *events as objects*? Can we still talk about the marriage without mentioning it as an event and come up with an n-ary relation that would encompass all the relevant features of it? Depends on what features we call relevant. What about "John married Mary at 11 o'clock at the church, Jenny, Bob and thirty other people attended and there was a delicious cake"? We still don't have to say explicitly that there was a marriage. But if we add more participants and factors, we will probably reach a point where such a linguistic representation would not be possible and we will have to talk about the marriage as an entity, like in the case of festivals and conferences. And also, we simply talk about marriages (in this sense) on a daily basis (at least some of us). So if there is a reification, it is not at the level of representation in a semantic web model.

But is there really a need to treat some events as objects from the beginning? "The conference took place last week." Yes, but couldn't we say: "Last week, John talked and Mary listened. Then Mary talked and John listened" and so on? True, maybe we miss the notion of "conference" a little bit more then the notion of "marriage" in the previous example. Even if it was possible to reduce the conference to such a description, there would still be need to refer to "it" as a whole. And maybe not *still* but rather *primarily.* In most semantic web use-cases it wouldn't arguably be very useful to perform such reductions. There is of course the problem of *granularity.* And there is also something else; that for example "Mary talked" is an event too. Is it also some kind of relationship? Shouldn't we reduce it to a complex of relationships too? Such method would probably lead to nonsense and certainly wouldn't be very useful. So there are definitely good reason to treat at least some events as objects.

The cited criterion of meaningfulness of talking about an event as an entity without mentioning its participants aims arguably in the same direction. Talking about the conference X without mentioning its participant or place seems like a thing we ordinarily do while talking about a publication of a book without referencing the book or its publisher would be odd.

From this, I think that we could infer that the distinction in the "nature" of the two considered "kinds of events" can be simply put in this way: Events like a publication of a book (and similarly a walk down the street etc.) are more specifically *actions*; someone did something (we can add: sometime, someplace, in some way etc.). Music festivals and conferences, on the other hand, are "events" in a more specific sense, in the sense of the event class in schema.org (as opposed to its general use in the Event Ontology and others). These "events" are "created" (put on, organized, planned etc.) by people, intentionally as events. (And they often have their proper names.)

Now, did we cover *all the events*? We were talking about planned events ($\mathcal{B}$-objects in PURO) and *actions* ($\mathcal{B}$-relationships). But we've seen in our analysis in the previous chapter that there's more. Even in our very tentative and *ad hoc* classification, there are four "kinds of events". Even if we put aside the "structural components of temporal entities" (it is not quite clear if these are events in the commonsensical way we are chiefly concerned about), there are still "happenings".

That *somebody did something* and that *something happened* seem to be grammatically very similar and could be arguably modeled in a similar way. The obvious difference is that in the first case there is an "active participant" (or *agent*, as in the terminology of the Event Ontology). But it seems, at least at first sight, that both can be modeled as relationships between objects, like, for example, in "x published y in z". Can this be generalized for other actions like "Mary talked" or "John walked" and happenings like "It rained"? Mary's talk and John's walk are *events* which are not really meaningful to talk about without mentioning their participants. That means that according to the quoted criterion we should model them as relationships. But relationship between what? Well, it is not said explicitly in the sentence "John walked", but it is obvious that he walked at some time and place. So, we could understand this "walk" as a relation between an "agent", place and time. If we now want to add how fast John walked, we need to change the relationship to one between an agent, time, place and a "mode of walking" (or something like that). This is precisely the problem Davidson was trying to solve by treating actions and events generally as "objects" in his analysis. "It rained." Is it a relationship between a time and a place? Or time, place and other things? If so, certainly a relationship of a specific type ("rain").

It is apparent from what we have discussed so far that we cannot simply construe an OBM for events in general. Even the distinction between two senses of "event" (as objects and as relationships) is not enough; it doesn't lead to two OBMs. The problem seems to be especially with events as relationships. We can say that in general all events apprehended in this way have time and place. Therefore they are relationships between a time, a place and some other things – but not necessarily (e.g. rain). Some have active participant, some passive, some both, some none. Some have participating objects, some not really. (In the rain, in a sense, the raindrops participate. Does it count? Why would we model it?). We cannot construe general OBM for actions because of the varying number and role of participants. We cannot construe *general* OBM for walks because there is always something we can add. One possibility is of course to constructs walks etc. as relationships with indeterminate arity, for example "3+". There is a person, a time, a place, and there might be more. This approach of course requires PURO to allow for relationships with indeterminate arity. There is also another possibility – to drop the distinction between (self-sufficient) event-objects and (dependent) event-relationships and follow Davidson in treating all events as objects.

There is however usually no need to construe such general models, because what the ontological engineers using PURO models typically intend to do is to design an ontology (or the core of an ontology) for a particular domain. Therefore there can be many PURO models that contain "events" in one way or another. It is even possible to re-use already designed PURO models and, for example, add new participants to events modeled as n-ary relationships. So the impossibility of creating a general model for *all kinds* of events does not undermine the usability of PURO. But it shows that even if we reconcile (using PURO) the modelling differences that we find in OWL ontologies, we are still not able to fully subdue the semantics of the wild semantic web.

5.3 PURO OBM fragment for the discussed ontologies

In the previous section, we have shown how problematic it is to try and construe a *general* ontology background model for events. It was also shown that even the construction of a background model isn't possible without some ontological considerations which have often not completely self-evident results. The difficulties of decisions between *relationships* and *objects* show this well. So it is understandable that what we will demonstrate in the remainder of this chapter will not be a background model to which all models of events could be reduced. What we can do is to develop an OBM fragment based on some of the previously discussed ontologies. But first a note on background-modeling of temporality which is of course an indispensable component of modeling events.

Temporality in PURO We have seen above (section 4.3) that time can also be modeled using various styles: datatype and object properties, "temporal entities" etc. The various ways of modeling should in principle be reducible to one common model in PURO. We will not occupy ourselves here with separate and more detailed analysis of the ontologies (although we will incorporate it partially into our example). But it is important to specify a universal way for PURO to model date and time. For our purposes, we will use a *valuation* which can be either a regular $\mathcal{B}$-valuation connected to an object, or a part of an n-ary relationship.

For purposes of generation of OWL fragments from PURO OBM it should be possible to specify different styles of modeling date and/or time. Therefore we will treat it for now as a valuation of a special kind.

5.3.1 The Event Ontology and SEM

Let's first state one more time the relevant prefixes:

```
@prefix event: <http://purl.org/NET/c4dm/event.owl#>.
@prefix sem:   <http://semanticweb.cs.vu.nl/2009/11/sem/>.
@prefix time:  <http://www.w3.org/2006/time#>.
@prefix geo:   <http://www.w3.org/2003/01/geo/wgs84_pos#>.
@prefix foaf:  <http://xmlns.com/foaf/0.1/>.
```

We already know we cannot make a PURO OBM for the Event Ontology in a straightforward way. If we observe that some "events" should be modeled in the background as objects and some as relationships and if we look at the various existing subclasses of `event:Event`, we can see that this cannot be reconciled in a single model. On the other hand, if we took seriously the textual definition of events in the Event Ontology (that we've cited repeatedly), we would model them all as relationships. We will now go for a compromise. In the OBM that should allow us to compare (at least) two ontologies we will model event as an object.

Diagrams of both ontologies in question (the Event Ontology and the Simple Event Model Ontology) can be seen in respective sections above. For our purposes here, we recreate them in a slightly different fashion, taking into account the instance level to allow better comparison with the PURO OBM. Please note that the diagrams do not represent all the elements and possibilities the two ontologies have. They illustrate their basic principles.

Both figures present a (very reductive) model of the battle of Waterloo. We can see that they correspond to each other in that they both have an event class (we've seen above there is a `skos:broadMatch` defined between these two event classes) and properties for time, place and agent/actor. We can also see that they differ in two things connected with the "modeling styles" which can be reconciled at the background level: modeling of date/time and modeling of types of events and agents (and other things not shown in these diagrams).

The Event Ontology is here used in conjunction with the OWL Time Ontology which uses a relatively complex style of modeling "temporal entities" and definitions of their components (year, month etc.). SEM, on the other hand, has its own datatype properties for whole timestamps (see section 4.3.3). It is however worth noticing that there is another `skos:broadMatch` defined between `sem:Time` and `time:TemporalEntity`.[3] The difference in modeling types of "entities" is also noticeable. In the Event Ontology they are modeled as classes, in SEM as instances of separate classes which are connected to their "instances" using dedicated object properties.

[3] See `http://semanticweb.cs.vu.nl/2009/11/sem/#sem:Time`

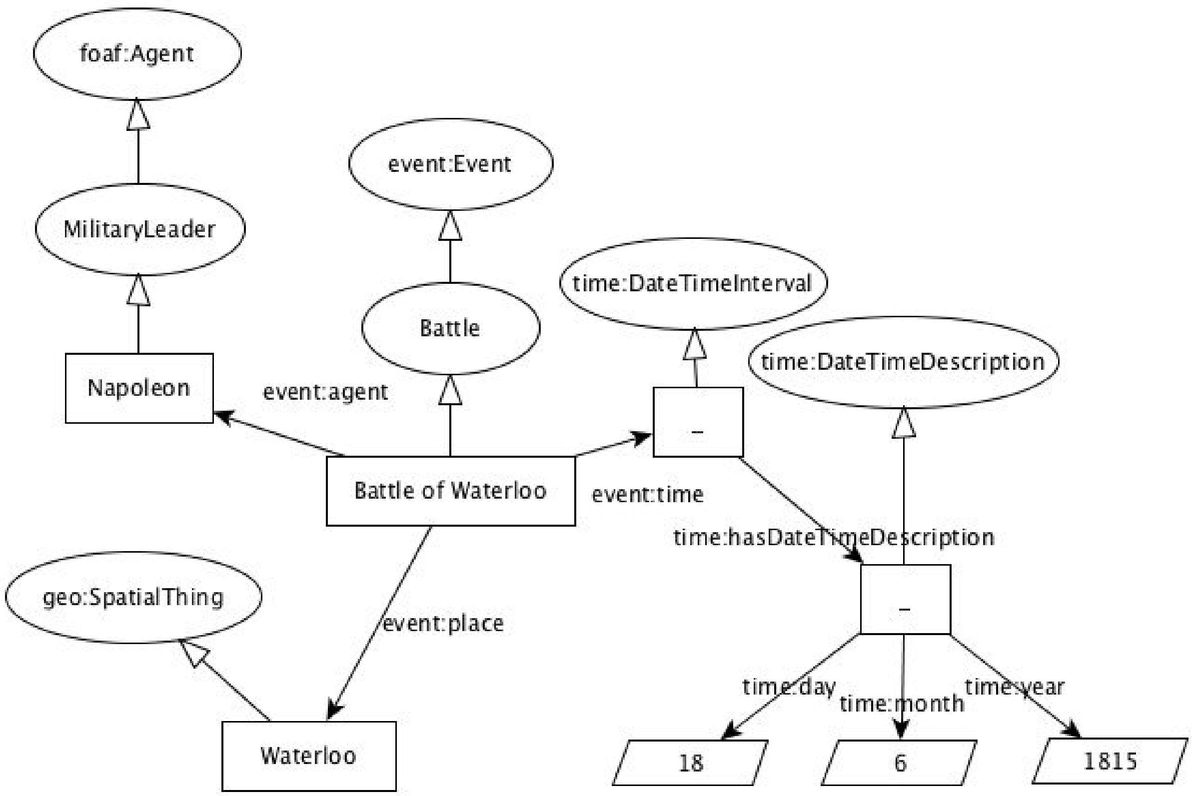

Figure 5.1: The Event Ontology

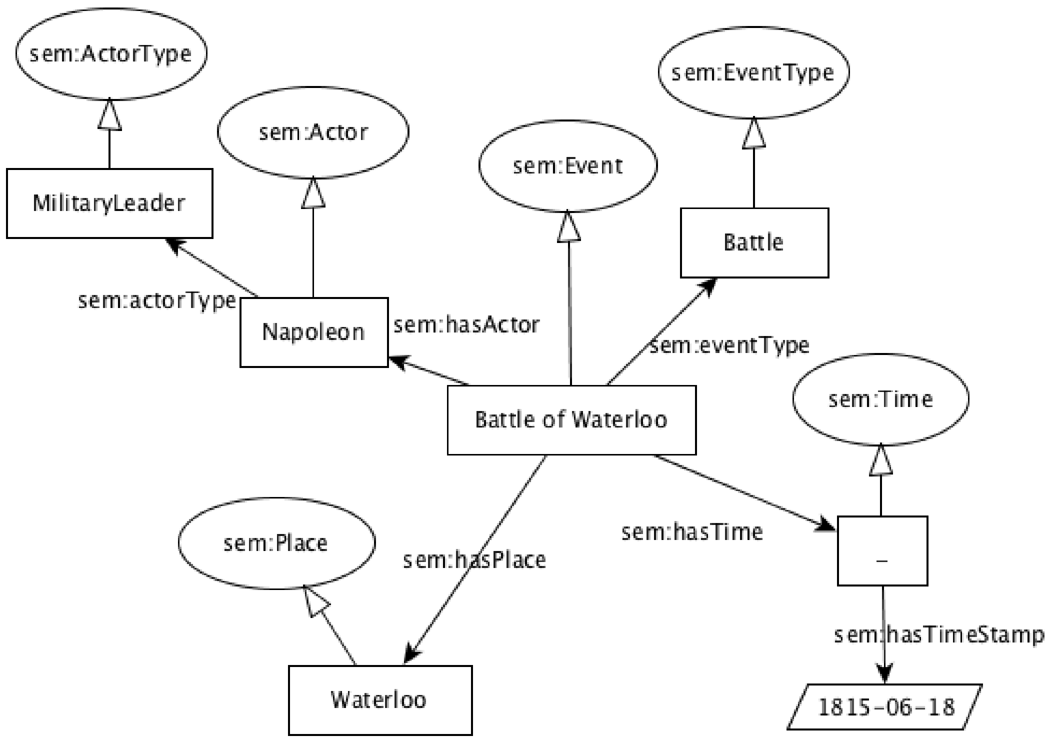

Figure 5.2: The Simple Event Model Ontology

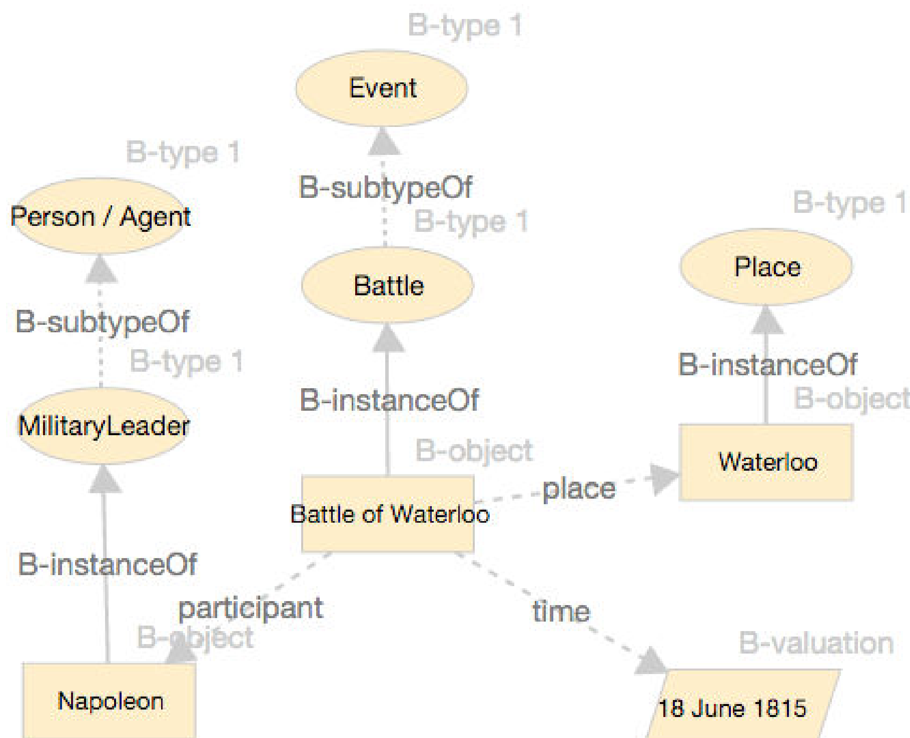

Figure 5.3: Example of a PURO OBM for events. Made using *PUROModeler*, an application by Marek Dudáš (`http://protegeserver.cz/puromodeler/`)

There are other things that each of these two ontologies can model and the other cannot. We have mentioned them in the corresponding sections above (e.g. the Event Ontology has properties *product* and *factor*; SEM, on the other hand, has the various constraints). Analysis of these differences would lead to another use-case of PURO models – making an OBM more general that each one of the compared ontologies and then highlighting for every ontology what part of the OBM in can describe (what is its "local coverage"). This approach was explored in [7].

From the OBM in figure 5.3 it is possible to generate foreground model fragments corresponding to both of the examples. The Event Ontology seems to be closer to the background model in the style of modeling types (using subclasses) but the alternative style used by SEM can be simply applied once we recognize that they model basically the same thing; which we did with the help of the PURO model. The time property is modeled extremely simply in the OBM. There is really no need for proliferation of some "temporal entities" in the background. What needs to be done is to recognize this temporal property in PURO as a special kind of valuation and prepare some patterns to transform it into foreground models with various modeling styles for various use-cases.[4]

Let's note again that what we have shown here is just a small example and that it cannot serve as a general ontology background model for *all kinds of events* because of the reasons discussed above. But such models can be useful for starting development of ontologies for particular domains. There are two things that should be paid attention to in PURO in connection with events:

1. Definitely resolving modeling temporality in PURO and its transformation to OWL variants.
2. Clarification what events in general are and connecting their types/kinds/subclasses to some general concept of event.

Problems with the second point are now probably clear. If there are both events as objects and events as relationships, we can hardly subordinate them under a common concept. And if we want to, say, subordinate under a common concept just all *event-objects*, we will need such concept which clearly cannot be defined in PURO models for particular domains as there

[4]The transformation from PURO OBM to OWL is done using *OBOWLMorph* (`http://lod2-dev.vse.cz/puromodeler-v2/OBOWLMorph/`). The patterns it currently uses can be found at `http://lod2-dev.vse.cz/puromodeler-v2/OBOWLMorph/patterns/`.

would be nothing that would connect the *event* classes defined in various ontologies except perhaps for their name but that does by no means ensure they are equivalent (cf. `event:Event` vs. `schema:Event`).

Conclusion

We have seen that events can be comprehended in different ways, not just in the “wilderness” of the semantic web but also in philosophy and foundational ontologies, which are directly based on philosophical considerations (unlike most of the semantic web vocabularies). We cannot definitively say what events in general are (besides definitions like “events are things that happen”). There are disputes over their ontological status; are they something (ontologically) inferior to objects, or are they equally important in our world and therefore should be admitted as entities too? We’ve seen that semantic web ontologies which explicitly comment their ontological assumptions do not treat events as something “real”; they usually work with a “commonsensical” ontology of physical objects. But it can be questioned whether events are for the common sense somehow less real or less clearly defined than physical objects.

Many things fall under the common notion of “events”. We have seen several different examples. On the semantic web the classifications of “kinds of events” are very wild and sloppy; in the foundational ontologies, on the other hand, they are thoroughly thought-out, defined using subtle distinctions, and in consequence generally unusable, especially for the semantic web. What would the semantic web arguably need would be something in between. It would need to make clear what we mean by saying that something is an event; to reduce the mess by defining more carefully the relationships between event (and “situation”) classes from various ontologies; to come up with a classification of events that would be meaningful and at the same time useful for the semantic web.

In the chapter about PURO, we have seen how the superficial differences in “modeling styles” can be reconciled by looking at the “ontological background”. But there are other things in the ontological background that cannot be reconciled so easily by examining the structure; namely the meaning of the notions that enter it. Calling something an “event” definitely means something but it may mean different things, especially on the semantic web. Overcoming these differences would have arguably useful consequences, e.g. for inferences or querying across datasets.

To sum up, we started with the observation that *events* are important in our perception of the world and in our descriptions of it, therefore also on the semantic web. There is however not one best way to model events, which is connected to the fact that even the question what events *are* can be approached in different ways. We also believe that there is more to semantics on the semantic web than just the structure of the ontologies and names of entities. That is why we started with philosophical conceptualizations of events and only after that moved to the semantic web ontologies, which we've analyzed in the light of those conceptualizations. We have shown some problems these ontologies have and indicated possible paths to their solution.

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