Representation of Event-Based Ontology Models: A Comparative Study

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Summary
Ontologies are knowledge containers in which information about a specified domain can be shared and reused. An event happens within a specific time and place and in which some actors engage and show specific action features. The fact is that several ontology models are based on events called Event-Based Models, where the event is an individual entity or concept connected with other entities to describe the underlying ontology because the event can be composed of spatiotemporal extents. However, current event-based ontologies are inadequate to bridge the gap between spatiotemporal extents and participants to describe a specific domain event. This paper reviews, describes and compares the existing event-based ontologies. The paper compares various ways of representing the events and how they have been modelled, constructed, and integrated with the ontologies. The primary criterion for comparison is based on the events' ability to represent spatial and temporal extent and the participants in the event.

Keywords:
Ontologies, Events, Event Ontologies, Spatial extent, Temporal extent

1. Introduction and Background

With the proliferation of the Semantic Web (SW), ontologies have grown more widespread and are regarded to be the backbone technology in most Knowledge-Based systems (KBs) [1]. In the areas of Information Technology and Artificial Intelligence, a widely acknowledged definition of ontology is that of Gruber [2], who defined ontology as *"a formal, explicit specification of a shared conceptualization*". Some researchers such as [3, 4] have agreed that this definition is more general and not specific because it is compatible with ontology usage as a set of concept definitions. Still, the ontology is beyond that, which is a specification used for making ontological commitments.

A technical analogy for ontologies is that they are knowledge containers that can be shared and reused about a specified domain. In other words, ontology represents knowledge as a set of concepts within a domain, and it uses shared terms to indicate the types, properties, and relationships of such concepts. It also offers a shared comprehension of a specific domain that facilitates communication between systems or between humans and a system [5]. Ontologies are the substrate of the Semantic Web, but it was beyond that and was used in several applications for different domains. Furthermore, ontologies play an essential role in facilitating information exchange in various fields, ranging from Artificial Intelligence areas like knowledge representation and natural language processing (NLP) to fields like information retrieval systems, requirements analysis, and, more recently, Semantic Web applications. [6].

Ontologies are ranked in terms of different classification approaches. Van Heijst et al. [7] have classified ontologies into two orthogonal dimensions: the amount and type of structure and the subject. Conversely, Guarino [8] has classified ontologies according to their level of dependence on a particular task, such as upper-level ontology, domain ontology, and application ontology. Lassila and McGuinness [9] have classified ontologies according to the information the ontology needs to express and the richness of its internal structure.

An upper ontology is a domain-independent ontology that can be used to generate additional domain-specific ontologies. In contrast, domain ontologies define ideas associated with a particular area of interest [10]. Hence, top-level ontology serves as a general foundation for a more elaborated ontology such as domain ontology. For this reason, usage of top-level ontology is essential as it facilitates reusability, interoperability, etc.[11]. The process of ontology development is regarded to be a complicated, tedious, expensive, and time-consuming task, and this task requires a well-designed methodology which discusses the processes and methods for ontology development [12]. One of the most important tasks in ontology development is to study the available ontology models to specify which upper-level ontology is to be reused to form a domain-specific ontology.

An event is something that happens within a specific time and place and in which some actors engage and show specific action features. Events have a critical role in representing data for various domains, including crime, history, multimedia, and geography. Due to its inherent complexity, event-centered modelling effectively captures a domain's dynamic characteristics. In addition, events serve as a natural method to explain complex relations between people, locations, actions, objects, and other entities.

The events are represented to answer the following three questions:

- When does the event take place (Location)?
- Where does the event take place (Time)?

Manuscript received July 5, 2022
Manuscript revised July 20, 2022
https://doi.org/10.22937/IJCSNS.2022.22.7.18

- Who participates in the event (Participant or Actor)?

Therefore, according to these questions, four core elements represent the event: spatial extent, temporal extent, participant, and sub-event, as shown in Fig. 1.
Event ontology is a type of event-oriented knowledge representation technique. It is a collaborative, formal, and explicit specification of a system model made up of various event classes [13]. According to Li et al. [14], there are three basic types of event-based ontology representation models, namely; i) Event ontology representation model based on the conceptual hierarchy of traditional ontology, ii) Event ontology representation model based on logical method, and iii) Event ontology representation model based on event elements.

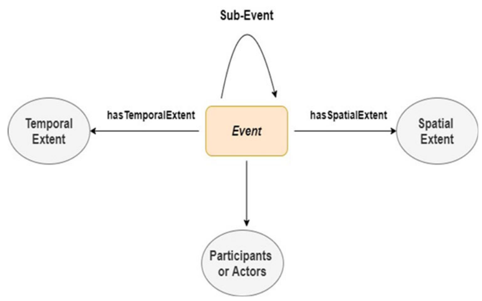

Fig. 1 Core elements of the event

In the last decades, many ontology models have been published for event modelling, so-called Event Ontologies [15-18]. They vary in their scope, domain specialization, size, and degree of formalization. Using event-based driven ontology models, it is highly useful to have a suite of well-crafted ontology created models accessible, which can be utilized for this purpose.

However, during several of our recent research activities, we discovered that the widely held concept of Event is not currently well-represented in the literature in general. These models do not adequately capture the concept of Event and are insufficient to bridge the gap between spatiotemporal ontological approaches to describing events such as crime. The purpose of this paper is to give a review of event-based ontologies. The study aims to analyze and compare the design choices of existing general-purpose ontology models for representing events. The remainder of this paper is organized as follows: **SECTION 2** describes the event-based ontology models and their applications, **SECTION 3** summarizes the results of this work, and finally, **SECTION 4** draws the conclusion.

2. Event-Based Ontologies

Although the existing event ontologies include classes and properties for representing events, they were developed to serve different purposes. However, the essential ideas in event definition and their relationships are still not articulated in these models for event process purposes in semantic-based systems[19]. Therefore, several existing ontologies that provide classes, properties, and relations used to model events and their relationships have been reviewed. Such models, purposes of the models, and their online URL are depicted in Table 1.

As shown in the table, existing general-purpose event ontologies are either designed to provide a very loosely defined upper-level ontology to which domain-specific ontologies can be linked, or they are focused on generating object hierarchies that are far more developed than event hierarchies. This section examines and analyses several RDFS+OWL models based on their main constituent properties, including the core event class and other related classes such as time, space, participation (active or passive), causality, and composition.

Table 1: Event Models

Ontology / Purposes	***Ontology URL***
The Event Ontology (EO) [18]. Digital Music	http://purl.org/NET/c4dm/event.owl#
Simple Event Model (SEM) [15]	https://semanticweb.cs.vu.nl/2009/11/sem/
Event-Model-F.[20]. event-based systems.	http://events.semanticmultimedia.org/ontology/2008/12/15/model
LODE [16]. events as Linked Data.	http://linkedevents.org/ontology/
OpenCyC Ontology [21]. Human Consensus Reality.	http://www.opencyc.org/
BBCCORE [17]. News	https://www.bbc.co.uk/ontologies/coreconcepts
SNaP Ontology. News and Press.	http://data.press.net/ontology/snap
ABC Ontology. Digital Libraries.	http://metadata.net/harmony/ABC/ABC.owl

2.1 The Event Ontology (EO):

The Centre for Digital Music at Queen Mary, University of London, developed the Event Ontology (EO) [18]. The work aimed to create an ontology model that could be used in the music domain in combination with other music-related ontology models [22, 23]. Yet, since this model was generic and nothing particular to the music domain, it may also be used in different domains.

This research mainly focuses on the music industry, which views the music production process as involving physical events that occur at a particular place and time, involving the participation of several physical objects, both animate and inanimate. As a result, the event ontology consists of the class event itself, and the class is connected with other external ontologies such as WGS84 Geo Positioning Ontology and W3C OWL Time Ontology.

EO was centered around reified events that define one central Event concept. This model used the straightforward event architecture, which consisted of a top-level class (eo: event). It was described as "an arbitrary classification of space/time region, by a cognitive agent". Herein, an event may include active participating agents, passive factors, products, and a spatial/temporal location.

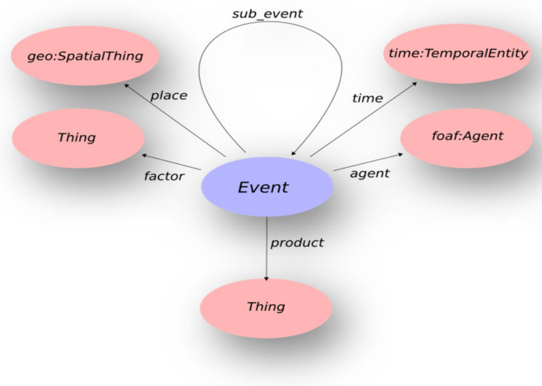

Fig 2. The Event Ontology (EO)

Fig 2 shows how the EO model represents an event, classes related to the event, and the properties that employed to involve the *Thing* classes in the event class:

a) ***Event*** *(Class:event:Event):* This class is the core class in this model, defined as an arbitrary classification of space/time region by a cognitive agent.
b) ***Product*** *(Class:event:Product):* This class represents everything an event produces. At the same time, the *event:product* property connects an event with something created during the event. The outcome is represented as an object event named event: Product.
c) ***Factor*** *(Class:event:Factor):* This class represents everything used as a factor in an event. The property *event:factor* establishes a connection between the event class and a passive factor. This implies that this property is used to give things for participation in the event and things that affect the event. Whereas the EO "does not distinguish between a thing's participation in an event and a thing's influence upon an event".

The EO does not define appropriate spatiotemporal extents; it uses the *geo:SptialThing* as a spatial component available from WGS84 Geo Positioning Ontology and the *time:TemporalEntity* as a temporal component available from W3C OWL Time Ontology. The EO uses W3C's Resources Description Framework (RDF) model, an open Web standard for data interchange, which can be spontaneously used as OWL files.

2.2 Simple Event Model (SEM) Ontology

A simple event model (SEM) ontology has been introduced by Van Hage et al. and Carnaz et al. [24, 25]. The SEM ontology was developed to represent events that occur in various application domains without making any assumptions about domain-specific vocabularies or implying any relationship to any domain.

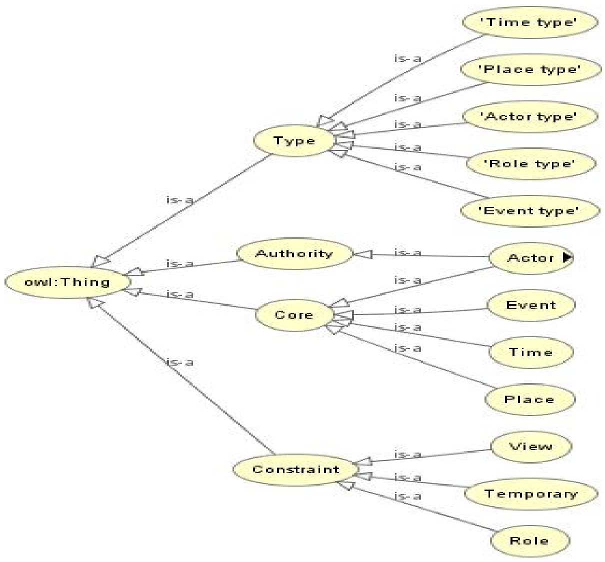

Fig 3. Simple Event Model Ontology (SEM)

As shown in Fig 3, SEM's classes are organized and split into three groups of classes, namely: core classes, type, and constraint. The class *sem:Core* is organized around four main classes: Events, Actors, Places, and Time.

i. ***Event*** *(Class:sem: Event): (To represent what happens*). This class is the core class in this model and is the central class where the ontology is based. Having as properties: eventProperty, eventType, hasSubEvent and SubEventOf.

ii. ***Actors*** *(Class:sem: Actor):* This class is to describe "who participated in the event, who is doing something". It is a powerful class and can actively or passively hold actors of a given event. In this context, actors are not seen only as active persons but also as objects, which are animate or inanimate and physical or not physical.

iii. ***Places*** *(Class: sem: Place):* This class is to describe "where" something is happening. Places are locations where an Event occurs.

iv. ***Time*** *(Class:sem: Time):* This class describes "when" something happens.

SEM's properties are also organized based on sem: event property, sem: type properties, and other sub-properties like *sem:accordingTo* and *sem:hasTimeStamp*. Moreover, the SEM project team paid great attention to time extent, considering it the most critical component of the ontology. They expressed the time stamp in seven attributes according to time intervals. SEM is modelled purely in RDF. Consequently, it contains vocabulary terms in the form of RDF-based classes. Carnaz et al. [25] have used SEM ontology to represent the crime events by the entities extracted from crime-related documents. They conclude that the SEM model can be used to represent the crime event and other events.

2.3 Event-Model-F:

The University of Koblenz-Landau in Germany has developed a formal model of events called Event-Model-F ontology [20]. This ontology was built on the DOLCE+DnS Ultralite (DUL) fundamental ontology, a lightweight upper ontology that serves as a foundation for domain-specific ontologies by enclosing them in well-analyzed essential concepts to provide full support for representing time and space, objects, and people. The model adds new properties and classes for modelling event participation and correlations between events. It also adds the capability to state that several models reflect alternative perspectives or interpretations of the same event.

The events in this model involve different types of information. It contains details about the objects involved, such as people or other non-living objects. Additionally, the time point of the event can be stored, which can be absolute or relative. Furthermore, the event specifies the spatial location of the affected object. Spatial position, like time, can be determined in absolute or relative terms.

Moreover, this ontology includes relationships between events that can be mereological, causal, or correlational. For example, the class *DUL: Event* is one of the classes in the DUL (DOLCE + DnS Ultralight) upper ontology. A *DUL:Event* occurs at a specific point in time. *DUL:Object* is another class used to represent a single entity that exists within a particular space. A *DUL:Object* can be a person or non-living entity. *DUL:Quality* is another subclass. It is an attribute of an entity or an event. Fig 4 shows the representation of the *class:Event* in the Event-Model-F ontology:

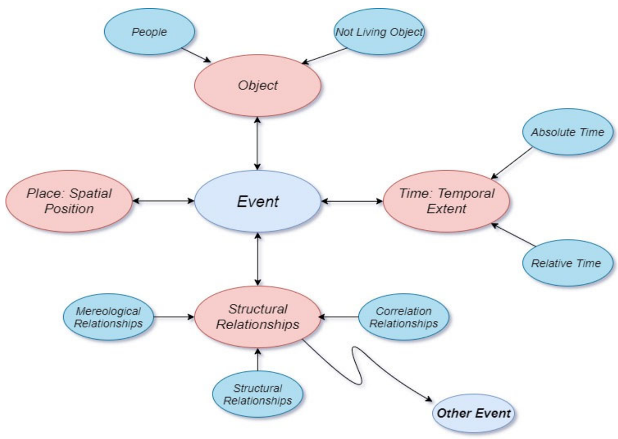

Fig 4. Event-Model-F ontology [26]

Three patterns are used to show the relationships between events. These are patterns of mereology, causality, and correlation. A mereology pattern is used only to depict such a relationship. At the same time, a causality pattern is used to illustrate the relationship between cause and effect. The ontology Event-Model-F defines two main types of events.

These are referred to as F: Cause and F: Effect. On the other hand, a correlation pattern establishes the relationship between two statistical variables. The correlation exists only when the events are independent of one another.

2.4 LODE: An ontology for Linking Open Descriptions of Events:

According to Shaw et al. and Rodrigues et al. [16, 27], LODE ontology was developed at the University of North Carolina to create a model that allows the representation of the most important properties to describe events. The aim of developing the LODE model was to focus on the factual aspects of the event and to answer questions such as ***What was happening?, Where and When was it happening?, and Who was involved?***.

Fig 5 illustrates how the LODE model represents the event class and the relations of classes related to the event. The *Class:Event* is the core class in this model to describe "something that happened", as reported in a news article or explained by a historian. An event consists of some temporal and spatial boundaries. The core class is connected to the three other related classes: *Class:Date, Class:Venue, and Class:Involved*. These classes have the following properties:

- **atPlace:** is a property used to answer the question, "Where did the event take place?". This property identifies an event with a specific or relative location. While sometimes, multiple locations might be associated with a single event.
- **atTime:** is defined as a property that provides an answer to the inquiry, "When did the event occur?" by specifying an abstract instant or a time span. This feature pertains to the relationship of an event to imposed temporal bounds (i.e., a time span). Thus, an event can be associated with a single period.
- **Involved:** is referred to any physical, social, or mental object or substance involved in an event. While involvedAgent: is referred to one event to anything with an agency such as a person, a group, an organization, a computational agent, etc.

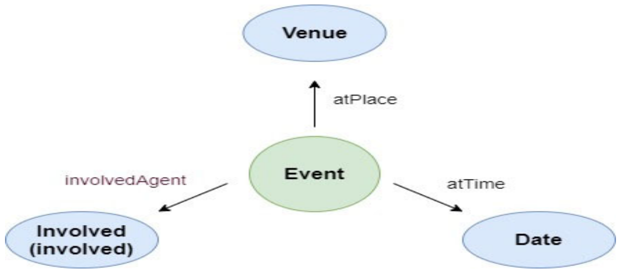

Fig 5. LODE: An ontology for Linking Open Descriptions of Events

When modelling factual components of events, the LODE ontology enables interoperability. However, similar to the Event Ontology Models mentioned above, it lacks a proper spatiotemporal extent. Indeed, LODE is defined in terms of several DOLCE Ultra-Lite concepts (DUL). For instance, it divides the spatial extent of an event as dul:Place and geo:SpatialThing, whereas the temporal extent is denoted by time:TemporalEntity.

2.5 OpenCyC Ontology:

OpenCyc was selected for this research because of its size and richness. It is categorized as a huge ontology that supports event modelling. Unlike the above-described ontologies, the OpenCyc ontology's description of events is explained in great depth here. This ontology offers the possibility for events to stretch over time and space. Additionally, events include live or non-living actors, which expands representation possibilities.

Furthermore, it is an application-independent upper ontology from which additional domain-specific ontologies can be built. It is Cyc Technology's open-source version [21]. It is an upper ontology designed to represent human knowledge about everyday objects and events.

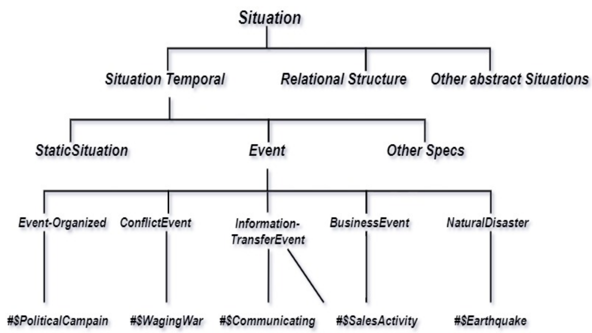

Fig 6. Representation of events in OpenCyc Ontology [26].

OpenCyc uses about 37,000 distinct event kinds to represent what occurs in the actual world [28]. The events depicted in

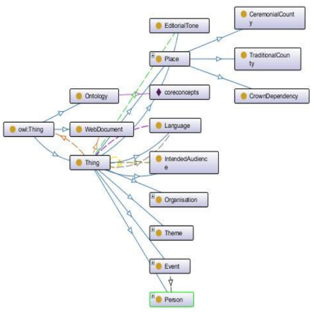

Fig7. BBC Core Concepts Ontology (BBCCORE)

OpenCyc ontology are as shown in Fig 6. This figure shows that the Situation-Temporal class consists of two classes, Event and StaticSituation. As a result, both specializations are temporal objects that extend over time. The distinction between these two collections is that StaticSituation contains situations that have been prolonged in time but have not changed. In contrast, the Event contains situations that have been extended in time but have changed. Specific ontologies make no distinction between these two categorization schemes: EO, LODE, and the Event-Model-F. The benefit of this categorization is that occurrences may be accurately modelled. Furthermore, both collections represent instances as temporal objects rather than predicates. This is necessary because events may include entities (e.g., the event's location or the performers) that would be impossible to express with a predicate.

2.6 BBC Core Concepts Ontology (BBCCORE):

According to Jeremy and Hodgkinson [17], BBC CORE Concept ontology was developed by the British Broadcasting Corporation (BBC) to create a general ontology model that allows the representation of the most important properties to describe events. This model is meant to be generic so that alternative domain representations of these key concepts can be combined. The generic BBC ontology for people, places, events, organizations, and themes represent things that make sense across the BBC.

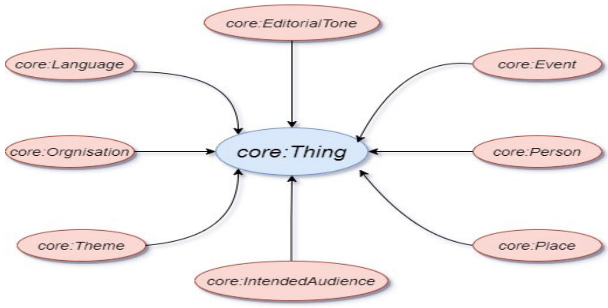

Fig 8. BBCCore Concept ontology from Protégé

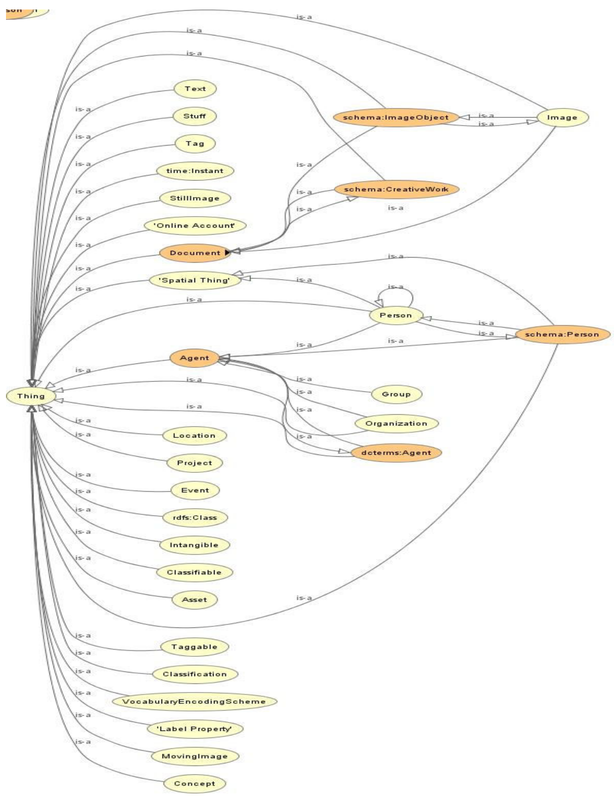

Fig 9. SNaP Ontologies Hierarchy

As shown in Fig 7 and 8, the BBCCore ontology contains more than 12 core classes, nearly 25 properties, and more than 40 relations. The latest release of BBC core concept ontology is available in OWL format.

2.7 Simple News and Press (SNaP) Ontologies:

The SNaP Ontologies for news content include several ontologies. One is the Asset Ontology which defines the assets such as text, pictures, and video that exist in news content. The other ontology is the Event Ontology, which prescribes news events and entities such as people, locations, organizations, and abstract concepts, as shown in Fig 9.

In the SNaP ontology, entities are classified into simple entities (i.e., stuff) and complex entities (i.e., events).

2.8 ABC ontology:

ABC metadata model has been developed in the multi-national project conducted by DSTC (Australia), JISC (UK), and NSF (US) funded Harmony Project. The primary purpose of this model was to serve as a guide for teams exploring and developing descriptive ontologies, provide a foundation for automatic mappings between metadata ontologies, and provide a foundation for comprehending and analyzing current metadata ontologies and instances. According to Wang et al. [29], the ABC Event Model is a fundamental ontology that serves as a foundation for domain-related or community-related development. The ABC event model is a straightforward model that defines event-related concepts such as event, situation, action, and agent and the relationships between these concepts.

3. Discussion and Findings

As shown in Table 2, several ontology models have been developed to represent events. The event in these models is a concept that can be treated independently to describe the fundamental ontology because the event can be expressed with the composition of some temporal extents, spatial extents, and participants. In this paper, eight event-based ontology models were investigated, including event-related concepts, which are the core concept of the ontology and several other essential concepts to represent the event concept. This section compares the investigated ontologies in terms of different extents such as time, location, participant, causality, etc.

Time is a necessary extent in the event whereby there are some possibilities in the explored event-based ontology models to modeling events with time extent. Two approaches ordinarily describe the time in the event ontologies either as a description or an individual object. Herein, all the ontologies describe time as an individual object and can be represented as absolute or relative. Yet another substantial comparison element in event modeling is that spatial extents, locations, and places can be involved in events. Some ontologies, such as EO and ABC, boost relations only to spatial extents (i.e., geospatial coordinate). Whereby other ontologies such as LODE, Event- Model-F and OpenCyc ontologies support relations to both spatial extents and place. The participants are another essential element for the event representation and usually involve living and non-living objects. The explored event-based ontologies use their own concepts to involve both objects in events.

Table 2 : Comparison table for ontologies that representing events.

Ontology	***Concepts***	***Availability***
Event Ontology EO	event:Event event:factor event:producedIn time:TemporalEntity geo:SpatialThing foaf:Agent	Open Source
Simple Event Model SEM	sem:Event sem:Actor sem:Time sem:Place	Open Source
Event-Model-F	DUL:Event (F:Cause / F:Effect) DUL:Object F:Time F:SpatialPlace	Open Source
An ontology for Linking Open Descriptions of Events LODE	lode:atTime lode:atPlace lode:inSpace lode:involvedAgent	Open Source
OpenCyC	#$Situation-Temporal #$StaticSituation #$Event #$Event-Orgnized #$ConflictEvent #$InformationTransferEvent #$BusinessEvent #$NaturalDisaster	Open Source
BBCCore	Core:Event Core:Person Core:Place Core:Agent Core:Theme Core:Language Core:Orgnisation Core:EditorialTone Core:IntendedAudience	Open Source
Simple News and Press (SNaP) Ontologies	Event Person Organization Location Instant Stuff Intangible Tag Image Identifiable Asset	Open Source

ABC ontology	Entity Temporality Actuality Abstraction Event Time Place	Open Source

The EO has initially developed for the use of music-related ontologies. Still, since it contains no music-specific terms, it may also be used to model events in other domains. EO representations of events can be modelled over spatiotemporal extents with limited constraints over absolute positions. However, it does not provide for proper spatiotemporal extents. Its spatial component is geo:SpatialThing from WGS84 Geo Positioning Ontology, while its temporal component is time:TemporalEntity from the W3C OWL Time Ontology. Extending the Event ontology to include such possibilities is a potential area for future study. However, on the other hand, the Event ontology does not allow for the modelling of complicated relations related to the complex domain, such as the crime domain.

The Event-Model-F ontology was created without consideration for domain-specific information to simplify event processing. These have allowed more complicated events to be modelled than previously feasible with existing ontologies. The Event-Model-F ontology is an easily extensible upper ontology that can easily be extended to a domain-specific ontology. It has formally defined events. Herein, events may include time, space and objects involved. Different types of relationships between events are conceivable in this ontology. Particular patterns are used to illustrate these relationships. The event model can be easily expanded to suit specific domains but not convoluted domains. The fundamental flaw in this model is that it does not correctly model spatiotemporal extents, even though some are offered.

The OpenCyc model ontology's event modelling capability was investigated. Due to the huge size of the ontology and the possibility of modelling events over time and location, it is possible to represent events in various ways using OpenCyc. Moreover, if a domain is specified, a domain-specific ontology may be derived from the upper ontology. OpenCyc is a notion that encompasses not just events but also other entities. This ontology has numerous applications in a variety of fields.

When modelling factual aspects of events, the LODE ontology enables interoperability. The LODE ontology is transformed into a standard language for event descriptions, facilitating data access in systems produced by other agencies. These aspects may be summarised in the four W's: What occurred? Where it occurred?, When it occurred?, and Who was involved?; each of these aspects is specified by the punctual attributes defined in the LODE ontology with relation to the occurring event. The temporal extent of the events is associated with the time in which they occur, whilst the spatial extent is linked with their location.

The SEM ontology is a generic ontology paradigm for representing events in various application domains. Despite that, some research groups have proved to a limited extent that the representation of the event and the named entities extracted from crime-related documents allow the representation of the crime event in SEM ontology. However, it does not provide proper spatiotemporal extents for the crime events. SEM ontology was purely modelled in RDF. As a result, it is considerably more permissive in modelling variants, and only a limited amount of automated reasoning can be accomplished.

The ABC ontology was created and built primarily to represent the formation, evolution, and transfer of objects across time, providing a straightforward model for domain-related development. Due to the simplicity of the ontology, it is straightforward to design and utilize.

Both SNaP and BBCCore Concept ontologies are news-related models representing events available in the news articles. SNaP ontologies have their own event ontology that defines the news events and entities such as people, locations, organizations, and abstract concepts. At the same time, the BBCCore Concept model contains more than 12 core classes for people, places, events, organizations, and themes that represent things that make sense across the BBC.

4. Conclusion

This study provides the latest comprehensive assessment of various event modelling choices. We have identified several characteristics to select the optimal ontology to be expanded for a specific domain. One of the most important characteristics is the availability of the ontology to the public; hence the ontology must be available and accessible for reuse. All the ontologies are accessible in different formats, including RDF and OWL. Another important feature is the number of classes in the ontologies and the total size of the ontologies.

Current ontologies are insufficient to bridge gaps between spatiotemporal ontological strategies to describe events in a specific domain (such as the crime domain). However, the best two models were the news ontologies: the BBCCore Concept ontology and the Simple News and Press (SNaP). These two ontology models are available with acceptable size and have sufficient classes. They are both expandable, and they both avoid ontological engagements that would restrict development and extension. They relate to correct spatiotemporal extents rather than the simplified perspective sometimes seen in event models that space and time are distinct.

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