Event Representation and Reasoning Based on SROIQ and Event Elements Projection

Wei Liu, Ning Ding, Yue Tan, Yujia Zhang and Zongtian Liu

Abstract Events have become central elements in the representation of information from various semantic web applications. It is necessary to develop a formal language for describing and reasoning event knowledge. Description logic is a well-defined knowledge representation language, but it is difficult to represent the event and elements with different characteristics. This paper proposes an event element projection method which is combined with SROIQ to build a new formalization method for event-centered knowledge. Event element projection unifies representation framework of event and event status, establishes the semantic relations between event and its elements. Through element projection and SROIQ, event classes, event instances and event elements can be effectively described in a unified style. An example of formalization on water pollution emergencies ontology is provided based on SROIQ and element projection method. The semantics of event relations based on element projection and reasoning on event relations are also discussed at last.

Keywords Event model · SROIQ · Event element projection · Event-based reasoning

1 Introduction

Events have become a key concept for representing knowledge and organizing and structuring media on the web and different application domains, such as emergency response, public opinion monitoring, history and cultural heritage, etc. Event ontology is a new paradigm for representation and reasoning on events. It highlights the representation of event classes and relations. However, the complexity of event

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structure results in the shortage of representation and reasoning language for event-based knowledge. Description logic is a well-defined knowledge representation language which has become the logic foundation of standard ontology language. In recently year, different extension work on description logics emerges massively, and some of them can be used to represent action, time and place concepts respectively. In another word, each element of event can be described isolatedly. There is a lack of a unified formalization framework for describing a whole events, elements and relations. Aims at a unified formal framework for event modeling, we propose an Event Element Projection (EEP) method, which is combined with SROIQ [1] (a standard description logic with rules) to describe and reason event elements. In EEP, SROIQ logic operators are used to construct a complex conceptual axiom that contains different event elements predicates, which can be projected onto an objective element for the simplification of inference. EEP provides inference for event elements and enhances the inference based on event semantic relations.

The remainder of this paper is structured as follows. Section 2 reviews the related work. Section 3 introduces several concepts about event model. Section 4 introduces the syntax and semantics of extended SROIQ and *Event Element Projection* method. Also, several inferences based on EEP are discussed in Sect. 4. An example of formalization on water pollution emergencies ontology is provided in Sect. 5. Finally, Sect. 6 concludes the paper.

2 Related Work

In recent years, research on the use of events as a key concept for representing knowledge is surging, especially in semantic web community [2, 3]. A good deal of relevant research on the modelling of events has been done in the semantic web community. Among these works, SEM is proposed [4, 5] to model events in various domains, without making assumptions about the domain-specific vocabularies used. SEM is designed with a minimum of semantic commitment to guarantee maximal interoperability. Reference [6] proposes a music ontology based on event calculus and OWL-Time. Reference [7] presents a formal model of events, called Event Model-F, which is based on the foundational ontology DOLCE+DnS Ultralite (DUL) and provides comprehensive support to represent time and space, objects and persons, as well as causal, and correlative relationships between events. LODE [8] defined event as an action or event happening during a period, but is not capable of describing event relations. In [9], we propose a 6-tuple event model and event ontology, and implement event-related applications of text information [10]. Whereas, most event model are concept-centered, there exist deficiencies while modeling event knowledge, such as separateness of concepts (the person, objects, places and action of event are not organized as a whole knowledge unit), insufficient capacities of capturing dynamic aspects of event.

Formalization of events, event classes and elements plays a key role of research on event ontology. Existing formal methods for the event knowledge focus on action and the process of event, such as situation and event calculus [11, 12]. Description logic is a series of knowledge-based formal logics which has become the logic basis of ontology language. Due to its clear model and theoretical mechanism [1, 13], description logic can effectively represent domain knowledge in applications via a static concept taxonomy to formalize specific model and reason on it [14]. Some existing work on extending description logic and specific ontologies are designed to represent and reason different event elements, including people, actions, time and so on. FOAF ontology [15] specifies a vocabulary that can be used to define, exchange and search for social information, describing people, their attributes and their relationships. Time ontology [16] is developed for describing the temporal content of web pages and the temporal properties of web services. The formalization of geographical ontology patterns are discussed in [17, 18]. Reference [19] presents a dynamic description logic for representation of actions, with an approach that embrace actions into the description logic. Most of these work ignore semantic relationship between event elements and events, resulting in the elements of the event are isolated, unconnected and static. It is necessary to develop a unified formal language for describing and reasoning the event elements (inner structure) and event relations (outer structure).

3 Concepts of Event Model

Events provide a natural way to express complicated relations between people, places, actions and objects. Event relationships provide more sophisticated description and reasoning of event-centered concepts. In this section, we will introduce an event model structure for representation of generic event information on Web.

Definition 1. (*Event*) We define an event as a thing happens in a certain time period and place, which some actors participate in and show some action features, along with the changing of internal status. Event e can be defined as a 6-tuple formally:

$$Event ::= (A, O, T, P, S, L)$$

A: an action or a set of actions usually regarded as a trigger word to identify an event.

O: objects involved in the event, including participants and entities.

T: the period of time that event lasting, including absolute time and relative time.
P: the location of an event happens.
S: status of object during an event happens, including *pre-condition* set and *post-condition* set.
L: language expressions of text-based event, it includes a *Core Words Expressions* (CWE) set and a *Core Words Collocations* set. *Core Words Collocations* (CWC) describe the fixed collocations between core words and other word.

Definition 2 Event class is an abstract event that represents a set of events with some common characteristics, denoted as EC:

$$EC = (E, C_A, C_O, C_T, C_P, C_S, C_L)$$
$$C_i = \{c_{i1}, c_{i2}, \ldots, c_{im}, \ldots\} \quad (i \in \{A, O, T, P, S, L\}, \ \ m \geq 0)$$

where E means an event set. C_i is the set of event elements. It denotes the common characteristics set of certain event element (element i). C_{im} denotes one of the common characteristics of event factor i. C_{im} is also called event elements class.

The relationships between the events are divided into two categories: taxonomic relation and non-taxonomic relations. The taxonomic relation describes the hierarchical structure of event classes. Non-taxonomic relations describe the internal semantic relationships between events or event classes, including composition relation, follow relation, causality relation and concurrency relation.

Subsumption relation (is_a): An event class can subsume or be subsumed by other event classes. It can be formalized as $EC1 \sqsubseteq EC2$.

Causality relation: If an event $e1$ (instance of $EC1$) happened, then another event $e2$ (instance of class $EC2$) happens at above a specified probability threshold, there is a causality relationship between $e1$ and $e2$ (or $EC1$ and $EC2$). $EC1$ is cause and $EC2$ is effect, causality relation formalized as $EC1 \rightarrow EC2$.

Follow relation: Follow means events coming after in time order, as a consequence or result, or by the operation of logic. It can be formalized as $EC1 \triangleright EC2$.

Concurrency relation: If there are event $e1$ (instance of class EC1) and event $e2$ (instance of class $EC2$) occur simultaneously or successively in a certain period of time (the two event are coincident events), there is a concurrency relationship between e1 and $e2$ (or $EC1$ and $EC2$), formalized as $EC1||C2$.

Composition relation: If an event instance e1 of class $EC1$ can be decomposed to several sub-events ei (i > 0, instance of class ECi) with smaller granularity, and while all the smaller events ei happened means e happened, there exists composition relation between e1 and ei (or $EC1$ and ECi), which can be formalized as $EC1 \angle EC2$.

4 Event Projection Method Based on SROIQ

Compared with some previous sub-language of description logic [13], SROIQ extends much more features, which describe different event element conceptions, especially dynamic elements. However, event elements described with SROIQ is static, it is difficult to reason about the status of event. In order to reason on the status of event elements, it is necessary to build link among the elements of event. *Event Elements Projection* is proposed in this section to solve this problem.

4.1 SROIQ Syntax and Semantics for Event Model

Definition 3. The language of SROIQ is interpreted in models over $\mathcal{I}$, which is triples of the form $\mathcal{I} = (\Delta^{\mathcal{I}}, \bullet^{\mathcal{I}})$, where $\Delta^{\mathcal{I}}$ is nonempty set of concepts (the domain of I) and $\bullet^{\mathcal{I}}$ is an interpretation function. $\Delta^{\mathcal{I}}$ is the domain of $\mathcal{I}$, including such general concepts: as to events, it represents event classes; as to elements, it represents elements, like object, time, place elements. $R^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$ describes the set of roles, that is, of property relation between concepts. In scope of events, it represents event relations, including taxonomic and non-taxonomic relations. In scope of elements, it represents actions in events, describing the property relation between two other elements, such as participants and entities. In this way, both the syntax solutions of event and element are the same but semantic different. Table 1 defines SROIQ syntax and semantics of event class or element.

Table 1 SROIQ syntax and semantics of event (element) class

Constructors	Syntax	Semantic
Concept (event class or element)	C	$C^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}}$
Nonempty set of concepts	$\top^{\mathcal{I}}$	$\Delta^{\mathcal{I}}$
Empty set of concepts	$\perp^{\mathcal{I}(t)}$	$\varnothing$
Negation	$\neg C$	$\Delta^{\mathcal{I}} \backslash C^{\mathcal{I}}$
Disjunction	$C \sqcup D$	$C^{\mathcal{I}} \cup D^{\mathcal{I}}$
Conjunction	$C \sqcap D$	$C^{\mathcal{I}} \cap D^{\mathcal{I}}$
Concepts inclusion	$C \sqsubseteq D$	$C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$
Role (event relation or element property relation)	R	$R^{\mathcal{I}} \subseteq \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}$
Eexist restrict	$\exists R.C$	$\{x \mid \exists y \langle x, y \rangle \in R^{\mathcal{I}} \wedge \mathrm{y} \in C^{\mathcal{I}}\}$
Value restrict	$\forall R.C$	$\{x \mid \forall y \langle x, y \rangle \in R^{\mathcal{I}} \Rightarrow \mathrm{y} \in C^{\mathcal{I}}\}$
Inverse of role	R^{-}	$\{\langle x, y \rangle \mid \langle y, x \rangle \in R^{\mathcal{I}}\}$
Role inclusion	$R_x \sqsubseteq R_y$	$R_x^{\mathcal{I}} \subseteq R_y^{\mathcal{I}}$
General role inclusioin	$R_1 \circ \ldots \circ R_{\mathrm{n}} \sqsubseteq R_m$	$\{\langle x_1, x_n \rangle \mid \langle x_1, x_n \rangle \in \Delta^{\mathcal{I}} \times \Delta^{\mathcal{I}}, x_1, \ldots, x_n \in \Delta^{\mathcal{I}}, \langle x_i, x_{i+1} \rangle \in V_i^{\mathcal{I}}\}$

Table 2 SROIQ syntax and semantics of event relations

Event relations	Syntax	Semantic
Cause	$EC1 \rightarrow EC2$	$\{\langle e_1, e_2\rangle \| arg\,max(P(e_2 \| e_1))\}$
Concurrence	$EC1 \,\|\|\, EC2$	$\left\{ <e_1, e_2> \| e_1^{[t_{11},t_{12}]}, e_2^{[t_{21},t_{22}]}, [t_{11}, t_{12}] \cap [t_{21}, t_{22}] \neq \varnothing \right\}$
Follow	$EC1 \triangleright EC2$	$\left\{ \langle e_1, e_2\rangle \| e_1^{[t_{11},t_{12}]}, e_2^{[t_{21},t_{22}]}, t_{12} \leq t_{21} \right\}$
Composition	$EC1 \angle EC2$	$\left\{ \langle e_1, e_2\rangle \| e_1^{[t_{11},t_{12}]}, e_2^{[t_{21},t_{22}]}, [t_{11}, t_{12}] \subseteq [t_{21}, t_{22}], C_{O1} \subseteq C_{O2} \right\}$

According to the definitions of event non-taxonomic relations, four extended symbols are introduced to represent four non-taxonomic relations, of which the syntax and semantics are defined in Table 2.

4.2 Event Element Projection

Definition 4. (*Event Element Projection*) The elements of events are abstracted as concepts (classes) or roles. Based on the constructors of description logic, a complex concept of element α in event e is built, which includes classes or roles of other elements. This complex concept is defined as the projection on α of event e, α represented as $e|_{\alpha}$.

Inside an event, the key element can characterize the type of event is the action element (or trigger words in some events); at the same time, participants, objects, time and place elements are linked with each other by means of action elements or trigger words in different events as the bridge. In description logic, an action element can be represented as the role associated with any other two elements, while the object, time, location and other elements are generally regarded as a class or concept. Figure 1 depicts various elements of the event are projected onto one of object elements, thus to construct a model for a complex concept of object element.

Event element projection plays an important role in the formalization and reasoning of events. In order to define concepts and roles in events based on

Fig. 1 Event element projection in event model

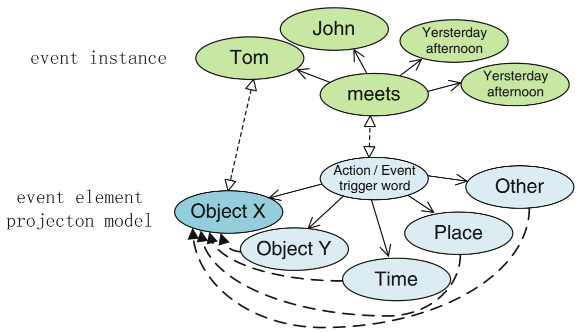

Table 3 Event element projection axioms examples

Event (class)	Element projected onto	Element projection axoims
E_1	Object Os (active object)	$E_1\|_O := Os \sqcap \exists V_r.Oo$
E_2	Object Os (active object)	$E_2\|_O := Os \sqcap \exists V\ when.T \sqcap \exists Vat.P \sqcap \exists Vr.Oo$
E_3	Time T	$E_3\|_T := T_1 \sqcap \exists V\ when^{-}.Os$
E_4	Place P	$E_4\|_P := P_1 \sqcap \exists Vat^{-}.Os$

description logic, action elements need to be created as several roles linked with different couples of event elements. Specifically, the action elements can be extended to three dimensions, building three roles as follow: in the dimensions of the object element, action element is represented as a role *Vr*, linking active object *Os* with passive object *Oo*; in the dimensions of the time element, action element is represented as the role *Vwhen*, linking with objects *Os* with time element *T*; in the dimensions of the place element, action element is represented as the role *Vat*, linking object *Os* with place *P*. At the same time, according to description logic constructors of event elements in 2.1, complex concepts of specific elements under event element projection can be constructed.

As is depicted in Table 3, while an event contains more elements, it is difficult to construct the element concept that can be projected onto. The key issue is how to select the element that should be projected onto. This tends to depend on the features of the event type and element links the event relations. For instance, we can project the couple of events in concurrence relations onto time element. Time consistency can be described as the rule that both the time element projections has conceptual consistency. By means of event element projection, concepts of different elements projected are constructed, which increases the flexibility of knowledge representation and facilitates element reasoning in different events.

4.3 Element Projection of Event Status

Events projection method can not only formalize the event, but also be used to indicate the event status, including preconditions or post-condition. An event seems to be a dynamic process of static event status. It is necessary to integrate status into formalization and inference on events for the improvement of expression and reasoning ability in the formalization framework.

The structure of elements in status is similar to 6-element model in event. As a result, event element projection can also be applied to the formalization and inference about event status. For instance, status in an event (class) is formalized as a 2-tuple, (S_{pre}, S_{post}), where S_{pr} is the precondition and S_{post} is the post-condition. Their element projection can be described as follows:

$$S_{pre}|_O := Os_1 \sqcap \exists V_r.Oo_1, \quad S_{pre}|_T := T_1 \sqcap \exists V \quad when^- \quad .Os_1$$
$$S_{post}|_O := Os_2 \sqcap \exists V_r.Oo_2, \quad S_{post}|_T := T_2 \sqcap \exists V \quad when^- \quad .Os_2$$

where, V_r is the role of a verb or trigger word in event status. In natural language, the action in event status often exists in attributive clauses of noun, such as "*carrying*" in "*a trunk carrying chemical*" and "*equipped*" in "*firefighters equipped with fire-fighting tools*". If the event and status are projected onto the same type of element concepts, projected event and projected status can be built as a concept conjunction, like $S_{pre}|_O \sqcap E|_O$. In this way, event element projection unifies formal representation of event and status.

Following is an example for formalization of event status.

Example e*1*: *Police officers managed to rescue a kidnapped child from kidnappers*

This event can be divided into pre-status, post-status and event itself.

pre-status: *The kidnapper abducted a child.*
event: *Police officers rescued a child.*
post-status: *The child has been saved.*

The event instance e_2 includes a police officer instance a, a kidnapper instance b and a child instance c. E_2 is the class of e_2, $S_{2\ pre}$ is the pre-status and $S_{2\ post}$ is the post status. Roles *Rescue* and *Hijack* are actions in the event.

$$E_2|_{O'} := Child \sqcap \exists Rescue^-.PoliceOfficer$$
$$S_{2pre}|_{O'} := Child \sqcap Hijack^-.Kidnapper$$
$$S_{2post}|_{O'} := Child \sqcap Saved$$
$$S_{2pre}|_{O'} \sqcap E_2|_{O'} \sqsubseteq S_{2post}|_{O'}$$
$$E_2(e_2); PoliceOfficer(a), Kidnapper(b), Child(c), Rescue(a,c), Hijack(b,c), Saved(c)$$

In the above axioms, $E_2|o$ is the E_2' projection onto *Child* element. Similarly, $S_{2\ pre}|_O$ and $S_{2\ post}|_O$ are status projections.

There always exists equivalence and inclusion between element concept of events and status. This makes it possible to use elements' concept conjunction to reason in the scope of elements in a unified way.

4.4 Event Relation Reasoning Based on Element Projection

In SROIQ, we formalize the non-taxonomic event relations as four roles, (R_{Cause}, $R_{CompositeOf}$, $R_{Concurr}$, R_{Follow}), and try to build links between elements of different events. These links reflect event relations in the scope of elements, which can help us to abstract more semantic information. To distinguish links in both scopes of event and elements, ***explicit link*** and ***implicit link*** are introduced in this section.

Table 4 Event relations semantic definition based on event element projection

Event relation	Semantic based on event element projection
$EC1 \sqsubseteq EC2$	$R_{is\_a} = \{(EC1, EC2)\|EC1\|_O \sqsubseteq EC2\|_O\}$
$EC1 \rightarrow EC2$	$R_{cause} = \{(EC1, EC2)\|EC1\|_O \sqsubseteq EC2\|_O\} \cup \{(EC1, EC2)$ $\|\exists EC3,\ then\, EC1\|_O \sqsubseteq EC3\|_O,\ EC3\|_O \sqsubseteq EC2\|_O\}$
$EC1 \,\|\|\, EC2$	$R_{concur} = \{(EC1, EC2)\|EC1\|_T \sqsubseteq EC2\|_T\}$
$EC1 \triangleright EC2$	$R_{follow} = \{(EC1, EC2)\|EC1\|_T \sqcap EC2\|_T \sqsubseteq \bot,$ $\|\exists a, b, EC1(a), EC2(b), \text{then} After(a, b) or After(b, a)\}$ (After is a role that describe time sequence)

In this paper, elemental links of event relations is defined as ***implicit link*** now. Implicit links can be named as *event relation projection*, represented as follows:

$$Relation|_{element}\ , Relation \in \{cause, follow, concur, compositeOf\},$$
$$element \in \{A, O, T, P\}$$

As is shown in Table 4, Event relations can also be formalized and reasoned based on the element projection method.

5 Formalization Example

In this section, a formalization program for *vehicle chemical leakage water pollution emergency* is provided. As is depicted in Fig. 2, event classes are linked with each other through relations while elements and their links are extended on it as well. These implicit links associate elements of different events. For instance, the

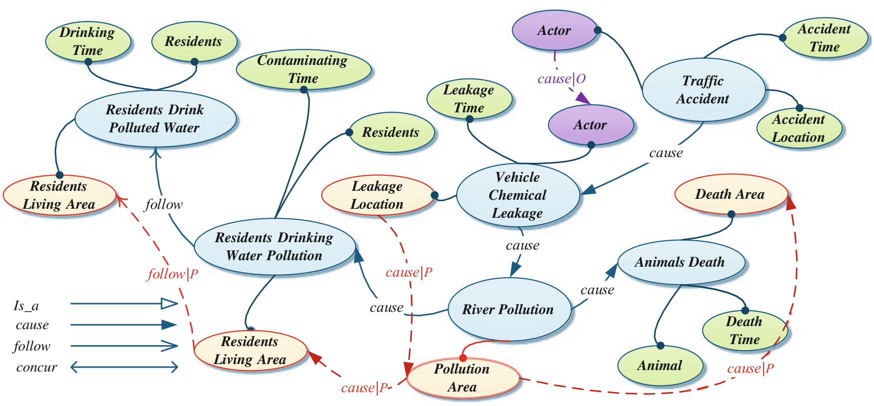

Fig. 2 Event classes model of *vehicle chemical leakage water pollution emergency*

implicit links between place element projection, like $cause|_P$ and $follow|_P$, contribute to represent the spatial associations and changes in scope of event elements.

In this solution, the formalization process of the upper part of *Vehicle chemical leakage water pollution emergency* can be offered as follows. Some event classes can be abstracted like E_0, E_1, E_2, E_3, and their concepts and roles description are given based on SROIQ, where E_0 denotes *Traffic Accident*, E_1 denotes *Vehicle Chemical Leakage*, E_2 denotes *River Pollution*, E_3 denotes *Animals Death*. Concepts *Vehicle*, *Chemical*, *Pollutants*, *River*, *Animals* are elements of the above event classes. Particularly, *EncounterTrafficeAccident* is regarded as a concept, for the action element of E_0 is intransitive. Roles *Carry*, *Leak*, *Leakat*, *PolluteAt*, *DieAt*, represent actions element. Among them, *Leak* associates active and passive objects while *Leakat* denotes object and place elements. *Carry* represents action in the pre-status of E_0. According to formalization method based on element projection, logic program can be established as follow.

$$
\begin{aligned}
&E_0|_O = Vehicle \sqcap EncounterTrafficAccident, \quad S_{0pre}|_O = Vehicle \sqcap \exists Carry.Chemical \\
&E_1|_O = Vehicle \sqcap \exists Leak.Chemical \sqcap \exists Leakat.River, \quad E_0|_O \sqcap S_{0pre}|_O \sqsubseteq E_1|_O \\
&E_1|_P = River \sqcap \exists (Leak^- \circ Leakat)^-.Chemical \\
&E_2|_P = River \sqcap \exists PolluteAt^-.Pollutants \\
&Chemical \sqsubseteq Pollutants \\
&E_1|_P \sqsubseteq E_2|_P, \quad E_3|_P = Area \sqcap \exists DieAt^-.Animal, \quad E_2|_P \sqsubseteq E_3|_P
\end{aligned}
$$

Then definition axioms of event element projection should substituted the element projection in other axioms. In this way, the extended symbols of element projection can be eliminated. The above logic program is simplified and converted into the following program.

$$
\begin{aligned}
&Vehicle \sqcap EncounterTrafficAccident \sqcap \exists Carry.Chemical \\
&\sqsubseteq Vehicle \sqcap \exists Leak.Chemical \sqcap \exists Leakat.River \\
&River \sqcap \exists (Leak^- \circ Leakat)^-.Chemical \sqsubseteq River \sqcap \exists PolluteAt^-.Pollutants \\
&Chemical \sqsubseteq Pollutants \\
&River \sqcap \exists PolluteAt^-.Pollutants \sqsubseteq Area \sqcap \exists DieAt^-.Animal
\end{aligned}
$$

This logic program contains axioms of elements in events. The description of semantic links strengthens the expression ability of formalization framework. At the same time, event element projection symbols in logic program can be eliminated, so the ultimate logic program conforms to the standard syntax of SROIQ. It is significant that formalization method based on event element projection does not affect the original reasoning ability of standard SROIQ. Therefore, event element projection is an effective method of formalization of event relations.

6 Conclusion

The event element projection proposed in this paper attempts to unify event, elements, status of formalization framework. Based on extended SROIQ, a formalization method for event ontology is proposed. A formalization example of *vehicle chemical leakage water pollution emergency* is provided to demonstrate the process of event element projection. It is noted that the extended symbols of event element projection can be eliminated in the final logic program at last. Therefore, the extended language will not affect the original formalization inference ability. Meanwhile, event relation reasoning can be converted into element inference based on element projection method, which provides a new point for the inference on event relations. Because of the ambiguity and complexity of non-taxonomic relations, event reasoning on these relations need further study.

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