Conceptual Framework for Process Ontology

Martina Číhalová

Palacký University Olomouc,
Department of Philosophy,
Czech Republic
martina.cihalova@upol.cz

Abstract. The author compares different approaches to process and event conceptualization in this article in order to obtain basic concepts and their definitions on which the ontology of processes needs to be built. With an emphasis on the aspect of sharing of ontologies, the conceptual framework for process ontology is designed to be close to natural language and existing process or event ontologies and logical conceptualizations. In the natural language, each event is specified using some special type of verb as a component of the phrase describing the respective event. This type of verb is called an episodic verb according to Tichý's distinction between episodic and attributive verbs. The referent of episodic verbs is referred to as an activity in this article and it is the crucial concept of process ontology building. The specification of activities is driven by the linguistic theory of verb-valency frames.

Keywords: Process · Event · Ontology · Activity · Verb-valency frames

1 Introduction

The problem of conceptualization of processes concerns not only philosophy and logic but also computer science. This problem represents a challenge at present especially for the field of artificial intelligence where the reasoning of intelligent agents has temporal aspects and has to deal with changes in their environment. To obtain basic concepts for process ontology and their definitions, different approaches to process and event conceptualization are compared in section 2, namely well-known ontological languages such as Event Ontology, etc., or situation and event calculus. The article suggests that ontologies may be linguistically based, as they intend to be shared. An event is often indicated by a verb in natural language. It therefore seems to be appropriate to make use of the results of linguistic analysis of verbs, specifically of the theory of verb-valency frames. Linguistically based approaches are introduced in section 3. The paper proceeds from John Sowa's thematic roles and the theory of verb-valency frames to propose the general conceptual framework for process ontology which is introduced in section 4.

A. Horák, P. Rychlý, A. Rambousek (eds.): Proceedings of Recent Advances in Slavonic Natural Language Processing, RASLAN 2021, pp. 83–90, 2021.

2 Different approaches to event and process specification

With the development of artificial intelligence, it became necessary to depict via conceptualization and ontology the time-dependent and variable phenomena in particular. In a number of contexts and approaches, the concepts of *process* and *event* overlap and these terms are treated as synonyms.[1] However, John Sowa made an essential distinction between them and I am going to proceed from his distinction in this paper. Sowa in [3, p. 220] suggests that "*processes* can be described by their starting and stopping points and by the kind of changes that take place between. [...] In continuous process, which is the normal kind of physical process, incremental changes take place continuously. In a discrete process, which is typical of computer programs or idealized approximations to physical process, changes occur in discrete steps called *events*, which are interleaved with periods of inactivity called *states*."

In order to be able to handle processes, it is important to make some idealization to regard them as discrete processes and divide them into static parts called *states* and into the parts of the change of some state to another state, called *events*. Hence the crucial distinction between the concept of event and process is that the event is some part of the process. Sowa in [3, p. 220] defines process as "an evolving sequence of *states* and events, in which one of the states or events is marked *current* at a context-dependent time called #now."

A similar approach is also applied in the well-known informatics representation, namely the *state-transition diagrams* for discrete processes. They represent states with circles and events by the arrows that connect the circles. Finite-state machines are the most widely used version of state-transition diagrams. The same approach was used also by Carl Adam Petri in [4] when designing his *Petri nets* in 1962. The events are called *transitions* in Petri nets and the states are called *places*.

McCarthy in [5] introduced a representation called *situation calculus* as a logical formalism designed for representing and reasoning about dynamical domains and change. This calculus was later modified by Reiter in [6]. From the logical point of view, situation calculus is a sorted, second-order language with equality. There are three sorts: *situations*, *actions* and *ordinary objects*, and these sorts can be quantified. A dynamic world is modelled as progressing through a series of *situations*, which are conceptualized as states reachable by some action. Actions are what make the dynamic world change from one situation to another when performed by agents.[2]

Another very important concept in situation calculus is *fluent*. According to situation calculus, fluent is the relation or the function whose last argument is a situation. Fluents are situation-dependent functions used to describe the effects

[1] Bach in [2] called events, states and processes collectively *eventualities*. Barwise and Perry in [3] use the term *situation* in this context.

[2] However, according to the later version of situation calculus developed by Reiter, a situation is a finite sequence of actions, i.e. a period (history) and not a state, see the web source [7].

of actions and they are changed by actions that have their preconditions and effects. While actions, situations, and objects are elements of the domain, fluents are modelled as either predicates or functions. Lin in [8, p. 649] presents the following examples of two types of fluents in situation calculus: "There are two kinds of them, *relational* fluents and *functional* fluents. The former has only two values: true or false, while the latter can take a range of values. For instance, one may have a relational fluent called *handempty* which is true in a situation if the robot's hand is not holding anything. We may need a relation like this in a robot domain. One may also have a functional fluent called *battery-level* whose value in a situation is an integer between 0 and 100 denoting the total battery power remaining on one's laptop computer."

One may have noticed that there is no autonomous concept for an event (or process) in the situation calculus and it applies the term of action in process specification. According to [8, p. 649], "to describe a dynamic domain in the situation calculus, one has to decide on the set of actions available for the agents to perform, and the set of fluents needed to describe the changes these actions will have on the world." As is the case with situation calculus, *event calculus* also uses the term action to treat events and conceptualize the time-varying properties or fluents. Event calculus was first presented by Kowalski and Sergot in [9] and was further extended by Shanahan and Miller in [10]. Event calculus represents the effects of actions on fluents, the conditions that can change over time. In his comparison of situation and event calculus, Mueller in [11, p. 671] emphasizes that "like situation calculus, event calculus has actions which are called events, and time-varying properties or fluents. In situation calculus, performing an action in a situation gives rise to a successor situation. Situation calculus actions are hypothetical, and time is tree-like. Otherwise, in event calculus, there is a single timeline on which actual events occur."

Hanzal, Svátek and Vacura in [12] provide a general survey of ontologies for modelling events and demonstrate how the dichotomy of *continuants* (entities that persist through time as wholes) and occurrents (entities that are not wholly present at every moment) is incorporated into several well-known foundational ontologies. They survey KR Ontology, the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE), PURO, and certain other chosen ontologies based on Web Ontological Language (OWL): The Event Ontology, The Simple Event Model Ontology (SEM), Linking Open Descriptions of Events (LODE). They summarize these approaches in the following way: "The surveyed OWL ontologies for modelling events generally share the basic structure, although they differ in certain details: same things are modelled using different 'modelling 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 modelling of different views (SEM)." The authors suggest that classes of different things dispersed in different models are merely subsumed under the common class of events, which gives rise to a relatively flat hierarchy that would be difficult to make sense of as a whole. They propose the following tentative classification of kinds of events into four categories to remedy the problem:

- *C1*, Actions. They assume an explicit or implicit deliberate agent performing them.
- *C2*, Happenings. They cover the situations when "something happened" without being initiated by a deliberate agent.
- *C3*, Planned "social" events. Besides being planned, they typically put emphasis on the spatio-temporal frame rather than on concrete participants.
- *C4*, Structural components of temporal entities. These events are "more arbitrary" than those falling under other categories and can be viewed as "regions", however, as merely temporal (and not spatio-temporal) ones. [12, p. 193]

3 Linguistically based process ontology

Ontological commitments and conceptualization carried out by ontology depend on the goals and purposes of the respective application. When designing an ontology, it is very important to find a balance between the fact that the ontology is designed to achieve the goals of the application and the ability to share such an ontology in the broader context, thus also outside of the interested team that created it. A necessary condition in order for an ontology to be shared is the respect for the role of conceptualized terms in natural language.

Each process can be constituted from the series of events and each event can be specified by a verb in natural language. The semantics of the respective verb is provided via its valency frame. For the linguistic theory of verb-valency frames, see [13]. In general, valency is the ability of a verb (or another word class) to bind other formal units, i.e. words, which cooperate to provide its meaning completely. These units are so-called *functors* or *participants* or *case roles*. Thus, the valency of a verb determines the number of arguments (participants) controlled by a verbal predicate. Valency participants can play an obligatory or a facultative role. One might consider, for example, the verb *chastise*. This verb has two obligatory participants *who* (agent) and *whom* (patient). In addition, this verb can be connected with other facultative participants which express inter alia locality and time such as in the following sentence: *A teacher chastises a student in the school early in the morning.* It would be useful to classify verb participants into types according to their semantics. There are many classifications, however, of the participant types described in the literature, for instance in [13]. Three approaches to classification, according to the two valency dictionaries for the Czech language VALLEX (see [14]) and VerbaLex (see [15]) and John Sowa's approach, are briefly compared in [16].[3] John Sowa also provides his own classification and uses the term *thematic roles* for the verb-valency participants. His summary of all the thematic roles can be found in [3, pp. 506-510]. Here are

[3] A very detailed comparison of these three classifications was provided in [17].

two examples of formalization of natural language sentence in his conceptual graphs:

Eve bit an apple, conceptualization: [Person: Eve] ←(Agnt) ←[Bite] →(Ptnt) →[Apple]; *Agent* as an active animate entity that voluntarily initiates an action,

Destination as a goal of a spatial process, example: *Bob went to Danbury*: [Person: Bob] ←(Agnt) ←[Go] →(Dest) →[City: Danbury]. For details, see [3, pp. 508-510].

An analysis of sentences with such a complex structure is particularly important when building up a multi-agent system (MAS) with deliberative agents.[4] In general, there is no central dispatcher; the system is driven by messaging so that each autonomous agent though being resource-bounded, can make less or more rational decisions. In addition, by communicating with other fellow agents as well as with their environment, agents are able to learn new concepts and enrich their ontology and knowledge base so that their behaviour is dynamic. Dynamic aspects of agents' reasoning embrace the appropriate conceptualization of participants of activities in their ontology. In the next section a general conceptual framework of process ontology based on the theory of verb-valency frames is proposed.

4 A general proposal for the conceptual framework of process ontology

A similar conceptual framework has been also introduced in [18], namely as a general framework for the logical classification of Wh-questions and possible answers to such questions in a multi agent system. We can distinguish between processes that are based on *actions* of deliberative agents and processes that are based on *passive events* like 'turning pale', 'subsiding', etc., which are not intentional. In [12], these types of processes are classified as C1 (Actions) and C2 (Happenings) in accordance with the above-mentioned classification. A *process* is divided into at least two *states* and one *event*. An event starts the change of state to some other state and is triggered by the respective action of some deliberative agent or some passive event. Hence, actions and passive events are what make the dynamic world change from one state to another. We will call actions and passive events *activities* in general. Each activity can involve other objects that are called its *participants*.

Consider the example of the process of 'going of an agent'. This process is divided into the $state_1$ in which the agent is standing. The action start going changes this state into the $state_2$ in which the agent is going. The measure of the process's granularity depends on the aims of the application that the ontology serves for. For instance, if we want to capture the speed changes, we need to specify the process in more detail. Each speed change has to be captured by adding accelerate and decelerate actions to the ontology.

The starting point of building a process ontology is to distinguish between *static objects* (*static entities*) such as concrete individuals and necessary relations

[4] For more details on the multi agent systems in general, see, for instance, [18].

between their properties and *dynamic entities* such as *activities* which are detected by some special types of verbs. The proposed analysis makes use of Tichý's formulation where such verbs are called episodic verbs. Tichý in [19] draws a distinction between episodic and attributive verbs. Episodic verbs (e.g. *drive, tell*, etc.) express the actions of objects or people as opposed to attributive verbs (e.g. *is heavy, looks speedy*) that ascribe some empirical properties to individuals. Both static and dynamic entities are characterised by their further specification. Static entities can be characterised by their properties and attributes, dynamic entities relating to activities can be characterised by the special relationships between activities and their participants.

Concerning static entities, from the linguistic point of view, the properties assigned to them are usually denoted by a copular verb + adjective or noun. Typical copular verbs are *is, am, are, ..., appear, seem, look, sound, smell, taste, feel, become* and *get*. In the conceptual analysis of a given domain, it is useful to distinguish between two basic classes of characteristics of static objects. They are relatively stable properties of objects (these characteristics usually remain unchanged over some life-span time) and dynamic empirical facts about these objects. The former can be called 'substantive' properties and the latter 'accidental' properties. For instance, according to the laws of physics and biology, if an individual is born as a person, then during its life-span it cannot become, say, a dog or a vase. Hence, being a person is a substantive property of such an individual. On the other hand, the property of being a student is accidental; one and the same person contingently becomes a student or stops being a student. Other accidental characteristics of the person-type individuals can be, for example, weight, height, age etc. *Substantive properties* are those that individuals have *nomically* necessarily, while *accidental properties* are possessed by individuals purely contingently.

Concerning process ontology, processes are composed of at least one event and two states. States can be formed by some activity (*Petr is standing, Petr is going*), or they are simply the states of affairs (*Apple is red*). On the other hand, events are always triggered by some *activity*. Each activity has an *actor* (who/what is doing the activity) and *participants* of activity. Thematic role or the type of a participant, such as Agent, Patient, Beneficiary, Destination, Instrument, etc., expresses the role that a noun phrase plays with respect to the activity described by a governing verb. The number and the categories of participants depend on the respective domain of interest and the functions of the system of agents. If we want to conceptualize, for example, a 'colour change', we have to include the activity of changing the colour in our conceptualization. It will therefore depend on whether we focus on the agent that causes the colour change, or we will take the colour change as an unintentional change (for example, if it is a natural event). In the first case, the state1 of one of the process may be the situation that the object has some colour. The activity of painting changes this state into state2 in which the object has another colour than in its initial state. The state is specified here by some entity and its attribute 'colour' which is the respective colour. The activity 'to paint' is then specified by the Agent of this activity, the Patient of the activity (the painted object) and by the Manner of activity execution (quickly, in the respective colour, etc.).

5 Conclusion

In this paper, different approaches to process and event ontology have been introduced to obtain basic definitions of the main concepts important for ontology of processes. The proposed approach is based on distinguishing between a static and dynamic part of the domain of interest. This division is based on some necessary idealization and may certainly be reductive. The world is too complex, however, and each effort of conceptualization has to be basically reductive by its very nature. When performing conceptualization, we have to leave out the details which are not fundamental from our point of view and the aims of the intended application.

The proposed conceptual framework follows the usage of the terms in existing ontologies and also their basic meanings in natural language. The specification of processes is based on the concept of activity which is based on Tichý's distinction between episodic and attributive verbs and the theory of verb-valency frames. Process is composed of at least one event and two states, where an event starts the change of state to some other state. Events are triggered by the activities, which can be actions of deliberative agents, or passive events like 'turning pale', 'subsiding', etc. Activities are the dynamic part of the domain. Each activity can concern other objects which are called *participants* according to the theory of verb-valency frames and are modelled as specific relations between the activity and involved objects.

Acknowledgements. The work on this paper was supported by the project *JG_2020_005 Times, events, and logical specification* of Palacký University and Grant of SGS No. SP2021/87.

References

1. Bach, E. On Time, tense and aspect: An essay in English metaphysics. In: R. Bauerle, C. Schwarze and A. von Stechnow (eds.) Meaning Use and Interpretation, pp. 19-38. New York: de Gruyter (1983).
2. Barwise, J., Perry, J. Situations and Attitudes. Cambridge, MA: Bradford Books, MIT Press. (1983).
3. Sowa, J. F. Knowledge representation (logical, philosophical, and computational foundations). Pacific Grove, CA: Brooks Cole Publishing Co (2000).
4. Petri, C. A. Kommunikation mit Automaten. Ph.D. Theses, University of Bonn, Bonn, German. English translation in technical report RADC-TR-65-377, Griffiss Air Force Base (1966).
5. McCarthy, J., Hayes, P. J. Some philosophical problems from the standpoint of artificial intelligence. In: Machine Intelligence, vol. 4, pp. 463–502 (1969).
6. Reiter, R. Knowledge in action: logical foundations for specifying and implementing dynamical systems. Cambridge: The MIT Press (2001).

7. Reiter, R. The situation calculus ontology. Electronic News Journal on Reasoning about Actions and Change (1998). https://www.ida.liu.se/ext/etai/rac/notes/1997/09/index.html, last accessed 2021/10/30
8. Lin, F. Situation calculus, In: F. van Harmelen, V. Lifschitz and B. Porter (eds.) Handbook of Knowledge Representation, pp. 649–669. Elsevier B.V. (2008).
9. Kowalski, R., Sergot, M. A logic-based calculus of events. In: New Generation Computing 4 (1), pp. 67–95 (1986).
10. Miller, R., Shanahan, M. Some alternative formulations of the event calculus, In: A. C. Kakas, F. Sadri (eds.) Computational Logic: Logic Programming and Beyond: Essays in Honour of Robert A. Kowalski Part II, Lecture Notes in Computer Science, pp. 452–490. Berlin, Heidelberg: Springer (2002).
11. Mueller, E. Event Calculus. In: F. van Harmelen, V. Lifschitz and B. Porter (eds.) Handbook of Knowledge Representation, pp. 671-708, Elsevier (2008).
12. Hanzal, T., Svátek, V., Vacura, M. Event categories on the semantic web and their relationship/object distinction. In R. Ferrario and W. Kuhn (eds.), Formal Ontology in Information Systems (pp. 183-196). Amsterdam: IOS Press (2016).
13. Horák, A. Verb Valency and Semantic Classification of Verbs. In Proceedings of TSD'98, pp. 61-66, Brno (CR): Masaryk University (1998).
14. Lopatková, M., Žabokrtský, Z., Kettnerová, V. VALLEX 2.5. – Logical structure of the lexicon (2006). http://ufal.mff.cuni.cz/vallex/2.5/doc/structure_en.html#sec:frame, last accessed 2021/10/30
15. Hlaváčková, D., Horák, A. VerbaLex - New Comprehensive Lexicon of Verb Valencies for Czech. In: Computer Treatment of Slavic and East European Languages, pp. 107-115 (2006).
16. Číhalová, M. Event ontology specification based on the theory of valency frames. In: T. Welzer, H. Jaakkola, B. Thalheim, Y. Kiyoki, N. Yoshida (eds.) Frontiers in Artificial Intelligence and Applications, Information Modelling and Knowledge Bases XXVII, pp. 299-313, Amsterdam: IOS Press (2016).
17. Číhalová, M. Jazyky pro tvorbu ontologií (Languages for ontology building). Ph.D. Thesis, VŠB-Technical University of Ostrava, Ostrava, The Czech Republic (2011).
18. Číhalová, M., Duží, M. Modelling dynamic behaviour of agents in a multi-agent world; logical analysis of Wh-questions and answers. Submitted to the Logic Journal of the IGPL.
19. Tichý, P. The semantics of episodic verbs. In: Theoretical Linguistics, vol. 7, pp. 263-296 (1980).
20. Wooldridge, M. An introduction to multi-agent systems. London: John Wiley & Sons (2009).