An Ontology of Environments, Events, and Happenings for Agent-Based Modeling of Engineering Design Systems and Processes

Vadim Ermolayev[1], Natalya Keberle[1], and Wolf-Ekkehard Matzke[2]
[1] *Zaporozhye National University, Zhukovskogo 66, 69063, Zaporozhye, Ukraine*
vadim@ermolayev.com, nkeberle@gmail.com
[2]*Cadence Design Systems, GmbH, Mozartstr. 2 D-85622 Feldkirchen, Germany*
wolf@cadence.com

Abstract

The paper presents our intermediate results in ontologizing a refined formal representation of environments, events, and happenings elaborated in PSI[1] *project. Our formal approach is based on the first order logic and is inspired by Discrete Event Calculus (DEC). In difference to DEC based on discrete linear time representation, it uses fuzzy time intervals [7]. Our framework also refines classic Event Calculi approaches by introducing explicit formal representations for environments and happenings as well as drawing a clear distinction between events and atomic actions. A reduced version of PSI Environment, Event, and Happening ontology based on crisp representation of time intervals has been implemented as an OWL-DL ontology and is used in PSI Design Process Simulation software. Fuzzy time interval based ontology is also implemented in OWL-DL and will be used in the future software versions.*

1. Introduction

People have long sought for the representations of change appropriate for commonsense reasoning [1]. Though the outcome of this research is enormous in depth and breadth, some aspects of modeling change and dynamics in open distributed systems, like the Semantic Web, still require refinements in our opinion. For example, the majority of mainstream theories for representing and reasoning about change do not draw explicit difference between events and actions, objective event occurrences and subjective percepts of their happenings. The role of the environments in representing events is also underrepresented.

Our research and development in PSI deal with modeling and predictive reasoning about the courses of dynamic engineering design processes (DEDP) [2]. The objective is to find the path of the best achievable performance [3] in a design problem solution space. The domain of engineering design is highly dynamic and non-deterministic. Design processes in it are planned and executed with strong subjective influence of their performers. Hence, refined representation of the mentioned aspects of the interrelationship among environments, events and happenings is very important.

This paper presents our intermediate results in developing a refined formal descriptive theory of change for engineering design processes and their environments. We also believe that the ontology and the underlying formal framework may be usable in wider frames because of their generic character. We therefore start with presenting our motivation using the example from a different domain – crude oil prices in Section 2. We continue by outlining our formal framework in Section 3. Ontology implementation and usage is discussed in Section 4. Partial evaluation of the ontology is presented in Section 5. Further we analyze our results with respect to the related work and conclude with their summary and our plans for future work.

2. Motivation and Example

World, or a particular part of the world which is a Domain of Discourse, is not static. Different changes occur in it. These changes are phenomena. Phenomena are manifested as events. If a phenomenon is the process of changing the World, then an event is a phase of the phenomenon in which the change goes

---

[1] Performance Simulation Initiative (PSI) is the research and development project of Cadence Design Systems, GmbH.

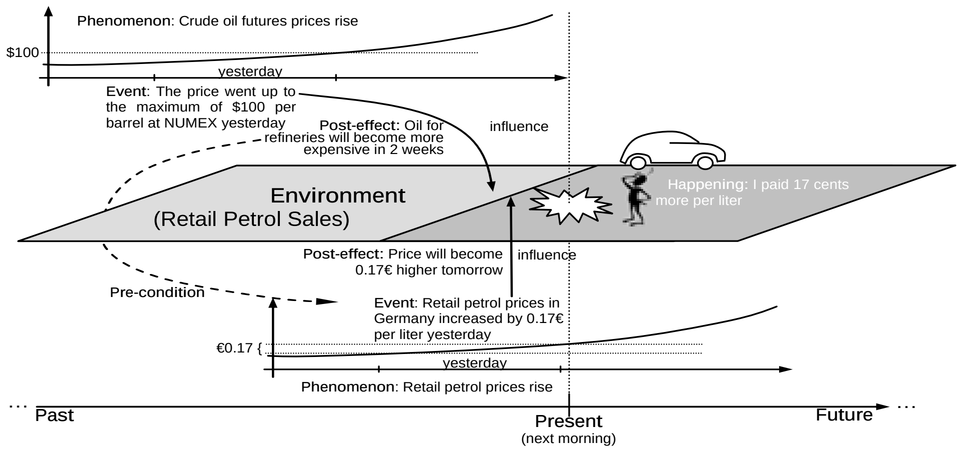


Figure 1. Relationship between phenomena, events, effects (influences), and happenings illustrated by the influence of crude oil futures price change on retail petrol sales

beyond a particular threshold. In that sense an event is the manifestation or the occurrence of the phenomenon. Considering different manifestations as the phases of a phenomenon is therefore a discretization of this phenomenon[2].

It is worth distinguishing subjective and objective stances of phenomena manifestations. An objective and noticeable occurrence of a phenomenon has been denoted as an event. Let us denote a perception of an event by an observer as a happening. An example explaining our understanding of the semantics of phenomena, events, and related happenings is given below.

A general tendency for crude oil prices is that they do not decrease. Sometimes the prices reach remarkable thresholds, like recently – a grand maximum of $100 per barrel (Fig. 1). Such a manifestation of the phenomenon is undoubtedly an event. This event definitely provides serious effects which may be revealed immediately or after some time. These effects are phenomena caused by the phenomenon of rising oil prices. If the magnitudes of these effects are noticeably substantial then they become events, for example, crude oil prices for German refineries will be increased substantially in two weeks. Such an event will definitely trigger the revision of the price of petrol produced in Germany, for example 0.17€ increase per liter. Hence, one event produces the effect which becomes effective in two weeks and is the pre-condition triggering another event. Events therefore may have causal dependencies. These dependencies are realized through the effects of the triggering event which become pre-conditions of the triggered event. We may predict certain manifestations of phenomena as events using knowledge about the effects of the events which already occurred and about the causal dependencies to the events which have not occur yet. As pictured in Fig. 1, the happening associated with the event of the increase of retail petrol prices is always coupled to the environment – for example, a gas station. An observer perceives this change of the world by paying more money for petrol. Of course, this perception is subjective. One can imagine drivers who will not even notice such a tiny increase in price. For them the happening will not occur. Even for those clients who were able to perceive the event it happens at different time instants. Again, in difference to the event of increasing the price, which has duration (from yesterday's afternoon till today's morning), the happening is instant. It occurs at the very time when money withdrawal is accomplished and the receipt is handed out.

To summarize, an event is the objective occurrence of a real world phenomenon. As far as for simulation purposes we use discrete models we skip phenomena in further considerations and use events only. Event may be instant or may have duration. In the latter case a crisp or a fuzzy time interval [7] is associated with the event. Events may have causal relationships with other events. Events are deterministic in the past or at present, but modal in the future, though predictions about their occurrences may be done using knowledge about causal dependencies among events and the regularity of their occurrences. A happening is a subjective perception of the influence of an event in a particular environment by a particular observer. In difference to events, happenings do not have durations

[2] In functional terms a phenomenon may be represented by a fluent [4], while an event is a discrete function having this fluent as its basic variable.

and are always associated to time instants – the points in time[3] at which perceptions are done. Happenings do not have causal relationships to other happenings. In difference to events happenings do not exist in the future, but only in the Past or at Present. Happenings may be believed to occur in the future.

3. Formal Framework

Formal treatment of environments, events, and happenings in PSI has been inspired by Discrete Event Calculus (DEC) by Mueller [5] and the key abstraction models of the agent-oriented mindset by Jennings and Wooldridge [6]. Our formalism uses PSI framework of fuzzy time intervals [7] for full expressiveness. As far as it has been proved that the fuzzy theory is the proper extension of the basic (crisp) theory of time intervals based on [8], the reminder of this section can be easily downgraded to the crisp subset of the theory.

3.1. Environments

One of the basic postulates of our framework is that any process or object has its environment(s). An environment is a temporal aggregation of different kinds of objects which surround the process or the object in question. We shall also say that a process or an object surrounded by its environment(s) is situated in these environment(s). By "surrounding" we understand several distinct things: (i) an object situated in the environment(s) may be changed by the objects constituting these environment(s); (ii) a process is always situated in one or more environments because it connects the states of its environment(s); (iii) an environment may be changed by the objects of this environment or by the objects external to this environment in events. By saying that we presume that processes are specializations of events. Processes are stateful and are pro-actively directed by Agents who manage them. In-depth treatment of process semantics is out of the focus of this paper. Please refer to [9, 10] for a more detailed description.

We specify basic generic semantic properties of an environment (Fig. 2) in PSI Meta-Ontology [9] and further elaborate them for the Domain of Engineering Design Performance by pointing to the particular sorts of objects which belong to an environment. These objects are: actors, resources, tools, and design artifact representations (Fig. 3).

[3] We consider that perceptions are done instantly because time is discrete in our theory [7].

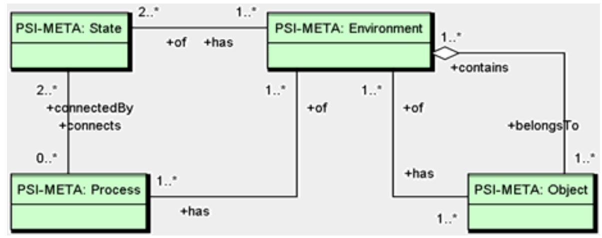


Figure 2. Semantic context of the concept of an Environment in PSI Meta-Ontology

3.2. Events

From a set theoretical perspective an event E is:

$$E = \{Pr, p, L_E, Ef, Po\} \quad (1)$$

where:

- Pr is the set of pre-conditions pr triggering E
- p is the phenomenon which occurrence is E
- $L_E = \{l_E^1,...,l_E^x,...\}$ is the set of life times of the manifestations of E – the life time of E. Life times l_E^x are all either time instants or time intervals. If life times are time instants then E has no duration in all its manifestations, otherwise its duration in a certain manifestation x can be computed as the duration of l_E^x.
- Ef is the set of immediate effects ef of E (the ones which may be revealed when E is not yet finished)
- Po is the set of post-effects po of E (the ones which may be revealed after E is finished)

Pre-conditions, immediate effects and post-effects are also events that have life time L which is a set of fuzzy time intervals. To put it formally, the life time L_{pr} of a pre-condition pr of event E should contain at least one fuzzy time interval l_{pr} which overlaps with or definitely meets at least one $l_E \in L_E$. Otherwise pr will not trigger E. Similarly, the life time of an immediate effect L_{ef} should lie within or overlap with L_E. As for post-effects, L_E should be before the life time L_{po} of the post-effect po of E.

$$\begin{aligned} &\forall pr \in Pr \exists l_{pr} \in L_{pr} \exists l_E \in L_E : Overlaps(l_{pr}, l_E) \\ &\forall ef \in Ef \forall l_{ef} \in L_{ef} \exists l_E \in L_E : Within(l_{ef}, l_E) \\ &\forall po \in Po \forall l_{po} \in L_{po} \forall l_E \in L_E : Before(l_E, l_{po}) \end{aligned} \quad (2)$$

Event E_1 causes E_2 when some of the immediate effects Ef_1 of E_1 or some of the post-effects Po_1 of E_1 are the part of the pre-conditions Pr_2 of E_2:

$$(Ef_1 \cup Po_1) \cap Pr_2 \neq \varnothing \quad (3)$$

An event may be caused by several other events and may cause several other events.

3.3. Happenings

A happening *H* of event *E* is the percept of *E* by an observer. An observer is an actor *a* situated in the environment on which *E* has an effect. These effects, called influences [10], are perceived by observers. Therefore, a happening takes place only in the environment of the observer and only if this environment is changed by the influence of event. A graphical illustration is given in Fig. 1. A happening may occur with a certain lag in time with respect to the causing event. This delay occurs because: (i) the influence may be associated with a post-effect and manifested after the event has already ended and (ii) the observer may take a certain time to notice the change in the environment. Formally, a happening *H* is:

$$H = \{a, t_H, Env, Ef_E\}, \tag{4}$$

where:

- a is the observer who perceived the change in the environment
- t_H is the time instant when the change in the environment is perceived
- *Env* is the environment
- Ef_E is the effect of event *E* which caused the change in *Env*. Ef_E may be either an immediate or a post-effect of *E*

3.4. Types of Events

Events may be singular, irregular, repeating, or regular. A *singular* event $E = \{Pr, p, L_E, Ef, Po\}$ is an event which may occur only once. Therefore, its life time $L_E = \{l_E\}$ contains only one fuzzy time interval if the event has occurred already or is empty if we predict that *E* may occur in the future but have no idea yet about when and for how long.

$$L_E = \begin{cases} \{l_E\} \wedge Within(Past, l_E) \\ \varnothing \end{cases} \tag{5}$$

For a singular event in the past the formulae describing causal relationship (2) may be reduced to:

$$\begin{aligned} &\forall pr \in Pr \exists l_{pr} \in L_{pr} Overlaps(l_{pr}, l_E) \\ &\forall ef \in Ef \forall l_{ef} \in L_{ef} Within(l_{ef}, l_E) \\ &\forall po \in Po \forall l_{po} \in L_{po} Before(l_E, l_{po}) \end{aligned} \tag{6}$$

The only possibility to predict the occurrence of a *singular* event *E* in the future is using the knowledge about its causal dependency on the other events which occurred in the past, are occurring at present, or on the occurrences of *regular* events in the Future.

An *irregular* event $E = \{Pr, p, L_E, Ef, Po\}$ is an event which may repeat, but there is no rule describing its occurrences in time. If an irregular event occurred in the past, the only way to present such a rule is to list the instances of its life time: $L_E = \{l_E^1, ..., l_E^x\}$. We have no possibility to predict such a set for the future. A singular event may be considered an irregular event which so far, up to present, occurred only once.

A *repeating* event differs from an irregular one by the number of its repetitions. An event $E = \{Pr, p, L_E, Ef, Po\}$ is considered repeating if at present more than one of its manifestations occurred: $L_E = \{l_E^1, ..., l_E^x\} \wedge x \geq 2$. Like for an irregular event, we can not specify a general rule describing when and for how long *E* has being occurring in the past and predicting its possible occurrences in the future.

A *regular* event $E = \{Pr, p, L_E, Ef, Po\}$ is an event which repeats regularly, according to the rule. For *regular* events a finite or an infinite number of repetitions may be specified. The rule determining these repetitions may allow estimating when a certain repetition started in the past or when it will start in the future. Some of *regular* events may have similar durations of their occurrences accurate within their fuzzy beginnings and endings, but it is not required. It is well possible that durations of different occurrences of a *regular* event differ.

The knowledge about the type of a certain event may be incomplete or even erroneous at present. An event which has been considered a singular one in the past may become irregular, repeated, or even regular after several its several occurrences observed as happenings.

4. Implementation and Use

PSI formal framework for representing environments, events, and happenings (E2H) has been implemented as an OWL-DL[4] ontology. UML diagram of PSI E2H ontology is pictured in Fig. 3. E2H ontology is one of six core ontologies of PSI Suite of Ontologies [11]. The structure of the PSI Suite and its extensions elaborated in PRODUKTIV+[5] project is pictured in Fig. 4. E2H central concepts are an Environment, an Event, and a Happening. The

---

[4] Web Ontology Language, http://www.w3.org/TR/owl-guide/

[5] PRODUKTIV+ (Referenzsystem zur Messung der Produktivität beim Entwurf Nanoelektronischer Systeme) is the R&D project funded by the German Bundesministerium für Bildung und Forschung (BMBF).

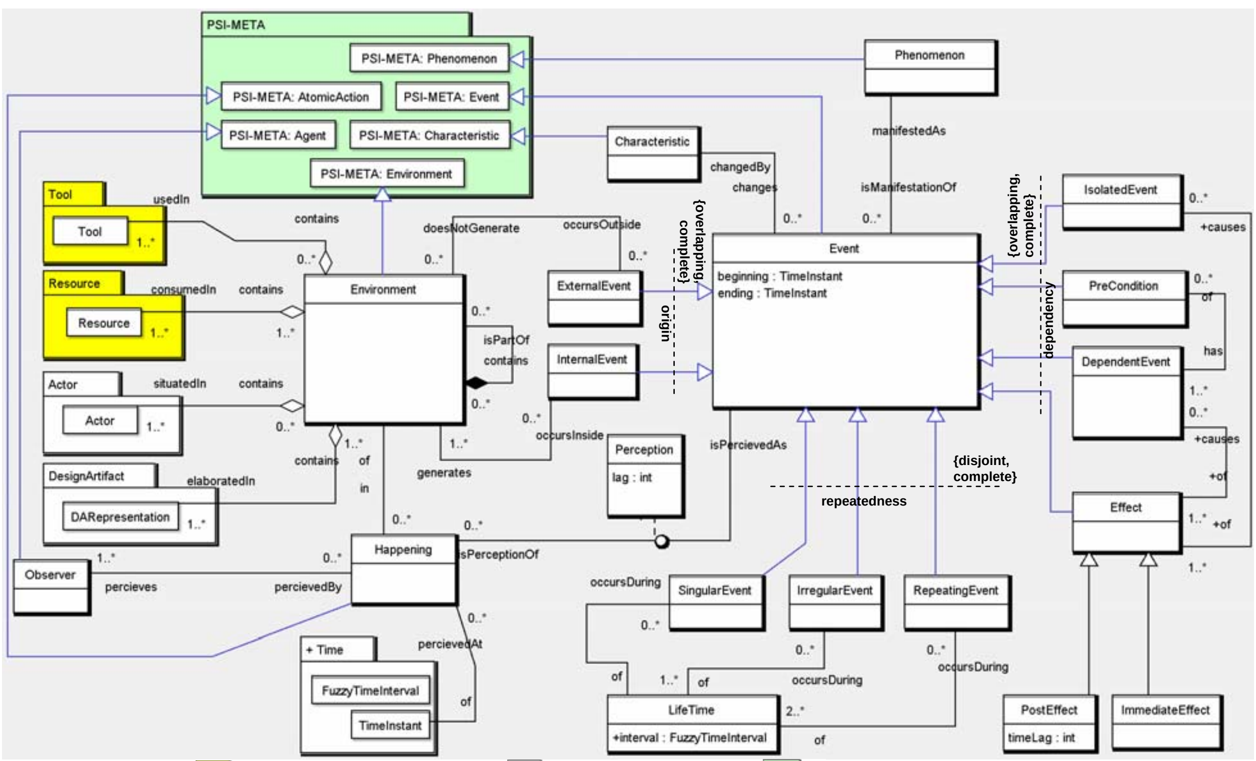
semantics of these concepts is specified as presented in Section 3.

An Event models the manifestation of a real world Phenomenon. By manifestation we assume that an Event noticeably changes a Characteristic of one to several Objects situated in an Environment. Such a change may also be comprehended as and Event which is denoted as an Effect. An Event may be treated as isolated or dependent on other events. DependentEvents differ from IsolatedEvents by having PreConditions. PreConditions trigger the DependentEvent. PreConditions and Effects as specific subclasses of an Event are therefore a mechanism for modeling causal relationships among Events. An IsolatedEvent, a DependentEvent, a PreCondition, and an Effect are subsumed by Event and denominated by dependency. This group of subclasses is overlapping because, for example, a particular instance of an Effect may be also an instance of a DependentEvent and a PreCondition.

Events may occur inside or outside the Environment which they change through their Effects. In the former case such Events are considered as InternalEvents, in the latter – as ExternalEvents. These two subclasses of an Event are also overlapping because a particular instance of an ExternalEvent may be generated by both the affected and the external Environment.

The ontology also distinguishes kinds of Events according to their repeatedness: SingularEvents, IrregularEvents, and RepeatingEvents. The difference between these kinds of Events is explained in the previous section. In the ontology it is explicitated using the concept of LifeTime. LifeTime denotes a fuzzy time interval [7] on which the event occur. FuzzyTimeInterval (Fig. 3) is the concept of Time-Full extension of PSI Time Ontology [11]. A SingularEvent may have only one LifeTime. An IrregularEvent may have one or more LifeTimes. A RepeatedEvent has at least two lifetimes. This group of Event subclasses is disjoint because an instance of a particular subclass can not be the instance of the other two subclasses. The group of Event subclasses under repeatedness denominator is complete because no other kinds of repeatedness except the given three are thought of.

Happenings, as mentioned above, are the perceptions of Events by Observers situated in the Environment. In difference to Events, Happenings are AtomicActions [9] performed by Observers, who are



Legend: - extension ontology, - core ontology, - upper-level (meta) ontology.

Figure 3. UML diagram of PSI E2H ontology

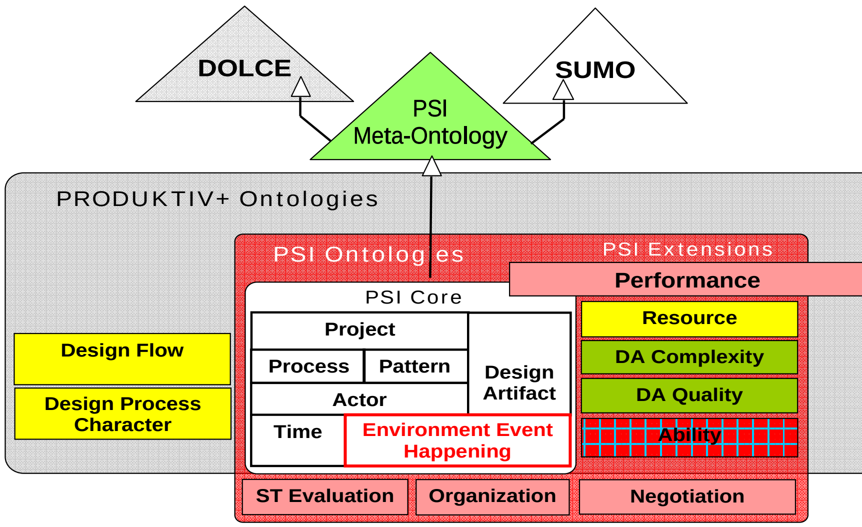


Figure 4. The structure of PSI Suite of Ontologies

Agents, in the sense of PSI Meta-Ontology [9].

PSI E2H ontology has been designed in a way to comply with the requirement of computational efficiency of the current and upcoming versions of the multi-agent software prototype of PSI DEDP Performance Simulator [12].

4. Evaluation

PSI E2H ontology has been partially evaluated using two complementary methods. Formal evaluation of its taxonomy has been performed using OntoClean [13]. Goal-based evaluation of the adequacy of the conceptual model and its implementation to the set of requirements [7] has been performed by the group of subject experts in microelectronic engineering design. Formal evaluation of E2H together with PSI Meta-Ontology revealed that the taxonomical structure is conceptually correct. Goal-based evaluation found out that the ontology adequately answers the competency questions formulated using the requirements by subject experts [14]. This evaluation is considered partial because the ontology is primarily designed for the usage in PSI software. So far this usage is limited to the reduced subset of concepts and the crisp subset of the underlying formal representation of time intervals which correspond to Time Crisp ontological model [7].

Furthermore, the mappings of E2H ontology concepts to SUMO [15] through WordNet [16] have been defined [9]. This work revealed that E2H adequately maps to SUMO – the chosen commonsense reference ontology. This fact allows us believing that E2H ontology may be used not only internally in PSI and PRODUKTIV+ projects, but broader – as a descriptive theory of environments, events, and happenings for intelligent software agents on the semantic web. Indeed, as pointed out by many noted experts, for example [24], the basic requirement for making Semantic Web agents a reality is the development of a machine-processable knowledge infrastructure. As OWL is a de-facto standard for the Semantic Web, our E2H ontology may become one of the elements of such an infrastructure enabling agents reasoning about environments, events, and their subjective perceptions.

5. Discussion and Related Work

As McCarthy stated in [17], “the most salient common sense knowledge concerns situations that change in time as a result of events.” This remains valid for any realistic open distributed system in diverse domains like the Semantic Web and engineering design. Research in representing, reasoning, and capturing knowledge about change and dynamics produced the plethora of premium quality results which can’t be even listed here due to space limit. Instead, we point to [1] as an excellent reference source. We also mention several related sources for analyzing our contribution.

Fundamentals. McCarthy and Hayes [18] were the pioneers in introducing a logical formalism which became a mainstream for commonsense reasoning and reasoning about change in particular – the Situation Calculus (SC). Several authors have further developed this approach resulting in several Event Calculi (EC) [19, 20]. Most of them use linear time instead of branching time characteristic to the Situation Calculus. A topical representative of a branching time logic approach is [21]. Our approach is particularly close to DEC [5] because DEC uses discrete linear time representation. In difference to the mentioned EC our framework uses discrete linear time and time intervals with fuzzy beginnings and endings [7]. This enhancement makes our representation of events more flexible and expressive. For all other desired representational capabilities like causality, event triggering, context sensitivity, delays in effects, concurrency, release from the law of inertia [4] we rely on [5]. Some of these have already been accounted for: causality, triggering, delays. Elaboration of the rest is planned for the future work.

Events and Actions. To the best of our knowledge, existing frameworks do not specify the difference between events and actions, except stating that actions are a kind of events: "the most important events are actions, and for a program to plan intelligently, it must be able to determine the effects of its own actions…" [cf. 17]. Such a view underestimates the role of events which occur without the involvement of an actor. In our opinion it is not sufficient for defining the semantics of events and actions explicitly – in a manner required for automated reasoning. Indeed, if we consider a person accidentally falling out from a window, this event can hardly be qualified as an action – the person had no purpose for or intention of falling out. He did not desire reaching this uncomfortable situation. The refinement proposed in PSI [9, 10] is that processes (compound actions) subsume to events, while atomic actions do that not. Atomic actions are a specific kind of an instrument for agents to pro-actively apply changes to their environment(s). In that sense a happening is an atomic action and is not an event because it is it is an instrument for an observer to perceive the changes in observer's environment. An observer will perceive the event only if he intends to. However, an event occurs irrespectively to somebody's perception or intent.

Environment(s) and the frame problem. One of the deficiencies of the classical SC which has drawn substantial efforts to be resolved is the frame problem [18:p.492] stating that a complete set of axioms describing fluents that remain unchanged is required for reasoning about change. Several papers, for example [22], suggest approaches to avoid it based on circumscription. Scherl and Levesque [23] extend this approach to knowledge producing actions which is particularly relevant for the Semantic Web and engineering design. Our approach is analogous to the mentioned ones. We sircumscribe by introducing nested environments and, therefore, allowing to account only for those fluents that are required in the context of our focus.

Ontologies. We performed Swoogle[6] search for ontologies mentioning "event", "environment", and "happening". The results are summarized in Table 1.

Table 1. Swoogle search for relevant ontologies

Search criterion	event	event AND environment	event AND environment AND happening
Matches	1,777	133	2

The only two ontologies mentioning "event" AND "environment" AND "happening" were OpenCyc[7] and SWINTO[8]. However, a closer look at them revealed that both of these ontologies treat happening as a predicate specifying event (or perdurant in case of SWINTO) occurrence, but do not relate such an occurrence neither to a subjective percept, nor to a particular environment. Examination of SUMO+WordNet[9], which has been used as a reference upper ontology in PSI [9], revealed that a happening is in the WordNet synset with an occurrence and a natural event, which all subsume to an event. We therefore may believe that our E2H ontology contributes with a refinement of the semantics of events, happenings, and environments.

6. Concluding Remarks

The majority of mainstream theories for representing and reasoning about change do not draw explicit difference between events and actions, objective event occurrences and subjective percepts of their happenings. The role of the environments in representing events is also underrepresented. The paper presented our intermediate results in ontologizing a refined formal representation of environments, events, and happenings elaborated in PSI project. Our formal approach is based on the first order logic and is inspired by DEC. In difference to DEC based on discrete linear time representation, it uses fuzzy time intervals. Our framework also refines classic EC approaches by introducing explicit formal representations for environments and happenings as well as drawing a clear distinction between events and atomic actions. Current implementation of E2H

[6] A Semantic Web search engine which returns matching ontologies in RDF(S) or OWL, http://swoogle.umbc.edu/

[7] May be browsed using http://www.cycfoundation.org/concepts/

[8] Available at http://www.smartweb-project.de/ontology/swinto0.3.1.rdfs

[9] KSMSA browser has been used: http://virtual.cvut.cz/ksmsaWeb/browser/title/

ontology has been influenced by the requirement of computational efficacy of the Performance Simulation software developed in PSI. Hence, its expressive power is so far restricted by the reduced subset of concepts and the crisp subset of the underlying formal representation of time intervals. In our future work we plan enhancing our ontology to fuzzy time representation and possibly incorporating fuzzy-DL reasoning like for example reported in [25].

Acknowledgements

Research presented in this paper has been funded in frame of PSI project of Cadence Design Systems GmbH. The authors would also like to acknowledge the comments of the anonymous reviewers which helped substantially in improving the final version of the paper.

References

[1] E. T. Mueller, *Commonsense Reasoning*, Morgan Kaufmann Publishers, 2006

[2] V. Ermolayev, E. Jentzsch, O. Karsayev, N. Keberle, W.-E. Matzke, V. Samoylov, and R. Sohnius, "An Agent-Oriented Model of a Dynamic Engineering Design Process", In: M. Kolp et al. (Eds.): AOIS-2005 Revised Selected Papers, LNCS Vol. 3529, 2006, pp. 168-183

[3] V. Ermolayev and W.-E. Matzke, "Towards Industrial Strength Business Performance Management", In: V. Marik et al. (Eds.) Proc. HoloMAS-2007, Regensburg, Germany, Sept. 3-5, 2007, pp. 387–400

[4] E. Sandewall, *Features and Fluents (Vol. 1): the Representation of Knowledge about Dynamical Systems*, Oxford University Press, Inc., Oxford, UK, 1994

[5] E. T. Mueller, "Event Calculus Reasoning through Satisfiability", *J. of Logic and Computation*, 14(5), 2004, pp. 703-730

[6] N. R. Jennings, "An agent-based approach for building complex software systems", *Communications of the ACM*, 44 (4), 2001, pp. 35–41

[7] V. Ermolayev, N. Keberle, W.-E. Matzke, and R. Sohnius, "Fuzzy Time Intervals for Simulating Actions", In: G. Fliedl et al. (Eds.) Proc. 2nd Int. Conf. UNISCON-2008, Klagenfurt, Austria, Apr. 22–25, 2008, pp. 429-444

[8] J. Allen and G. Ferguson, "Actions and Events in Interval Temporal Logic", *J. of Logic and Computation*, 4(5), 1994, pp. 531–579

[9] V. Ermolayev, E. Jentzsch, N. Keberle, and R. Sohnius, "Performance Simulation Initiative. Meta-Ontology v.2.2. Reference Specification", Technical Report PSI-ONTO-TR-2007-4, VCAD EMEA Cadence Design Systems GmbH, 12.01.2008, 75 p.

[10] V. Ermolayev, E. Jentzsch, W.-E. Matzke, M. Pěchouček, and R. Sohnius, "Performance Simulation Initiative. Theoretical Framework v.2.0", Technical Report PSI-TF-TR-2007-1, VCAD EMEA Cadence Design Systems GmbH, 30.09.2007, 43 p.

[11] V. Ermolayev, E. Jentzsch, N. Keberle, and R. Sohnius, "Performance Simulation Initiative. The Suite of Ontologies v.2.2. Reference Specification", Technical Report PSI-ONTO-TR-2007-5, VCAD EMEA Cadence Design Systems GmbH, 28.12.2007, 131 p.

[12] R. Sohnius, E. Jentzsch, and W.-E. Matzke, "Holonic Simulation of a Design System for Performance Analysis", In: V. Marik et al. (eds.) Proc. HoloMAS-2007, Regensburg, Germany, Sept. 3-5, 2007, pp. 447–454

[13] N. Guarino and C. Welty, "Supporting ontological analysis of taxonomic relationships", *Data and Knowledge Engineering*, 39(1), 2001, pp. 51–74

[14] V. Ermolayev, E. Jentzsch, N. Keberle, and R. Sohnius, "Performance Simulation Initiative. Theory of Time, Happenings, and Events", Technical Report PSI-T-TR-2007-2, VCAD EMEA Cadence Design Systems, GmbH, 30.10.2007, 26 p.

[15] I. Niles, and A. Pease, "Towards a Standard Upper Ontology", In: Proc. FOIS-2001, Ogunquit, Maine, USA, Oct. 17-19, 2001

[16] C. Fellbaum (ed.), *WordNet: An Electronic Lexical Database*, MIT Press, 1999

[17] J. McCarthy, "Some expert systems need common sense", In: H. R. Pagels (Ed.) Proc. Symp. on Computer Culture: the Scientific, intellectual, and Social Impact of the Computer, New York Academy of Sciences, New York, NY, 1984, pp. 129-137

[18] J. McCarthy and P. J. Hayes, "Some Philosophical Problems from the Standpoint of Artifcial Intelligence", In: B. Meltzer and D. Michie (Eds.), Machine Intelligence 4, Edinburgh University Press, 1969, pp. 463–502

[19] R. A. Kowalski and M. J. Sergot, "A logic-based calculus of events", *New Generation Computing*, 4(1), 1986, pp. 67–95

[20] R. Miller and M. Shanahan, "The event calculus in classical logic - alternative axiomatisations", *Linkoping Electronic Articles in Computer and Information Science*, 4(16), 1999

[21] G. Shafer, P. R. Gillett, and R. B. Scherl, "The logic of events", *Ann. Math. Artif. Intell*, 28(1-4), 2000, p. 315-389

[22] R. Reiter, "The Frame Problem in the Situation Calculus: a Simple Solution (sometimes) and a Completeness Result for Goal Regression", In: V. Lifschitz (Ed.) Artificial Intelligence and Mathematical Theory of Computation: Papers in honor of John McCarthy, Academic Press, San Diego CA, 1991, pp. 359–380

[23] R. B. Scherl and H. J. Levesque, "Knowledge, action, and the frame problem", *Artif. Intell.* 144, 1-2, Mar. 2003, pp. 1-39

[24] J. Hendler, "Agents and the Semantic Web", *IEEE Intelligent Systems*, 16(2), 2001, pp. 30-37

[25] F. Bobillo and U. Straccia, "FuzzyDL: an Expressive Fuzzy Description Logic Reasoner", In: Proc. IEEE FUZZ-2008, to appear