A Context Model for Knowledge Workers

Vadim Ermolayev[1], Carlos Ruiz Moreno[2], Marcel Tilly[3],
Eyck Jentzsch[1], Jose Manuel Gomez-Perez[2], Wolf-Ekkehard Matzke[1]

[1] Cadence Design Systems GmbH, Mozartstr 2 D.85622 Feldkirchen Germany,
vadim@ermolayev.com, jentzsch@cadence.com, wolf@cadence.com
[2] ISOCO, Pedro de Valdivia 10 28006 Madrid, Spain,
cruiz@isoco.com, jmgomez@isoco.com
[3] European Microsoft Innovation Center, Ritterstr 23 52072 Aachen Germany
Marcel.Tilly@microsoft.com

Abstract. The paper presents the model of a context that is further used in the software tools that deliver proper pieces of information and knowledge to knowledge workers in their everyday professional activities. The main contribution of the paper is the upper-level context model which is a part of the PSI Upper-Level ontology. The formal correctness of the model ic checked using the OntoClean methodology. The model is further refined in the two different domain-level knowledge representations – the PSI Environment, Event and Happening ontology and the ACTIVE Knowledge Process Model. The adherence of the upper-level model to the common sense is checked by analyzing if its semantics is aligned with context denotations in several foundational ontologies. It is also outlined that the presented context model is effectively used for improving the productivity of knowledge workers in the software tools developed in both mentioned projects.

Keywords: context, model, ontology, process, object, agent, environment, state

1 Introduction

A friend told me on the phone that she enjoyed "Tequila Sunrise" yesterday evening. What would be my qualification of the object? The context grasped in the conversation has been too general for comprehending the message unambiguously. More knowledge about the situation has been required for disambiguation. If it was at the bar, then the cocktail[1] was luckily well mixed (not too much tequila). If, however, it was over the home cinema, then I'd have been quite certain that she was amused by Mel Gibson[2]. Very similar things happen to us in our professional life. We play different roles in different situations circumscribed by different contexts. We often switch contexts in our work that is known to be an obstacle in the way of maximising

[1] http://en.wikipedia.org/wiki/Tequila_Sunrise_(cocktail)
[2] http://en.wikipedia.org/wiki/Tequila_Sunrise_(film)

productivity, especially for knowledge workers whose processes are to a big proportion informal – i.e. very loosely defined and often alterable at execution time.

The research described in this paper is being undertaken as a part of ACTIVE[3], an EU-funded research project that seeks to remedy some of the defects of current knowledge worker tools. It addresses the need for greater knowledge worker productivity by providing more effective and efficient instruments based on the use of different sorts of knowledge acquired within an organization. One central theme that drives the research work in ACTIVE is the prioritization of the information and knowledge delivery through an understanding of the current context of a knowledge worker. Therefore the development of a rigorously defined context model that is further operationalized in the ACTIVated software tools has been one of the important tasks. Architecturally such a model has to be at a high level of abstraction for being generic enough to cover the requirements and specificities of the project case studies. It was also important to ensure that the model is harmonized with the available domain-level knowledge representations of the case study partners. One of such representations in the form of the Suite of Ontologies is being developed in the PSI[4] project that is parallel to ACTIVE. It has been decided that the PSI Upper-Level Ontology (PSI-ULO) would be the right setting for placing the high-level context model of ACTIVE. The reasons for that are: (i) the PSI-ULO is a well founded upper-level representation of a descriptive theory of informal processes; and (ii) the PSI Suite of Ontologies is used as the knowledge representation formalism for one of the ACTIVE case studies. Thus, providing the abstract context model at the upper level allows bridging the context models at domain level for different case studies and technology development.

The remainder of the paper is structured as follows. Section 2 reviews the related work in modeling and using contexts. Section 3 presents our upper-level context model that is further used as a conceptual bridge for domain-specific models in PSI and ACTIVE projects. Section 4 describes these domain-specific models with the emphasis on the refinement of the semantics of a Context[5]. Section 5 analyses the alignment of our representation of a Context with foundational theories. Section 6 outlines the use of the presented context model in the software tools developed in PSI and ACTIVE projects. Section 7 concludes the paper and outlines the planned future work.

2 Related Work

Apparently the notion of a Context is both: (i) reflecting a mental state that people use or are aware of quite frequently for determining the pragmatics in their situations; and (ii) very vaguely defined for machine processing. Indeed, the definitions of a Context

[3] ACTIVE – Enabling the Knowledge Powered Enterprise (http://active-project.eu/) is the EU FP7 Integrating Project.

[4] Performance Simulation Initiative (PSI) is the internal R&D project of Cadence Design Systems GmbH

[5] Here and further in the paper a capital letter at the beginning of the word means that a concept, a model or a tool name is mentioned.

vary substantially depending on a field [16]. Several reviews (for example [8], [9], [10]) point out to the cross-disciplinary nature of a Context mentioning different stances in denoting and modeling contexts.

In theoretical Artificial Intelligence (AI), more specifically in the study of events and situations, in commonsense reasoning, a Context is understood often synonymously to a Situation [1]. Different aspects of contexts are highlighted and used in defining categorizations and formal logical representations [1]: projections, approximations, ambiguities, mental states. One of the prominently widely accepted metaphors of a context is the box model [2] that allows analyzing the dependencies of contexts following the dimensions of partiality, approximation, and perspective. The idea of this approach is to look at a circumscription of a context and analyze its placement and dependencies on the "terrain" of the observable contexts structured alone the mentioned dimensions. Such an analysis allows understanding the situation circumscribed by the interior of the context. At a very general level of understanding AI approaches find their root in the definition by Abowd et al [4]: "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves". These "situationalist" approaches of AI find reflection in the "environmentalist" approach that has been pursued by us in the former work [5] and further in the ACTIVE project. Our approach differs by the incorporation of processes as possible element kinds comprising a Context.

In Conceptual Modeling (CM) and Knowledge Representation (KR) more attention is paid to the structural aspects and categorization of context kinds. One of the well founded approaches to context modeling [3] is based on the understanding that a Context is a referential kind per se and therefore has to be separated from the representation of an Entity. The context kinds are further classified as intrinsic and relational. Situations are modeled by involving the combinations of contexts of different kinds. Our approach to modeling contexts is aligned with the referential character of a Context and its attribution to "MomentUniversals" [3]. In addition to that, in PSI and ACTIVE we place our model in the setting of loosely defined dynamic informal processes, environments, and subjective perceptions of what happens in these environments. The emphasis in the PSI and ACTIVE domain "serializations" of our upper-level model of a Context are slightly different. In PSI the model is closer to the situational and referential representation of a Context. In ACTIVE a Context is modeled in a holistic way as a part of an Environment. Many of the foundational ontologies contain the formalizations of the semantics of a Context at a high level of abstraction. Cyc [7] for instance is even structured in contextual parts for better usability.

Yet another perspective in the vast body of research on contexts and context-awareness is the use of contexts in software applications. Here as well exist a number of context definitions in different areas, for example in Ambient Intelligence [4] or the Semantic Web [22]. The area covered by our work in PSI and ACTIVE is more related to exploiting user contexts in knowledge-involved daily tasks. The approaches to context modeling and use around user context models and applications are as presented below.

In EPOS project [17] a user context is denoted as the things that influence knowledge work. Following an approach that is similar to the one of ACTIVE, a context-sensitive application can detect the user's current working context through user observation and logging and further support the user with suggestions and other services[6]. As a part of this approach the two ontologies were developed: (i) UserContextOntology[7] that is a top-level RDF Schema for modeling and processing user context and also providing operators and comparators for that data; and (ii) NopOntology (Ontology of Native User Operations)[8] that is an RDF schema to model the native operations a user does when working. The NopOntology models generic information objects (file, website, mail) and operations on them (open, close, save).

The work on user context done in EPOS has been further used as a basis in the NEPOMUK project[9]. NEPOMUK developed a UserContextService as part of their framework[10] that can be divided in three parts that work together:

(i) Observing user operations via plugins that send messages to the UserWorkContext service. The observations are expressed using the NopOntology, but only describes the actions (browse to, open mail), but not the objects of operations (website, mail) which are well-defined through the NieOntology and PIMO Ontology[11] [20].

(ii) Gathering user operations in the UserWorkContext service and computing and updating the user context thread. Then, the work context is represented in the UserContextOntology describing objects related to user's tasks which attributes are computed and change constantly (like relevance).

(iii) Using context in the GUI and to support the users

This approach is used as part of NEPOMUK's implementation[12] in KDE (the graphical desktop environment for Unix/Linux workstations)[13].

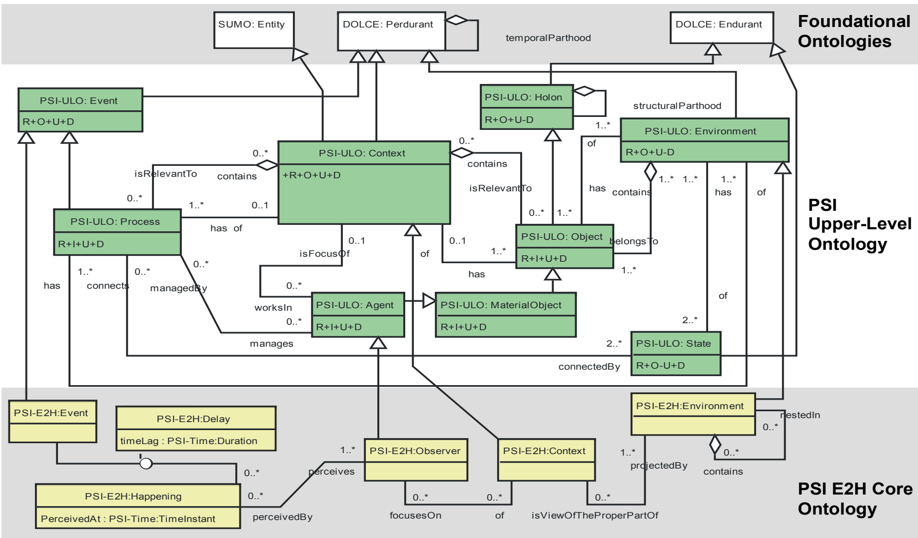
APOSDLE project enhances knowledge worker productivity by supporting informal learning and teaching activities in knowledge workers' everyday work processes and within their work environments [18]. This is done including the learner's current work context for the three roles (called 3spaces) a knowledge worker performs at the professional workplace: (i) the role of a learner, where APOSDLE presents contextual knowledge sources as part of learner's current work context; (ii) the role of an expert, where APOSDLE enriches artifacts with context information turning them into contextualized collaboration artifacts; and (iii) the role of a worker, where APOSDLE enables workers to access content from several diverse knowledge sources without having to change the environment based on their working context. APOSDLE characterizes user context [19] by a relevant subset of all surrounding potentially dynamic (e.g. temporal, environmental) information and external and internal conditions considering a goal bounded to a knowledge worker. The User Context is then an abstraction of three context spaces depending on the particular role

[6] http://usercontext.opendfki.de/
[7] http://usercontext.opendfki.de/wiki/UserContextOntology
[8] http://usercontext.opendfki.de/wiki/NopOntology
[9] http://nepomuk.semanticdesktop.org/
[10] http://dev.nepomuk.semanticdesktop.org/wiki/UserWorkContext
[11] http://www.semanticdesktop.org/ontologies/pimo/
[12] http://techbase.kde.org/User_talk:Harikrishna
[13] http://nepomuk.kde.org/

in each particular moment. The work-related context space is defined by a knowledge worker's tasks and the resources necessary to execute tasks. The learning-related context space is defined by a knowledge worker's competencies. The knowledge-related context space is defined by a knowledge worker's knowledge with regard to a certain knowledge domain.

3 Context Model

The upper-level context model (Fig. 1) has been developed in response to the requirements of the ACTIVE project in order to enable user context awareness in ACTIVE software for information delivery [13]. The context model has been made the part of the PSI-ULO v.2.3[14] that has been developed using the Shaker Modeling methodology for ontology refinement [6]. The upper-level model has been further used for developing the domain extensions of context models both in the Suite of PSI Ontologies v.2.3 that is used in the ACTIVE Case Study on engineering design in Microelectronics [12] and in the ACTIVE Knowledge Process Model that is used in the other software developed in ACTIVE, for example in the Context Visualizer.



Legend: **(mA…MA), (mB…MB)** are the multiplicities denoting the (instance) cardinality of the relationship:
(m,M)A specifies how many (**m**inimally, **M**aximally) instances of **A** may be related to the ONE SPECIFIC instance of **B**;
(m,M)B specifies how many (**m**inimally, **M**aximally) instances of **B** may be related to the ONE SPECIFIC instance of **A**.
DOLCE is the foundational ontology of the WonderWeb ontology library [14]; SUMO is the Suggested Upper Merged Ontology [15].

Fig. 1: The upper-level context model and its domain-level refinement by PSI E2H Ontology.

[14] The reference specification of the PSI Upper-Level Ontology is available on the Wiki at http://isrg.kit.znu.edu.ua/ontodocwiki/index.php/PSI_Upper-Level_ontology

A Context[15] of an entity (that has the context) is the selection of related things that facilitate interpreting, using, or performing the entity having this context in a pragmatic way. For denoting a Context it is therefore required to answer:

(i) **The context of what is specified?** A Context could be either of a Process or of an Object. Examples are: the context of a development team affiliated to an organization, the context of a project, the context of the development process of the configurable multimedia controller.

(ii) **What is relevant for the inclusion in the context?** An instance of a Context may contain the instances of a Process or of an Object as relevant referential constituents. Examples are: (a) the context of the process of engineering design may refer to the members of the development team, the manager, the resources used or consumed, the tools used, the design artifact under development; (b) the context of the development team (subclass of an object) may contain the design processes performed by the team, the organization to which the team is affiliated, the tools and the resources, etc.

An Object[16] in PSI-ULO is a Holon[17] that has Environment, belongs to an Environment, and may be changed in the execution of an AtomicAction. An Object may have Characteristics and may be either material or immaterial. As an Object inherits the structuralParthood relationship of a Holon the context model accounts for the objects of any structure and complexity. The constraint that is put by the model onto its object related part is that a Holon is an Endurant. Therefore the compositions and aggregations of Objects are static in time. However a Context allows for temporally dynamic aggregations of its referential components, objects in particular. Therefore a Context, like an Event or an Environment, is a Perdurant.

In contrast to an Object, a Process in PSI-ULO is a Perdurant. A Process[18] is a specialization of an Event that is stateful and possesses pro-active character. A Process has its Environment – the part of the world which is changed in the course of the Process. A Process is pro-actively directed by the Agent who manages it. As the context model contains the concept of a Process with its relationship to the concept of a State, the situations can be modeled as the states of the Environment. Moreover, as a Process is explicitly related to its Environment, the model possesses a clear environmentalist grounding.

(iii) **Who uses the Context?** A Context is used by an Agent to define the current working focus and determine working priorities. For example if a manager supervises several design projects he has to concentrate on each of them at different time. When he is focused on a particular project the things relevant to the context of this project become more important. Therefore we may say that the manager has switched his work to the context of this project and considers that his actions applied on the items relevant to the chosen context are of the higher priority than the actions applied to the other contexts.

[15] http://isrg.kit.znu.edu.ua/ontodocwiki/index.php/Context

[16] http://isrg.kit.znu.edu.ua/ontodocwiki/index.php/Object

[17] A holon is a term that denotes a system (or phenomenon) that is a whole in itself as well as a part of a larger or a higher-level system (or phenomenon). The term is attributed to A. Koestler (e.g. [24]).

[18] http://isrg.kit.znu.edu.ua/ontodocwiki/index.php/Process

After the introduction of the context model the refined PSI-ULO taxonomy has been formally evaluated using OntoClean Methodology [11]. The meta-properties have been assigned to all the concepts (see Fig. 1 for the Context-related part) and the analysis of the adherence of the taxonomy to formal constraints has been undertaken[19]. The concept of a Context has been qualified as rigid (+R), supplying identity (+O), carrying unity (+U), and externally dependent on the other concepts (+D). A Context is rigid because for any instance of a Context it holds true that it is always a Context. If x (at time instant t) and y (at time instant t') are Contexts and they referentially contain the same instances of a Process and an Object ($\Gamma(x,y,t,t')$), then $x = y$. Hence, a Context supplies (its own) identity. A Context subsumes to DOLCE: Perdurant and therefore inherits its temporalParthood relationship to self, which is a unifying relation. Indeed, a Context carries unity condition because it is a whole comprising other instances of a Context as proper temporal parts. A Context is externally dependent on other concepts: a Process, an Object, and an Agent. For instance it is impossible to qualify something (x) as a Context without explicitly pointing to y which is the process or the object relevantTo the context, or the agent that worksIn the context.

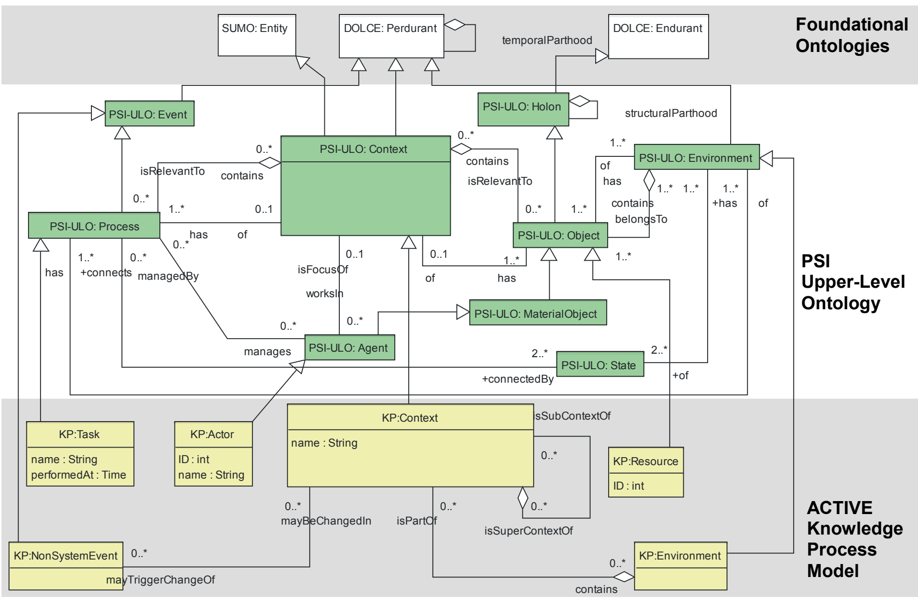


Fig. 2: ACTIVE context model as a domain-level refinement of the PSI-ULO context model.

The upper-level context model (Fig. 1, 2) as a part of the PSI-ULO serves as a semantic bridge [6] for enabling interoperability between different context-aware applications in different though overlapping domains. Via this bridging the upper-level model puts both domain-level models in one semantic context circumscribing

[19] The outline of the OntoClean meta-properties, constraints and assumptions is given in Annex A

the unifying feature of these domains. This feature is the account for the personalized user context of a knowledge worker performing informal, loosely defined, and dynamically ramified processes in his everyday work using his tacit knowledge.

4 An Environmentalist View on Contexts in Informal Processes

The domain-level models that are bridged by the context model of PSI-ULO are the context model of the PSI Environment, Event, and Happening ontology (E2H) and the ACTIVE Knowledge Process Model.

E2H provides a subjectivist view of an Agent, presented by an Observer concept, and the model of his individual perceptions of the events that happen in his Environments [5]. A Context in E2H (Fig 1, and also http://isrg.kit.znu.edu.ua/ontodocwiki/index.php/Environment,_Event,_and_Happening_ontology) is the view of an Observer on the proper part of the Environment. An Observer is a PSI-ULO: Agent that perceives events as happenings. In positioning itself in an Environment and adjusting its behavior an Observer focuses on a Context. For example, an Observer being situated in different environments may have different properties: play different roles, have different beliefs, have different availabilities, execute different atomic actions, etc.

An E2H: Environment in the ontology subsumes to PSI-ULO: Environment and refines the model of environment by specifying the way an environment changes. An Environment contains objects (an AffectedObject) which characteristics (AffectedCharacteristic) are affected in the Event changing its AffectedValue. From the other hand, the Environment containing the AffectedObject is the Environment in which an InternalEvent affecting this object occurs. One more refinement provided by E2H: Environment in the property of being a structural aggregate of Environments. This parthood relationship allows modeling nested environments. Finally, an Environment could be projected by the Context of an Observer. Such a context is the view on a particular proper part of the Environment.

A Happening of an Event is the perception of this event by an Observer. Hence, in terms of PSI-ULO a Happening is a specific sort of an atomic action performed by an Observer. A Happening is atomic because it can not be split in parts without ceasing being a happening of this event. An Event could be perceived as a Happening by an Observer only if the event affects the object belonging to the part of the environment that is in the context of the observer. A Happening, in difference to the associated Event, never has duration but occurs instantly – at a TimeInstant when the perception is recognized by the observer. A Happening may occur with a certain lag in time with respect to the percept Event. The reasons for such a delay may be: (i) the observer may take a certain time to notice the change in the value of the characteristic of the affectedObject, or (ii) the change may become apparent with a delay.

In ACTIVE project the Context Model (Fig. 2) is one of the central parts of the ACTIVE Knowledge Process Model (KPM) [30]. The Context is contained within the Environment. The Context itself is defined as a collection of related things of a specific State of the Environment. The things related to a Context are Actors, Tasks, Resources, and Events. A Resource is an object which is associated with a Task and belongs to a specific Context.

The KPM is bridging the common understanding of processes, either tacit or formal, to the implemented software underneath. It facilitates turning informal processes into more formal (or semi-formal) processes by defining terms such as states, state transitions, admissible actions, as well as composing processes in various, dynamic ways.. The model does not require any concrete and explicitly defined sequence of action. It puts the actor – the knowledge worker – into the center of driving his or her knowledge processes.

A Knowledge Process (KP) is denoted as a loosely defined and structural ramified collection of actions. The structure of such a process and the order of action are not fully defined at the start of a KP. Many actions require a decision by an actor about the follow-up action. At such a decision point the actor uses his (tacit) knowledge and the current working context to decide about the successor action.

To complicate matters, as circumstances change, the actor may decide to work in a different context, rather than follow the normally expected pattern. In this way the actor drives and carries out the KP. The context in the KPM is the part of the working environment in which the KP is carried out. The context is composed of the elements of the working environment that have to have a priority treatment by the actor in this KP. Therefore the constitution of a context influences the decisions taken by the Actor. Those decisions have to been taken during execution time over the process development path and lead to emerging structural ramification constituted by admissible alternatives. The outlined higher level denotation of knowledge processes, contexts, actions, and actors is leading to a more formal mapping and alignment with the PSI-ULO.

A Task (subclass of PSI-ULO: Process) is managed by an Actor (subclass of PSI-ULO: Agent) containing subtasks. The AdmissibleAction is a PSI:AtomicAction and therefore wrapped by a Task. A KnowledgeProcess is a specialized Task. The Actor as a sub class of a PSI:Agent uses either tacit or explicit Knowledge, to decide about FollowupActions and to drive the KP. The Decision about the FollowupAction is driven by the Goal (subclass of PSI-ULO: Goal).

A PrimitiveEvent is an evidence of an action, e.g. something which a system is aware of, and which forms an input to the event mining for event pattern detection. We distinguish between system and non-system events. System events are observable by the system, such as 'file opened' or 'file closed'. Non-system events are not observable by the system because the happen outside the system itself, such as talk to a colleague. An Environment has States. The transition from one State of the Environment to another State is caused by a PrimitiveEvent.

ACTIVE is trying to combine top-down and bottom-up approaches to transform informal knowledge processes into more formal processes. Top-down means that we start from a descriptive level where the knowledge worker defines his tasks and activities (or derives these from a business- or master process). Those definitions are shared within the organization and evolve over time. The bottom-up approach is about mining and learning from event and action patterns to predict follow-up actions and recommend alternatives to the knowledge worker. Patterns in general are Rules as defined in PSI-ULO. An EventPattern is a *regulatory* on the event log which could be connected to a defined ActionPattern. In the KPM EventPattern, TaskPattern, and

ActionPattern are the patterns that will be identified by the underlying mining services (bottom-up).

Thus, the ACTIVE KPM provides concepts to express stateful creative dynamic processes, actors, context and tasks situated in nested dynamic environments based on the formal representation of time, events, and actions.

5 Checking Context Model with Foundational Theories

Several foundational ontologies have been reviewed to check if the proposed context model is aligned with their top-level definitions of the semantics of a Context: CYC [25], the D&S extension to DOLCE [14], SUMO [15] and WordNet [26], and BFO [14].

In CYC a Context is a specialization of CYC: AspatialInformationStore and CYC: AbstractIndividual. An individual context is the representation of the corresponding instance of a CYC microtheory that is an atemporal, aspatial, informational thing, though its components may possess temporal or spatial extent. Each context serves to group together a set of assertions that share some common assumptions; the assertions in a microtheory constitute the content of that microtheory. Hence, contexts are used for circumscribing corresponding microtheories to enable adding new assertions and facilitating reasoning with less effort. A Context is understood as a region in a knowledge space having several dimensions (projections) as outlined in Fig. 3 in a simplified way. It is mentioned that the order of analyzing the "footprint" of an assertion onto these projections is important – so the dimensions of the knowledge space are not orthogonal. However, no recommendations on the order of applying projections are given, probably because of the foundational nature of CYC. In essence, CYC context model is the abstract collection of assertions that hold true within a particular region circumscribed by a combination of dimensional constraints.

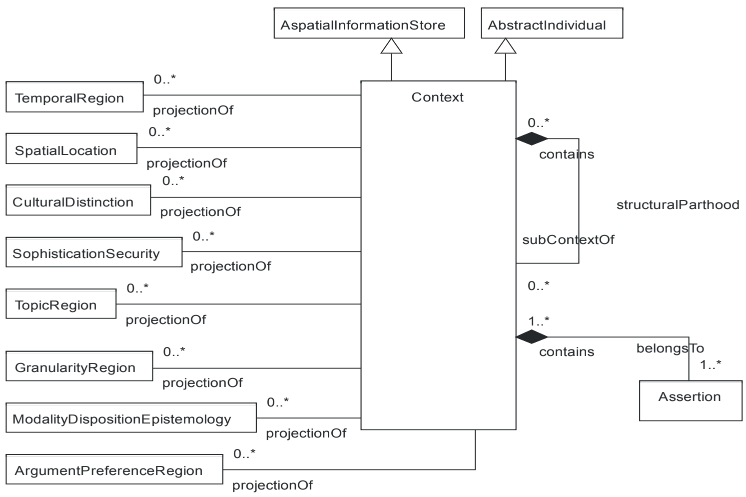


Fig. 3: A simplified context model of CYC reconstructed from [25].

A primary distinction of the proposed model is that contexts in PSI-ULO contain components that belong to environments and are not abstract, while the constituents of CYC contexts are disembodied. Therefore a PSI-ULO: Context could be considered a subclass of a CYC: Context only to a limited extent – both are circumscribed using several dimensions. The primary dimensions for a PSI-ULO: Context are temporal regions, structural compositions, and attribution to an Agent. Contexts differ temporally as they are Perdurants. So, there is a correspondence to a CYC: TemporalRegion dimension in the proposed model. Contexts differ in their structures because both Processes and Objects inherit temporal or structural parthood properties respectfully by subsumption. The structural dimension of the PSI-ULO context model corresponds roughly to the Topic/Granularity projections of SYC. Contexts in PSI-ULO are associated to an Agent who has this Context as his working focus. This dimension corresponds to the CulturalDistinction projection of CYC as it is also called "restrictions on the AgentType" [25].

The ontology of Descriptions and Situations (D&S) has been developed [14] as an extension to DOLCE. D&S is a descriptive theory that outlines the distinctions between the states of affairs (flux-like things), logical theories structuring these fluxes denoted as Situations, and the Descriptions of these structures satisfied by the corresponding structuring theories in the terms of a foundational ontology (DOLCE). The UML model of D&S ontology reconstructed from the description in [14] is given in Fig. 4.

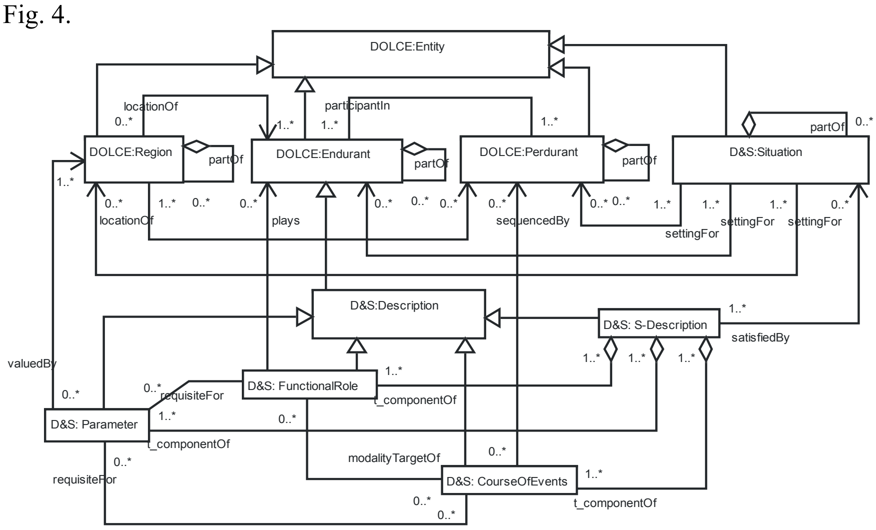


Fig. 4: Descriptions and Situations ontology – extension of DOLCE.

D&S ontology follows a "situationalist" approach in defining contexts. Contexts are the descriptions of Situations (S-Description) specified in terms of the sequences of events (D&S: CourceOfEvents) that essentially are PSI-ULO: Processes, D&S: FunctionalRoles played by DOLCE: Endurants that are participants in processes, and D&S: Parameters describing constraints on the characteristics of the modeled state of affairs. Hence, a PSI-ULO: Context can be mapped to a D&S: S-Description, but again to a limited extent.

One important difference of the PSI-ULO model is that it involves both objects (Endurants) and processes (Perdurants) as the components belonging to a Context while the model of D&S contains process descriptions only. Another difference that allows positioning our approach as "environmentalist" is that contexts in PSI-ULO are situated in environments as the containers of Process and Object instances that have their environments and belong to their (possibly different) environments. Finally, in the proposed model agents (specialization of an Object) are not only the components of contexts, but also the active users of contexts as their working foci.

SUMO only states that a WordNet: Context subsumes to a Proposition that is a subclassof an Abstract (thing). In WordNet the relevant definition of a Context states that a Context is "the set of facts or circumstances that surround a situation or event" – Fig. 5.

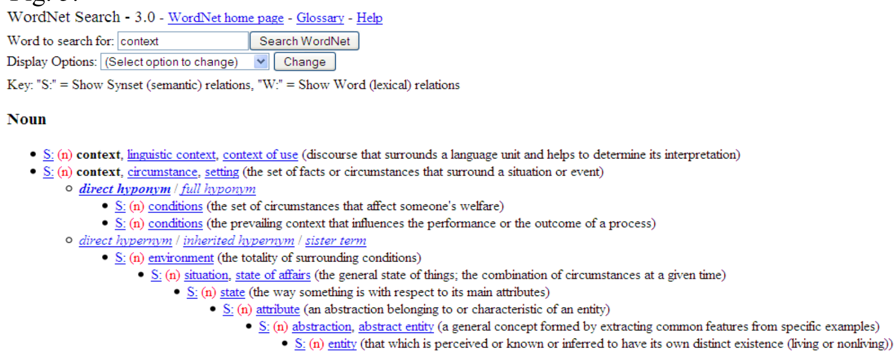


Fig. 5: The definition of a Context in WordNet.

Like in CYC a WordNet: Context is a disembodied abstract thing but in difference to CYC it subsumes directly to an Environment. However, an Environment in WordNet is denoted as a hyponym to a Situation or a State of Affairs. Such a definition makes our model disaligned with WordNet.

In BFO [27] only processual contexts (settings) are defined as Occurrent entities consisting of a characteristic spatial shape inhering in some arrangement of other occurrent entities. Processual contexts are the entities at or in which other Occurrent entities can be located or occur. Hence, contexts in BFO are situations or states of affairs attributed to spatial regions. The PSI-ULO model is very partially aligned with the BFO model of a Context – only in the sense that in both models a Context is a Perdurant and circumscribes a state of affairs.

6 Context Model in Use

The proposed context model has been used in software tool implementations for PSI and ACTIVE projects. In PSI it is the basic model for representing structural contexts within an ontology for knowledge engineers in the Ontology Difference Visualizer (ODV) software tool [28]. In Active the model has been used as a basic upper-level formal knowledge representation for knowledge workers in the Context Visualizer front-end of the ACTIVE Knowledge WorkSpace (AKWS) software [29].

A proof of concept prototype of ODV has been implemented in PSI as an ontology engineer plug-in for Cadence ProjectNavigator software. The composition of a context of an ontology concept, as implemented in the ODV, could be formed by specifying the radius of the neighborhood of this concept. Further it could be fine-tuned by manual inclusion or exclusion of the concepts, object properties, subsumption relationships. The analyzed ontological context may be placed on the wafer of the source (old) ontology. The context may be also altered by considering or filtering out the concepts belonging to the imported ontology modules. All the mentioned constituents of a context are Objects in terms of the context model. Finally the "owner" filter may be employed for concentrating on the changes that have been introduced by a particular ontology engineer in the team. These "owners" are the instances of an Agent in terms of the context model.

A key factor in ACTIVE is to help knowledge workers manage and understand the context (elements, boundaries, and environment) of their daily collaborative processes. This visualization can be addressed from different perspectives. Moreover, as each complex collaborative process is performed in some context, the visualization of such a context helps understand the underlying relationships within collaborative processes in which those contexts are shared.

Contexts in the enterprise environments have some specifics that should be considered in user-tailored representations: (i) there are different views on context, varying by the observation perspective (the aspect in focus) and the purpose of using that context – particularly in terms of the range of possible entities to be considered, e.g. tags as a new interesting resource; (ii) the relationships within a context among files, people, tasks, and any type of resource are multiple and complex, where different items have different relevance to the context; (iii) an easier comprehendible interpretation of a context for non-expert users has to be provided – for example by visualizing contexts in the terms that are native for knowledge workers.

Consequently, the outlined specifics lead us to accounting for the following set of features for the ACTIVE context visualization tool: (i) use a human understandable visualization paradigm of the underlying context model; (ii) identify graphically different entities relevant to the visualized context as well as their relationships; (iii) identify the relevance (importance) of an item in the context to the user (the larger the icon is, the more relevant or important the item is to the user – for example the more time the user spends working on this item; (iv) provide easy to use facilities for filter the context elements; (v) deal appropriately with the size and complexity of context visualizations by providing the features for reducing the inherent complexity and facilitating understanding of the complex relationships within a context.

Component-wise the Context Visualizer comprises the: Context Mapper, Context Representation Model, Context Presentation Engine. The Context Mapper receives the incoming knowledge from the AKWS Services [23] (in particular, the User, Resource, Task, and Mining services) in terms of the KPM. For a better comprehendability by non-specalist users it maps the received context instances and consolidates them into the internally used Context Representation Model in terms of the resources within a context in ACTIVE platform [21].

7 Conclusions

The paper presented the context model developed in a parallel effort of ACTIVE and PSI projects in response to the requirements of the ACTIVE case studies. The upper-level context model, as a part of the PSI-ULO, serves as a semantic bridge for enabling interoperability between different context-aware applications in different, though overlapping domains. Through this bridging the upper-level model puts both domain-level models in one semantic context circumscribing the unifying feature of these domains. This feature is the account for the personalized user context of a knowledge worker performing informal, loosely defined, and dynamically ramified processes in his everyday work using his tacit knowledge. It has been also shown how the upper-level model is refined for the needs of finer-grained domain-level descriptive theories in the contexts of PSI (the E2H ontology) and ACTIVE (the KPM). Finally the paper outlines that the context model is used for developing software tools for knowledge workers. One such tool – the Context Visualizer – is the front-end part of the ACTIVE knowledge worker desktop, another is the tool for contextualized visualization of structural differences in ontologies developed in PSI for knowledge engineers.

Acknowledgements

The work described here has been funded as part of the IST-2007-215040 EU project ACTIVE and the internal R&D project PSI of Cadence Design Systems GmbH.

References

1. Guha, R., McCarthy, J.: Varieties of Contexts. In: P. Blackburn et al. (eds.): CONTEXT 2003, LNAI, vol. 2680, pp. 164--177, Springer, Heidelberg (2003)
2. M. Benerecetti, P. Bouquet, C. Ghidini, On the dimensions of context dependence: Partiality, approximation, and perspective. In: Akman, V. et al. (eds.): CONTEXT 2001, LNAI vol. 2116, pp. 59--72, Springer, Heidelberg (2001)
3. Dockhorn Costa, P., Guizzardi, G., Almeida, J.P.A., Ferreira Pires, L., van Sinderen, M.: Situations in Conceptual Modeling of Context. In: EDOC 2nd International Workshop on Vocabularies, Ontologies and Rules for the Enterprise, IEEE Press, NY (2006)
4. Abowd, G. D., Dey, A. K., Brown, P. J., Davies, N., Smith, M., Steggles, P.: Towards a Better Understanding of Context and Context-Awareness. In: Gellersen, H.(ed.): HUC 1999, LNCS, vol. 1707. 304—307, Springer, London, (1999)
5. Ermolayev, V., Keberle, N., Matzke, W.-E.: An Ontology of Environments, Events, and Happenings. In: 31st Annual International Computer Software and Applications Conference, pp. 539-546, IEEE Press, NY (2008)
6. Ermolayev, V., Keberle, N., Matzke, W.-E.: An Upper-Level Ontological Model for Engineering Design Performance Domain. In: Li, Q., Spaccapietra, S., and Yu, E. (eds.) ER 2008, LNCS, vol. 5231, pp. 98--113, Springer, Heidelberg (2008)
7. Lenat, D.B., Guha, R. V.: Building Large Knowledge-based Systems: Representation and Inference in the Cyc Project. Addison-Wesley (1990)

8. Bettinia, C., Brdiczkab, O., Henricksenc, K., Indulskad, J., Nicklase, D., Ranganathanf, A., Riboni, D.: A survey of Context Modelling and Reasoning Techniques. Pervasive and Mobile Computing, 6(2), 161--180 (2010)
9. Baldauf, M., Dustdar, S., Rosenberg, F.: A survey on Context-Aware Systems. Int. J. Ad Hoc Ubiquitous Comput. 2(4), 263—277 (2007)
10. Bradley, N.A., Dunlop, M.D.: Toward a Multidisciplinary Model of Context to Support Context-Aware Computing. Human–Computer Interaction, 20, 403--446 (2005)
11. Guarino, N., Welty, C.A.: Ontological Analysis of Taxonomic Relationships. In: Laender, A., and Storey, V. (eds.) ER 2000, LNCS, vol. 1920, pp. 210--224, Springer, Heidelberg (2000)
12. Ermolayev, V., Dengler, F., Jentzsch, E., Matzke, W.-E.: Articulation and Sharing of Distributed Design Project and Process Knowledge. In: IDC 2010, Springer, (2010)
13. Gomez-Perez, J. M., Grobelnik, M., Ruiz, C., Tilly, M., and Warren, P.: Using Task Context to Achieve Effective Information Delivery. In: 1st Workshop on Context, information and ontologies, pp. 1--6, ACM Press, New York (2009)
14. Masolo, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A.: Ontology Library (final), WonderWeb Deliverable D18 (2003)
15. Niles, I., Pease, A.: Towards a Standard Upper Ontology. In: Int. Conf. on Formal Ontologies in Inf. Systems, pp. 2--9. ACM Press, New York (2001)
16. Bazire, M., Brézillon, P.: Understanding Context Before Using It. In: Dey, A. et al. (eds.) CONTEXT 2005, LNCS, vol. 3554, pp. 29--40, Springer, Heidelberg (2005)
17. Schwarz, S.: A Context Model for Personal Knowledge Management Applications. In: MRC 2005, LNCS, vol. 3946, pp. 18--33, Springer, Heidelberg (2005)
18. Lindstaedt, S., Mayer, H.: A Storyboard of the APOSDLE Vision. In: Nejdl, W., Tochtermann, K. (eds.) EC-TEL 2006, LNCS, vol. 4227, pp. 628-633, Springer, Heidelberg (2006)
19. APOSDLE Scope and Boundaries, APOSDLE Project Deliverable D6.1, 2006
20. Sauermann, L., van Elst, L., Dengel, A.: PIMO - a Framework for Representing Personal Information Models. In: I-Semantics' 07 (2007)
21. Mladenic, D., Getoor, L., Ferlež,, J., Grobelnik, M.: Context definition and representation within enterprise environments. Deliverable of EU-FP7 project ACTIVE. D2.3.1 (2009)
22. Bouquet, P., Giunchiglia, F., van Harmelen, F., Serafini, L., Stuckenschmidt, H.: C-OWL: Contextualizing Ontologies. In: Fensel, D., Sycara, K.P., Mylopoulos, J. (eds.) ISWC 2003, LNCS, vol. 2870, pp. 164--179 (2003)
23. Warren, P., et al.: Improving Knowledge Worker Productivity -- the ACTIVE Integrated Approach, BT Technology Journal, 26, pp 165--176 (2009)
24. Koestler, A.: Beyond Atomism and Holism -- the concept of the holon. In: Koestler, A., Smithies, J.R. (eds.) Beyond Reductionism: New Perspectives in Life Sciences, pp. 192—216, Hutchinson, London (1969)
25. Lenat, D.: The Dimensions of Context-Space. Cycorp (1998)
26. Fellbaum, C. (ed.): WordNet: an Electronic Lexical Database. The MIT Press (1998)
27. Spear, A. D.: Ontology for the Twenty First Century: An Introduction with Recommendations. IFOMIS, Saarbrücken, Germany (2006)
28. Ermolayev, V., Copylov, A., Keberle, N., Jentzsch, E., Matzke, W.-E.. Using Contexts in Ontology Structural Change Analysis. In: Ermolayev, V., Gomez-Perez, J.-M., Haase, P., Warren, P, (eds.) CIAO 2010, CEUR-WS (2010)
29. Warren, P., Gomez-Perez, J.-M., Ruiz, C., Davies, J., Thurlow, I., Dolinsek, I.:. Context as a tool for organizing and sharing knowledge. In: Ermolayev, V., Gomez-Perez, J.-M., Haase, P., Warren, P, (eds.) CIAO 2010, CEUR-WS (2010)
30. Tilly, M.: Dynamic Models for Knowledge Processes – Final Models and Evaluation. ACTIVE Deliverable D1.2.2 (2010)

Annex A. Meta-Properties, Constraints and Assumptions

As suggested by the OntoClean methodology for the formal evaluation of the ontological adequacy of taxonomic relationships [11]:

Definition 1: *rigidity*, *non-rigidity*, and *anti-rigidity*. A *rigid property* (+R) is a property that is essential to *all* its instances, i.e. a property ϕ such that: $\forall x \phi(x) \rightarrow \Box \phi(x)$. A *non-rigid property* (–R) is a property that is not essential to *some* of its instances, i.e. $\exists x \phi(x) \rightarrow \neg \Box \phi(x)$. An *anti-rigid property* (~R) is a property that is not essential to *all* its instances, i.e. $\forall x \phi(x) \rightarrow \neg \Box \phi(x)$.

Definition 2: *identity*. An *identity condition* (IC) is a formula Γ that satisfies either (1) or (2) below, excluding trivial cases and assuming a predicate E for *actual existence* at time *t* or *t′*:

$$E(x,t) \wedge \phi(x,t) \wedge E(y,t') \wedge \phi(y,t') \wedge x = y \rightarrow \Gamma(x,y,t,t') \quad (1)$$

$$E(x,t) \wedge \phi(x,t) \wedge E(y,t') \wedge \phi(y,t') \wedge \Gamma(x,y,t,t') \rightarrow x = y \quad (2)$$

An IC is necessary if it satisfies (3) and sufficient if it satisfies (4). Based on this, two meta-properties are defined:

Identity (I): Any property *carries* an IC (+I; –I otherwise)) iff it is subsumed by a property supplying that IC (including the case where it supplies the IC itself).

Own Identity (O): A property ϕ *supplies* an IC (+O; –O otherwise) iff: (i) it is rigid; (ii) there is a necessary or sufficient IC for it; and (iii) the same IC is not carried by *all* the properties subsuming ϕ.

Definition 3: *unity.* An object *x is a whole under ω* iff *ω* is an unifying relation such that all the parts of *x* are linked by *ω*, and nothing else is linked by *ω*. A property *ϕ carries a unity condition* (+U; –U otherwise) iff there exists a single unifying relation *ω* such that each instance of *ϕ* is a whole under *ω*. A property has *anti-unity* (~U) if every instance of the property is not a whole.

Definition 4: *dependence.* A property *ϕ* is *externally dependent* (+D; –D otherwise) on a property *ψ* if, for all its instances *x*, necessarily some instance of *ψ* must exist, which is neither a part nor a constituent of *x*:

$$\forall x \Box \ (\varphi(x) \rightarrow (\exists y \psi(y) \wedge \neg P(y,x) \wedge \neg C(y,x)), \quad (3)$$

where $P(y,x)$ is a parthood relationship; $C(y,x)$ is a constitution relationship.

Assignment of OntoClean meta-properties imposes several constraints on taxonomic relationships. If ϕ and ψ are two properties then the following constraints hold:

$\phi^{\sim R}$ can't subsume ψ^{+R} (4)

ϕ^{+I} can't subsume ψ^{-I} (5)

ϕ^{+U} can't subsume ψ^{-U} (6)

$\phi^{\sim U}$ can't subsume ψ^{+U} (7)

ϕ^{+D} can't subsume ψ^{-D} (8)

Properties with incompatible ICs/UCs are disjoint. (9)

Finally, the following assumptions regarding identity are made. **Sortal Individuation**: every domain element must instantiate some property carrying an IC (**+I**). **Sortal Expandability**: if two entities (instances of different properties) are the same, they must be instances of a property carrying a condition for their identity.