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Informatik

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Nr. 5/2011

Arbeitsberichte aus dem Fachbereich Informatik

Universität Koblenz-Landau • Campus Koblenz • Universitätsstraße 1 • 56070 Koblenz
Telefon +49 261 287-0 • http://www.uni-koblenz.de

Arbeitsberichte des Fachbereichs Informatik

ISSN (Print): 1864-0346
ISSN (Online): 1864-0850

Kontaktdaten der Verfasser

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Designing Core Ontologies

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February 22, 2011

Abstract

One of the key factors that hinders integration of distributed, heterogeneous information systems is the lack of a formal basis for modeling the complex, structured knowledge that is to be exchanged. To alleviate this situation, we present an approach based on core ontologies. Core ontologies are characterized by a high degree of axiomatization and formal precision. This is achieved by basing on a foundational ontology. In addition, core ontologies should follow a pattern-oriented design approach. By this, they are modular and extensible. Core ontologies allow for reusing the structured knowledge they define as well as integrating existing domain knowledge. The structured knowledge of the core ontologies is clearly separated from the domain-specific knowledge. Such core ontologies allow for both formally conceptualize their particular fields and to be flexibly combined to cover the needs of concrete, complex application domains. Over the last years, we have developed three independent core ontologies for events and objects, multimedia annotations, and personal information management. In this paper, we present the simultaneous use and integration of our core ontologies at the example of a complex, distributed socio-technical system of emergency response. We describe our design approach for core ontologies and discuss the lessons learned in designing them. Finally, we elaborate on the beauty aspects of our core ontologies.

1 Introduction

Domains that require the exchange of a high amount of complex, structured knowledge such as medical systems, distributed media management, and emergency response have a high pressure for systems integration in order to facilitate efficient communication and information exchange. For example, in emergency response different entities such as an emergency hotline, police department, fire department, and emergency control center are involved. These entities need to exchange among others knowledge about what happened during an incident, tasks communicated between the entities, and media information that documents the incident. Due to the lack of appropriately integrated systems at the different emergency response entities, the complex, structured knowledge is currently exchanged via natural language on the phone. This is very error-prone and inefficient. Rather, the different, heterogeneous systems used by the emergency response entities should be integrated to provide a more efficient and effective exchange of the knowledge. One of the key factors that hinders integration of these systems is the lack of a formal basis for modeling the complex, structured knowledge that is to be exchanged. So far, this problem has not been solved due to the lack of networked ontologies that provide a flexible means to model the complex structure of the knowledge exchanged and at the same time provide a formal semantics to that structure.

In this paper, we propose an approach based on core ontologies to alleviate this situation. An ontology allows for formally representing the relevant concepts and relations of a considered domain in a machine readable format (Oberle et al., 2009b; Oberle, 2006). Core ontologies provide a precise definition of structural knowledge in a specific field that spans across different application domains, e.g., software services, personal information management, knowledge organization, multimedia annotations, and others (Oberle, 2006). They combine a number of specific properties that have been derived from reported experiences in designing core ontologies (Oberle et al., 2007, 2006; Oberle, 2006) and the development of our own core ontologies (Arndt et al., 2009; Scherp et al., 2009a; Staab et al., 2008; Arndt et al., 2007; Franz et al., 2007). These properties are axiomatization and formal precision, modularity, extensibility, reuseability, and separation of concerns.

Axiomatization and Formal Precision. A high degree of axiomatization and formal precision is provided by core ontologies. By this, a common understanding in a particular field is established in order to ensure interoperability through machine accessible semantics. Systems can reason about the represented knowledge and carry out semantic checks on its validity. The axiomatization and formal precision is achieved by basing on a foundational ontology.

Modularity. Core ontologies should follow a pattern-oriented design approach. By this, they are modular within the field for which they are designed. Similar to design patterns in software engineering (Gamma, 2007), ontology design patterns provide a modeling solution to a recurrent ontology design problem (Gangemi and Presutti, 2009). The core ontology is a composition of such ontology design patterns with appropriate dependencies between the patterns (Gangemi and Presutti, 2009). This enables a pathway for extensibility and reuseability.

Extensibility. Being modular, a core ontology allows for adding new and updating or removing modules, i.e., ontology design patterns it defines. By this, the core ontology is able to reflect system evolution (cf. adaptability in (Vrandečić, 2009)). It is extensible towards new developments and functional requirements that arise.

Reuseability. Different systems are built for different purposes and users in different domains. Being modular, a core ontology supports reuse of its modules, i.e., the ontology design patterns despite of the different foci and domains the concrete systems have. At the same time a core ontology still guarantees formal precision of the overall knowledge it represents. In addition to the reuse of the domain-independent, structured knowledge defined by the core ontologies themselves, also existing domain knowledge can be reused. Core ontologies are able to incorporate existing domain ontologies and make use of that domain knowledge rather than requiring to remodel it.

Separation of Concerns. The structural knowledge defined in a core ontology is clearly separated from the domain-specific knowledge. This allows core ontologies to be applied in arbitrary application domains. Domain-specific knowledge such as a domain ontology on emergency response or sports can be integrated and reused without affecting the core ontology itself.

In this paper, we will show that combing these properties in a core ontology can lead to elegant solutions and interoperability in complex application domains. Due to the characteristics of their design such core ontologies can be flexibly combined to cover the needs of concrete, complex application domains. Thus, from our perspective they are to be considered *beautiful* ontologies.

Over the last years, we have developed three of those beautiful core ontologies. These core ontologies have been used over a long time, are very stable with respect to their design, and thus provide a sustainable solution for ensuring interoperability in complex socio-technical systems such as emergency response. These core ontologies are the Event-Model-F, COMM, and X-COSIMO. The core ontology Event-Model-F is designed for modeling events and objects (Scherp et al., 2009a). It allows for representing human experience and participation in real world occurrences and provides comprehensive support for modeling time and space, objects and persons, as well as mereological, causal, and correlative event relationships and event interpretations. The Core Ontology on Multimedia (COMM) (Arndt et al., 2009; Staab et al., 2008; Arndt et al., 2007) is designed for describing arbitrary digital media data. It allows for (semantic) annotations of media data and their decompositions. Finally, the Cross-Context Semantic Information Management Ontology (X-COSIMO) is designed for semantic information management and communication (Franz et al., 2007). It supports modeling the communication taking place between different persons and systems and the information associated with it such as task descriptions.

Our three core ontologies, i.e., the Event-Model-F, COMM, and X-COSIMO are based on the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) (Gangemi et al., 2002; Masolo et al., 2003). As foundational ontology, DOLCE aims at modeling the very basic and general concepts and relations (Borgo and Masolo, 2009; Oberle, 2006) that make up our world, e.g., objects, events, participation, and parthood. Foundational ontologies are generic across many fields (Oberle, 2006). They have a large scope and are highly reusable in different modeling scenarios (Borgo and Masolo, 2009). By their nature, foundational ontologies are much broader than core ontologies such as our Event-Model-F, COMM, and X-COSIMO. Core ontologies provide a refinement to foundational ontologies by adding detailed concepts and relations in their specific field. DOLCE already has proved to be a good modeling basis for core ontologies such as (Scherp et al., 2009a; Arndt et al., 2007; Franz et al., 2007; Oberle et al., 2006, 2007).

The Event-Model-F, COMM, and X-COSIMO have been carefully aligned with the foundational ontology DOLCE+DnS Ultralight[1] (DUL), a lightweight version of DOLCE. By this alignment, our core ontologies can be flexibly combined to cover the needs of complex application domains. Our core ontologies follow a pattern-oriented ontology design approach, i.e., they define a set of ontology design patterns targeted for the specific field they model. These patterns are based on the very generic patterns DUL provides such as the Descriptions and Situations (DnS) pattern and the Information Object (IO) pattern (Borgo and Masolo, 2009). By using a foundational ontology and following a pattern-oriented design approach, the core ontologies possess a solid, semantically precise basis. At the same time these core ontologies become modular and extensible with respect to their use in concrete applications and to changes in functional requirements. By applying the DnS pattern, our core ontologies allow for a clear separation of the structured knowledge captured by the core ontology and the domain knowledge provided by a domain ontology. Thus, they allow for integrating and reusing existing domain ontologies.

The remainder of the paper is organized as follows: In the next section, we motivate the need for core ontologies to model complex, structured knowledge by presenting a scenario of a complex, socio-technical system in the domain of emergency response. In Section 3, we demonstrate the simultaneous use and smooth interplay of our three core ontologies Event-Model-F, COMM, and X-COSIMO in the emergency response scenario. It demonstrates the use of the three core ontologies to model the complex, structured knowledge that needs to be exchanged between the different systems involved. The properties of core ontologies and our design approach for developing such core ontologies are presented in detail in Section 4. The concrete design of our three core ontologies the Event-Model-F, COMM, and X-COSIMO is presented in Section 5. In Section 6, we discuss the lessons learned when designing and using our core ontologies. We argue for the beauty of our core ontologies in Section 7, which lies in their ability to both formally conceptualize their particular fields and to be flexibly combined to cover the needs of concrete scenarios, before we conclude the paper.

2 Modeling and Sharing Complex, Structured Knowledge in Emergency Response

In the emergency response scenario of the EU project WeKnowIt[2] depicted in Figure 1 different emergency response entities are involved using different, heterogeneous systems. These systems need to exchange complex, structured knowledge that needs to be shared among the emergency response entities. Examples of emergency response entities are the emergency hotline, police department, fire department, emergency control center, and forward liaison officers. The emergency control center is in charge of coordinating the emergency response entities. It receives event descriptions from the emergency hotline, processes them, and communicates event descriptions with the police department and fire department. In addition, the emergency control center forwards

[1] http://ontologydesignpatterns.org/wiki/Ontology:DOLCE+DnS_Ultralite
[2] http://www.weknowit.eu/

event descriptions together with task descriptions to their forward liaison officers. Forward liaison officers are out in the field to report about a situation, verifying it, and documenting it, e.g., by taking photos and notes. As the following scenario shows, this socio-technical system for emergency response becomes very active in the case of an incident. Many different pieces of structured knowledge such as events, tasks, and multimedia data with metadata are created, combined, and communicated between the different emergency response entities involved. Subsequently, we discuss how our core ontologies are involved in modeling this complex, structured knowledge.

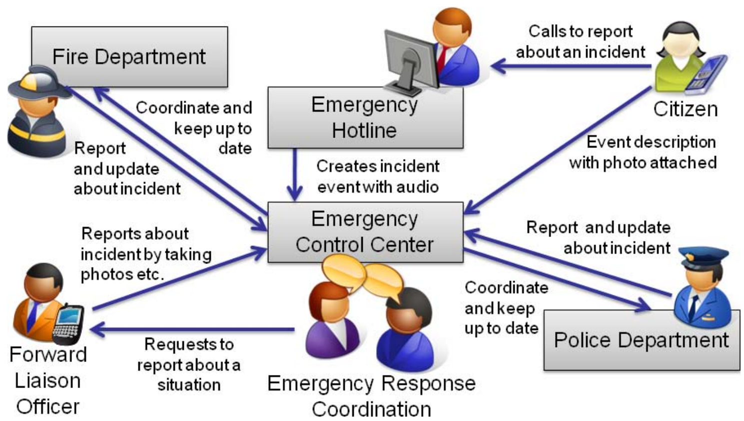

Figure 1: A distributed system for emergency response

2.1 Scenario

In an incident of a heavy storm a major flooding may happen. During the flooding a power outage occurs. Some citizens are lacking power supply and are calling the emergency hotline to report about the power outage event. The officers at the emergency hotline record these calls. In addition, they type in a textual description for each call to document the reported event in their system. The recorded calls are automatically processed by some speech recognition techniques, which creates a transcript of the calls. The algorithm also automatically distinguishes the different voices of the participants in the phone call and can automatically associate and differentiate utterances made by the citizen and the officer at the emergency hotline. Subsequently, the event description together with the processed call recording and its transcript are automatically transferred to the system of the emergency control center. The emergency control center also receives event descriptions from the systems of the police department and fire department that happen during the incident. Based on the evidence of the event descriptions, the officers in the emergency control center use their system to formulate hypothetical events that might have caused the power outage. To this end, event descriptions are analyzed, (semi-)automatically clustered, visualized, and put into relation. The officers conclude that there are two possible interpretations that might have caused the power outage, namely a snapped power pole close to the river that was reported by a citizen calling the emergency hotline or a serious problem with the power plant nearby. The correct assessment of the situation is very crucial in order to most effectively deploy the available emergency response resources. Thus, the different event interpretations modeled in the system need to be verified by the officers as soon as possible in order to confirm or reject the hypothesis. For this purpose, the officers in the emergency control center may contact the personnel of the power plant. At the same time, the description of the hypothetical event of a snapped power pole together with a task description is sent to the mobile device of a forward liaison officer. The forward liaison officer receives the task description. She drives to the location of the events to verify it and to document it by taking photos and notes. The photos can also be tagged or otherwise annotated. The event description extended by annotated photos are send back to the system of the emergency control center.

As the scenario shows, the different entities involved in an emergency response have to share structured knowledge among each other through the different systems they use. The structured knowledge is a combination of event descriptions that happen during an incident, e.g., provided by the citizens calling the emergency hotline or annotated by forward liaison officers when verifying a situation. It also comprises task descriptions that are communicated and shared, e.g., the forward liaison officers receive task descriptions (together with the event description) to clarify a specific situation at a certain place and to document about it by taking pictures and notes. Finally, these pictures and notes taken and the metadata that is attached to the media is another kind of structured knowledge that is communicated within the distributed socio-technical system for emergency response shown in Figure 1. As the discussion shows, the structured knowledge that is to be communicated is quite complex. In addition, the entities involved with this structured knowledge, i.e., the events, media data, and tasks appear and are relevant in different contextual settings that need to be modeled. For example, an event reported by a citizen to the emergency hotline and represented appropriately may become an attachment of a message with a task description that is sent by the emergency control center to one of their forward liaison officers.

2.2 Involved Ontologies

To model the complex, structured knowledge in the emergency response scenario, i.e., the events, media data, and tasks we use and combine our three core ontologies Event-Model-F, COMM, and X-COSIMO. For representing events and the multiple relationships between them, we use the Event-Model-F (Scherp et al., 2009a) that has been developed in the WeKnowIt project. The Event-Model-F provides a formal representation of the different aspects of events in which humans participate such as time and space, composition, correlation, and documentation. Compared to existing models, the Event-Model-F differs in providing sophisticated support for modeling causality, correlation, and interpretation of events.

The Core Ontology on Multimedia (COMM) (Arndt et al., 2009; Staab et al., 2008; Arndt et al., 2007) allows to represent arbitrary digital media data such as images, videos, and audio. It supports the different kinds of annotations of media data and their decomposition into segments. COMM is highly influenced by and specifically designed to support the low-level descriptors of MPEG-7 (MPEG-7, 2001). Its roots go back to the EU project aceMedia[3], where a first attempt to model a MPEG-7 ontology has been undertaken. This ontology is not based on a direct translation of MPEG-7 but on an analysis of the MPEG-7 standard. It follows a formal approach for modeling the multimedia annotation domain based on DOLCE (Bloehdorn et al., 2005). In the EU Network of Excellence K-Space[4], this idea of analyzing MPEG-7 in order to model a formal core ontology for multimedia has been taken up again. In contrast to the aceMedia approach, the COMM developed in K-Space is further axiomatized and based on ontology design patterns in order to acquire an easier to use and formally more sound model.

Finally, the Cross-Context Semantic Information Management Ontology (X-COSIMO) supports for modeling semantic information management and communication (Franz et al., 2007). X-COSIMO allows to represent the communication taking place between different persons and systems and the information associated with this communication like a task description. The core ontology has been developed in the X-Media project[5], which is dedicated to research on large scale and cross-media knowledge management solutions. In the X-Media project also COMM has been used and extended. Both core ontologies COMM and X-COSIMO play a key role in the shared representation of automatically extracted and newly created information in the X-Media project. Among others, the shared representation is exploited in user interfaces that enable users to deal with the diversity of the knowledge represented.

2.3 Summary

We have shown the requirement of sharing complex, structured knowledge at the example of a socio-technical system for emergency response. The structured knowledge to be modeled and exchanged within this scenario are the representation of events and objects, multimedia data and its annotations, and personal information management such as communication and tasks. In the next section, we present how such structured knowledge can be modeled with the core ontologies Event-Model-F, COMM, and X-COSIMO we have developed. We demonstrate the use of our core ontologies at the example of the emergency response scenario of the WeKnowIt project.

3 Modeling the Emergency Response Scenario

Referring to the scenario of the distributed socio-technical system for emergency response presented in Section 2, we exemplify in this section how the structured knowledge that is exchanged in this system can be modeled. We pick out a small part of the scenario and fully represent it by applying the core ontologies we have developed, namely the Event-Model-F for modeling events and objects (Scherp et al., 2009a), COMM for representing multimedia annotations (Arndt et al., 2007), and X-COSIMO for personal information management and communication (Franz et al., 2007). With

[3] `http://www.acemedia.org/`
[4] `http://kspace.qmul.net/`
[5] `http://www.x-media-project.org/`

modeling the scenario, we show the interplay of these core ontologies, before we discuss the properties of core ontologies in Section 4 and their concrete design in Section 5.

In the following, we consider a power outage that has happened in the course of a major flooding. Many citizens are calling the emergency response hotline such as Paul. He calls the emergency hotline to report about an observation he made, a power pole in his street has just snapped. Shortly after, the power outage happens. Thus, Paul reports to the hotline that he thinks that the snapped power pole has caused the power outage. The officer Rita at the emergency hotline answers Paul's call. She types into her system what Paul reports, while also an automatic recording of the conversation is taken. In our ontologies, the citizen Paul is represented by the individual `paul-1` and the power pole is represented by the individual `power-pole-1`. We model the event when the power pole snapped as the individual `snapped-pp-1`, the event of the power outage as `power-outage-1`, and the event in which Paul calls the hotline as `call-1`. The officer Rita working at the emergency hotline is represented by the individual `rita-1`. She is answering the `call-1`. The overall flooding event is referenced as `flooding-1`.

Using our Event-Model-F, we model the participation of the person `paul-1` in the event of a `snapped-pp-1` as shown in Figure 2 by applying the core ontology's participation pattern. The pattern is based on the generic ontology design pattern Descriptions and Situations (DnS) (Gangemi, 2008; Gangemi and Mika, 2003). The ontology design pattern DnS provides an ontological formalization of context (Oberle, 2006; Gangemi and Mika, 2003). It allows for a formally precise representation of different, contextualized views by defining roles. Thus, besides representing the participation of a person in an event, the participation pattern shown in Figure 2 also defines that Paul plays the role of a citizen in this participation, indicated with `paul-citizen-1` which is of concept `CitizenRole`. In another situation, Paul might have a different role, e.g., if he is besides being a citizen also a professional firefighter. Thus, Paul can play the role of a `FiremanRole` in other events. It is important to note that both the `CitizenRole` and the `FiremanRole` are not defined within the participation pattern of the Event-Model-F. However, they are provided from some external, domain-specific ontologies. Thus, the participation pattern and the Event-Model-F in general allows to reuse existing domain knowledge. The use of the DnS pattern in an ontology such as the Event-Model-F can be easily recognized. It always defines a situation that satisfies a description. The situation includes the events and objects of a concrete contextual situation, i.e., the real-world entities that can be observed in a concrete situation. The description defines the roles of these events and objects in the observed situation.

In the concrete example, the situation `part-sit-snapped-pp-1` is an `EventParticipationSituation` that `satisfies` the description `part-desc-snapped-pp-1`, which is an `EventParticipation-Description`. The individual `desc-ev-snapped-pp-1` classifies the real-world event of the snapped power pole `snapped-pp-1`, which is of interest, i.e., described in the considered situation. In addition, we can model the time of the event and location of Paul when participating in the event. This is not shown

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