A SURVEY OF UPPER ONTOLOGIES FOR SITUATION AWARENESS

Norbert Baumgartner
team Communication Technology Management GmbH
Goethegasse 3/3
1010 Vienna, Austria
email: norbert.baumgartner@te-am.net

Werner Retschitzegger
Department of Information Systems (IFS)
Johannes Kepler University Linz
Altenbergerstrasse 69
4040 Linz, Austria
email: werner@ifs.uni-linz.ac.at

ABSTRACT
Situation awareness enables an intelligent agent to determine the meaning of perceived information in highly dynamic environments and to share the thereby discovered knowledge. Recently, ontology-based approaches to situation awareness have been proposed; some of them facilitate upper ontologies in order to provide a common vocabulary for collaborating agents and information sources. This paper proposes an evaluation framework for such upper ontologies to elaborate missing features and to develop a better understanding of the diverse concepts involved. To demonstrate the applicability of the evaluation framework, four upper ontologies providing concepts for situation awareness are compared. The findings from this comparison indicate common as well as mutual weaknesses of the examined approaches.

KEY WORDS
Ontologies, intelligent agents, situation awareness, context awareness

1 Introduction

With advances in the field of sensor technology, also the amount of information, which has to be processed by intelligent agents, increases. This information overload also rises the need for technologies that *determine the meaning* of the available information and enable the *exchange* of the thereby *discovered knowledge*. Computational approaches to situation awareness (SAW) tackle these problems in heterogeneous, highly dynamic environments, which involve physical objects ”within a volume of time and space” [1]. An example for such an environment is the field of road traffic telematics, as it usually involves a large number of intelligent agents [2] which have to share knowledge on different levels of abstraction.

In order to comprehend the *meaning* of the objects perceived by intelligent agents, i.e. to achieve SAW, relevant relations among these objects have to be found [3]. The resulting sets of interrelated objects are called *situations*. The aggregation of objects to situations then again enables the *exchange* of the thereby discovered knowledge. Intelligent agents with different purposes and different levels of abstraction can use the situations they assess as the common vocabulary for exchanging knowledge. By handing over situations, unnecessary details of the different levels of abstraction have not to be carried along.

In recent years, the usage of *ontologies* for SAW (and similar problems) has been motivated by various communities (e.g. data and information fusion [3], knowledge sharing [4]). Consequently, different domain-specific approaches have been developed. For instance, Tecuci et. al. [5], Boury-Brisset [6] or Smart et. al. [7] describe the usage of ontologies for SAW with a focus on the military domain. Although certainly enhancing the existing approaches, there are just few examples that employ *upper ontologies*[1] for SAW. The usage of upper ontologies for integrating information and sharing knowledge among heterogeneous sources has been motivated in various related work (e.g. [8], [9], [10]). The thereby identified advantages would also be applicable to SAW. For example, an appropriate upper ontology for SAW could serve for

- integrating heterogeneous information about the perceived objects,
- identifying the relevant situations in a domain-independent manner, and
- sharing knowledge about situations among intelligent agents across domains and different levels of abstraction.

In order to develop a better understanding of the diverse concepts involved, an evaluation framework for SAW upper ontologies is proposed in this paper. The applicability of the evaluation framework is demonstrated by the comparison of four appropriate upper ontologies. The findings from this comparison indicate common as well as mutual weaknesses of the examined approaches.

Since our work is elaborated in cooperation with a prominent Austrian highways agency, the assumptions

[1] Upper ontologies, which define high-level but at the same time possibly domain-dependent vocabularies, should not be confused with top-level ontologies, which model the most basic fundaments of the world. Naturally, the frontiers between both are blurry.

throughout this paper are illustrated by examples from the field of road traffic telematics. By the way, the concepts of road traffic are easy to follow, as one meets such situations in everyday life.

The remainder of this paper is structured as follows: The mentioned evaluation framework for SAW upper ontologies, which is based on inherent characteristics of SAW, is introduced in Section 2. Since there are just few upper ontologies for SAW, also approaches from the similar area of context awareness (CAW) are examined in the subsequent comparison in Section 3. Lessons learned, reporting on common missing features and beneficial improvement opportunities for SAW as well as CAW, are detailed in Section 4. In Section 5, related work concerning surveys of approaches to SAW and CAW as well as top-level ontologies is discussed. Conclusions and an overview of further prospects are given in Section 6.

2 Evaluation Framework

In this section, an evaluation framework for upper ontologies for SAW is proposed. In detail, the criteria, which mainly focus on the essential concepts an appropriate upper ontology should include, are separated into three categories.

The first category details *top-level concepts* of SAW, which have been derived from common *top-level ontologies*. Especially John Sowa's top-level ontology [11] respectively the Standard Upper Merged Ontology (SUMO) [12], which is partly based on Sowa's work, are utilized for detailing the top-level concepts of SAW. These top-level ontologies are chosen because their concepts largely concord with the characteristics of SAW (e.g. objects are physical entities, situations relate objects). Second, *SAW-specific concepts*[2] based on *situation theory* ([13], [14]) and the *JDL Data Fusion model* [3] are discussed. Situation theory, which origins from the field of philosophy, is a formal approach for determining the meaning of information using the concept of situations. In particular, situation theory's partial view of the world constitutes its adequacy concerning SAW and is, thus, incorporated into the evaluation framework. Moreover, the work by the International Society of Information Fusion [15], especially the JDL Data Fusion model [3], provides valuable insights into the characteristics of SAW. Finally, general *modelling characteristics of upper ontologies* are incorporated into the evaluation framework. These characteristics are based on the suggestions of the Cyc project [16] and subsequent work [17]. Figure 1 depicts these categories and gives an overview of the criteria that are detailed in the following subsections.

[2]Note that this categorization is not always distinct, since some SAW-specific concepts may also be found in lower levels of top-level ontologies.

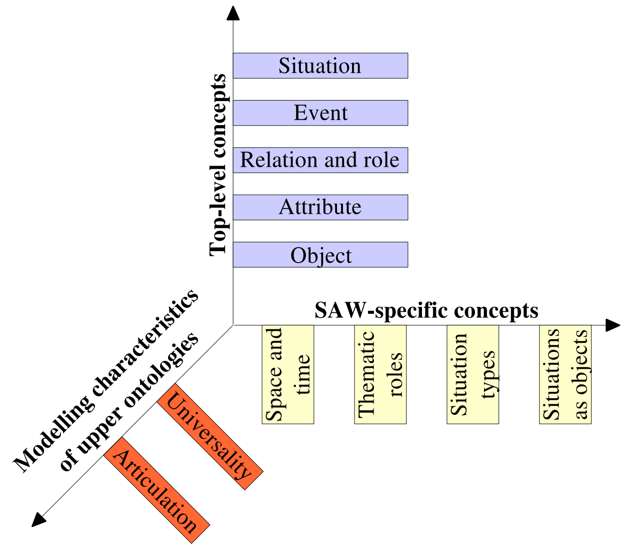

Figure 1. Overview of the evaluation framework

2.1 Top-Level Concepts

In this section, top-level concepts, which should be incorporated into a SAW upper ontology, are introduced. In case a top-level concept can not directly be found in an evaluated upper ontology, appropriate concepts, which can be reduced or subsumed to the corresponding top-level concept, should be identified.

The following top-level concepts have been derived from common top-level ontologies; because of this high level of abstraction, they are partly very basic. Thus, just deviations from their common interpretation as well as the motivation for their selection are detailed in the following.

1. **Object**. First of all, the most prominent kind of concept, object, is examined. According to Sowa [11], objects are solely physical entities, i.e. they have spatio-temporal locations, and their identities remain stable during their lifetime. Objects are dominant in SAW; an example from the field of road traffic telematics are cars which are identified and tracked using video surveillance cameras.

2. **Attribute**. Attributes are properties of objects that do not relate them to other objects (e.g. the velocity of a car). Although one could specify the attributes of an object by using metalevel constructs of an ontology representation language, there are multiple reasons for incorporating attributes into an upper ontology. First, *not all* attributes of a domain object could be relevant for SAW; instantiating just the relevant attributes allows to abstract from unnecessary details. Second, events, which are introduced below, are dependent on attributes. Last, the identity of an object is determined by a subset of its attributes.

3. **Relation and Role**. In contrast to attributes, relations relate objects with objects (e.g. an accident *causes* a traffic jam). In conjunction with relations, also the concept role deserves a special focus regarding SAW. For example, imagine the two objects accident and traffic jam. The traffic jam causes the accident, thus, the accident respectively the traffic jam exhibit the roles causer and effect. Since SAW relies on finding relations among objects and, consequently, the assignment of appropriate roles to objects, both should be reflected in a corresponding upper ontology.

4. **Event**. Principally, achieving SAW is not a discrete task; rather, there are *flows of information* [14] that continuously change attributes of objects and form situations. However, in order to computationally achieve SAW, these continuous changes are discretized and represent, analog to Sowa's discrete processes, events. Between events, attributes have a *state*. Considering all objects of interest, all assessed situations are static in the interval between two events. That is, events trigger situation assessment and determine the resulting SAW. Hence, this event-orientation constitutes an information-push scenario. Since events play a central role in SAW, its support should go further than the mere incorporation of the concept *event* into an upper ontology. That is, events should be explicitly tracked in order to determine the *evolution of situations*[3].

5. **Situation**. Within the scope of computational SAW, situations are sets of interrelated objects. According to Sowa [11], situations are occurrents, i.e. they have no stable identity. Furthermore, they have a spatio-temporal location and relate other objects. From a philosophical point of view, one can agree with this definition. However, the lack of identity results in computational problems, what is detailed in the below criteria towards the handling of situations as objects.

2.2 SAW-specific Concepts

In this section, SAW-specific concepts, which should also be reflected by an appropriate upper ontology, are introduced. These concepts, which are largely motivated by situation theory and the JDL DF model, include the representation of space and time, thematic roles, situation types and situations as objects.

1. **Space and Time**. Space and time are ubiquitous concepts in SAW. Using common upper ontologies, it is possible to represent quantitative spatio-temporal locations which are to some extent domain-independent attributes. However, achieving SAW depends on finding relations among objects—spatio-temporal locations can only implicitly represent such relations.
   In the field of semantic information integration, Visser [18] also motivates approaches to qualitative spatio-temporal representation using relations. Regarding time, Allen's [19] time intervals algebra, which involves a set of disjoint relations over time intervals (e.g. before, after, during), seems to be promising for representing temporal relations among objects. As a matter of fact, Allen's relations are also present in SUMO [12]. Furthermore, Cohn's [20] RCC-8, the region connection calculus with eight disjoint relations (e.g. disconnected, tangential proper part), is appropriate for representing spatial relations (among regions) in a qualitative manner. The usage of qualitative approaches to spatio-temporal representation implies multiple advantages ([19], [20]). For example, the applicability of these relations is metric-independent and it enables the representation of fuzzy as well as uncertain information.

2. **Thematic Roles**. Within the scope of SAW, thematic roles relate objects with situations—they actually detail the meaning of situations. Sowa [11] provides four types of thematic roles, with respect to the evolution of situations, they can be interpreted as follows:

   - *Initiator*—controls the direction of the main activity of a situation and is present at the beginning of the situation (e.g. an agent).
   - *Goal*—controls the direction of the main activity of a situation and is present at the end of the situation.
   - *Resource*—is not active throughout and is present at the beginning of a situation.
   - *Essence*—is not active throughout and is present at the end of a situation.

   Imagine the exemplary situation "An accident has been caused by a lorry which got into a skid and crashed into a car on the opposing roadway". Examining the evolution of this situation, the lorry would be an initiator, the car a goal (as it is not present at the beginning of the situation), the roadway a resource, and the resulting accident an essence. The classification of objects regarding these thematic roles bears potential for understanding the meaning of situations, since it allows an intelligent agent to determine the relevance of objects in a situation. Thus, an upper ontology for SAW should incorporate concepts for distinguishing the mentioned thematic roles or adequate derivatives (e.g. agents).

3. **Situation Types**. Applying the notion of situation types [13] to SAW, they can be informally defined as situations without spatio-temporal locations. For example, "Fog causes an accident" is a situation type that involves the two domain-specific kinds of objects "fog" and "accident" which are in the relation "causes". An instance of this situation type would have a spatio-temporal location which is based on the

[3] Barwise and Perry call this evolution the *course of events*, whereas static situations constitute the *state of affairs* [13].

locations of the instances of ”fog” and ”accident”. Although one can finally define situation types just with knowledge of the domain, they can partly be represented in a domain-independent manner. Using spatio-temporal relations as proposed in the above discussion about space and time, kinds of objects, which contribute to situation types, can be related without concepts from the domain (e.g. an accident happens *during* a period as well as *in the area of* fog).
Situation types bear potential for representing an intelligent agent's purpose[4], i.e. in a concrete application, one could define several situation types which determine situations an agent is interested in. Consequently, situations that instantiate these situation types could be focused.

4. **Situations as Objects**. The set of objects, which forms a situation, is dependent from various factors, e.g. the application domain or the environment an intelligent agent is working in. Even multiple agents from the same domain in the same environment may identify different situations, since their purpose may differ. In the following, we motivate that treating situations as objects may enable exchange of knowledge among such agents.
Unfortunately, treating situations as objects is conflicting with our definition of objects and situations, as situations have no stable identity. Nevertheless, increasing the level of abstraction, situations can be regarded as objects which are identified by the contributing objects and their spatio-temporal locations. With this assumption, situations can be related like objects and can be composed of situations; imagining the resulting hierarchies of situations, intelligent agents with different purposes on different levels of abstraction can share knowledge about situations.
For example, an agent's purpose could be to determine traffic jams by perceiving cars and their spatio-temporal relations. Another agent should process accidents and quickly growing traffic jams in order to react on such dangerous traffic situations. These two agents operate on different levels of abstraction—the latter agent is not interested in cars, whereas the first agent knows nothing about accidents; thus, both have different purposes. The first agent's output (situations that constitute traffic jams) is the latter agent's input. Considering multiple agents that accordingly exchange their knowledge, a hierarchy of situations is developed. Hence, an upper ontology for SAW should allow the handling of situations as objects.

2.3 Modelling Characteristics of Upper Ontologies

In this section, desirable modelling characteristics of upper ontologies ([16], [17]) are examined. These characteristics determine, whether an ontology is universal and articulate. In the course of the evaluation, universality and articulation are again examined using examples from the road traffic telematics domain.

1. **Universality**. As long as a domain is principally adequate for SAW, i.e. it involves physical objects with spatio-temporal locations in a highly dynamic environment, one should be able to express its concepts with the vocabulary an upper ontology for SAW offers. Thus, an upper ontology should be *universal* in terms of SAW. As Gómez-Pérez et. al. [17] describe this characteristic, ”every concept imagined in a specific ontology can be correctly linked to the upper-level ontology in appropriate places”.

2. **Articulation**. An upper ontology is articulate, if there is a justification for each concept and there are enough concepts for capturing the essence of all thinkable application domains [17]. With respect to SAW, the essential set of concepts has been introduced above, whereas the first requirement regarding the justification for concepts is illustrated in the following.
An example for a missing justification could be the classification of objects into grounded and flying objects. Applying an ontology from the road traffic telematics domain, it is evident that there are no flying objects. Although such an upper ontology would be universal, it would not be articulate, as this classification can not be justified across all application domains. An evaluated upper ontology for SAW should be examined for such assumptions about potential domain ontologies, i.e. each concept should be justified by the designers of the upper ontology.

3 Comparison

In this section, four upper ontologies are described and compared according to the introduced evaluation framework. Since there are just few upper ontologies that origin from the area of SAW, also approaches from the field of context awareness (CAW) are examined. This is reasonable since CAW[5]—especially its approaches in the area of pervasive computing—is subsumed by SAW. Context information characterize the situations of objects that are relevant for an agent (e.g. [21]). The aggregation of all context information, the *whole context* of an agent, can be regarded as the single situation the agent is involved with. Contrarily, SAW can rather be regarded as a bird's eye view of the relevant situations and, hence, the objects of interest does not necessarily include the assessing agent. For example, a highways operator, who monitors road traffic, should be aware of all relevant traffic situations. Contrarily, a car driver, who is a classical example for an agent that has to achieve CAW, is only interested in the situation he is involved with. Accordingly, it could also be

[4] According to Sowa [11], an agent's purpose is the crucial part for distinguishing meaningful situations.

[5] Note that interpretations of context and CAW immensely differ [11].

stated that situations are on a higher level of abstraction than contexts [22]. Thus, CAW can be looked upon as SAW.

However, it should be noticed that the approaches from the field of CAW are evaluated with regards to SAW, i.e. they are likely to score worse than the others. Nevertheless, the goal of the following comparison is not to identify the best approach; rather, common missing features as well as mutual improvement opportunities should be identified.

Figure 2 lists the chosen approaches and describes their origins. All approaches utilize the Web Ontology Language (OWL) [23] as their ontology representation language. Whereas SAWA [24] provides the only pure SAW upper ontology, the situation ontology by Yau et. al. [25] bridges situation and context awareness. Both, CONON [26] and SOUPA [27], which is the core of the Context Broker Architecture (CoBrA) [28], origin from the field of CAW in pervasive computing. Although SOUPA is the more elaborate one, CONON was, besides the original CoBrA ontology, one of the first upper ontologies for CAW and has therefore been chosen for comparison.

Name	Background
SAWA (Situation Awareness Assistant)	Upper ontology for SAW; origins from the military domain
Situation Ontology	Upper ontology for SAW in pervasive computing environments
SOUPA (Standard Ontology for Ubiquitous and Pervasive Applications)	Upper ontology for CAW in pervasive computing environments; part of the Context Broker Architecture (CoBrA)
CONON (Context Ontology)	Upper ontology for CAW in pervasive computing environments

Figure 2. The evaluated approaches

Our findings, which are subsumed in section 4, are based on a literature study of the publications that are available for the examined approaches. While further details and evaluation results are discussed per approach, section 4 provides a summary of the results and allows a comparison at a glance. The evaluation of each approach roughly follows the ordering of the criteria introduced in the previous section.

3.1 SAWA

SAWA (Situation Awareness Assistant) [24], which origins from the military domain, is a set of tools developed by a commercial company[6]. The fundament of SAWA is an upper ontology for situation awareness (see [29] and [30] for the evolution of this ontology). In addition to OWL, the SAWA upper ontology uses SWRL (Semantic Web Rule Language) [31] for deriving relations among objects using rules.

Regarding the supported top-level concepts, the SAWA upper ontology is widely conform with the criteria in the evaluation framework. SAWA, however, does merely not incorporate roles. Events are actually more powerful, since they also track the evolution of relations. Furthermore, each situation has a goal, the so-called ”standing relation”, for constraining the number of relations which have to be determined.

Concerning the SAW-specific concepts, situations are treated as objects, since the concept situation is derived from the concept object. Qualitative approaches to the representation of time and space are not considered. Thematic roles are also not present. Although the concept of standing relations can be regarded to represent an agent's purpose, they can not be used for defining patterns of situations like situation types are supposed to do. Since the SAWA upper ontology origins from SAW, it is, compared to the approaches from the field of CAW, a very high-level approach; thus, universality is obtained. Regarding articulation, there are some concepts which are not completely justified. First, the motivation for standing relations seems to origin from an algorithmic and not from an ontological point of view. The implication, that situations are reduced to a couple of high-level relations, is too restricting and induces a biased view on situations. Second, the concept physical entity, which is derived from object, is sketchy, as a definition for non-physical objects is missing.

3.2 Situation Ontology

The situation ontology by Yau et. al. [25], which incorporates situations as well as contexts, origins from the field of pervasive computing. Situations are classified into atomic and composite situations; they are not composed of objects—rather, they are directly (atomic) or indirectly (composite) represented by contexts. This is an ambiguous approach, as they can be mapped to attributes *as well as* objects in the terminology of the evaluation framework. The upper ontology also contains *entities*, which specify related context data; anyway, their role is unclear with respect to situations and they cannot easily be mapped to the concept of objects. Subsuming this discussion about the supported top-level concepts, the existence of appropriate concepts for objects and attributes is sketchy. There are no explicit relations, roles, and events, only the situation concept is present.

[6] Versatile Information Systems, Inc., `http://www.vistology.com`

Continuing with SAW-specific concepts, space and time, thematic roles, as well as situation types, are not anchored in the upper ontology. Very thoroughly elaborated is the possibility to treat situations as objects. Within the situation ontology, an atomic situation has a single context (e.g. user, device, environment) respectively context values (e.g. the current velocity of a car), whereas a composite situation is composed of other situations. It is even possible to define the kind of composition in case of overlapping situations (i.e. conjunction, disjunction, negation).

Furthermore, since the levels of abstraction are too lumped together, universality is endangered. For example, it is only possible to treat cars as objects, if one derives a complex class car from context and interprets instances of car as context values. Although cars can be captured this way, it is not possible to incorporate their identities (e.g. number plates) into the upper ontology. This weaknesses can be transcribed to articulation as well—although anything can be put into the context concept, it is too generic and lacks essence. All in all, the situation ontology lacks concepts for determining the meaning of a situation, that is, it can be rather associated with the field of context than situation awareness.

3.3 SOUPA

The SOUPA (Standard Ontology for Ubiquitous and Pervasive Applications) [27] ontology is the core of the Context Broker Architecture (CoBrA) [28], a system for supporting context-aware computing. The upper ontology is the result of the SOUPA project which is backed by a special interest group in the Semantic Web community[7]. SOUPA actually consists of two ontologies: Whereas SOUPA Core focuses on CAW for pervasive computing, SOUPA Extension should provide support for certain applications.

Examining the supported top-level concepts, object can be roughly mapped to the SOUPA concepts person, agent, and event. Furthermore, attributes, relations, events, and situations are not explicitly anchored in the upper ontology. Proceeding with SAW-specific concepts, space and time are well-established in the SOUPA ontology. SOUPA Core allows the representation of time instants and intervals; moreover, temporal relations, which are similar to Allen's time intervals algebra [19], are available. In SOUPA Core, the representation of space is similarly elaborated; SOUPA Extension even enhances the upper ontology by incorporating the region connection calculus [20]. Since agents as well as their beliefs, goals, etc. are incorporated, they can be interpreted as the basic support for expressing thematic roles of objects. Since there is no concept for representing a situation respectively a whole context, there are also no situation types and situations are not treated as objects. As an approach from the field of CAW cannot be universal and articulate from a SAW's point of view, the criteria regarding the modelling characteristics are not applicable.

[7] http://pervasive.semanticweb.org/

3.4 CONON

The Context Ontology (CONON) was one of the first approaches that used OWL [23] for modelling context in pervasive computing environments [26]. The central concept in CONON is the context entity and its subclasses computational entity, location, person, and activity. Person and computational entity can be roughly mapped to object in the evaluation framework. Similar to SOUPA, CONON does not model attributes, events, and situations respectively whole contexts. Moreover, activities can be regarded as specialized relations, since they relate persons with computational entities. In contrast to SOUPA, locations in CONON are rather quantitative; for example, one can specify the longitude and the latitude of a location. Except from classifying locations into indoor and outdoor locations, no qualitative spatial as well as temporal approaches are considered. Thematic roles, in form of agents, are also present. Since situations are not explicitly modelled, there are also no situation types and situations are not handled as objects. As with SOUPA, the criteria regarding modelling characteristics are not applicable.

4 Lessons Learned

In this section, the lessons learned from the above comparison, which is subsumed in Figure 3, are detailed. Not surprisingly, SAWA performs best, since it origins from the field of SAW. Some criteria are, however, better fulfilled by other approaches. In particular, SOUPA's approach to spatio-temporal representation and the situation ontology's possibilities for combining situations are clearly more sophisticated. Although none of the approaches from the field of CAW can keep up with the—for pervasive computing admittedly very abstract—kinds of concepts, intimations of thematic roles in form of agents can only be found in SOUPA and CONON. The only criteria, which is not incorporated by any approach, are situation types; this gaffe can be interpreted as a general negligence of concepts for classifying situations. Regarding modelling characteristics, articulation can be regarded to be more complex than universality, as SAWA's results indicate. The situation ontology fails concerning these criteria, particularly, because of its very narrowed view of SAW. In contrast, SOUPA and CONON do not claim to bridge context and situation awareness; thus, they have not been examined regarding modelling characteristics.

As a side effect of the comparison, one can track the evolution of upper ontologies in the field of CAW. Starting

Approach	Top-level Concepts					SAW-specific Concepts				Modelling Characteristics of Upper Ontologies	
	Object	Attribute	Relation and Role	Event	Situation	Space and Time	Thematic Roles	Situation Types	Situations as Objects	Universality	Articulation
SAWA	+	+	+	+	+	-	-	-	+	+	~
Sit. Ont.	~	~	-	-	+	-	-	-	+	-	-
SOUPA	~	-	-	-	-	+	~	-	-	/	/
CONON	~	-	~	-	-	-	~	-	-	/	/

Legend

+	complies with the criteria
~	partly complies with the criteria or it is assumed that it complies with the criteria
-	does not fulfill criteria
/	criteria not applicable

Figure 3. Comparison of the evaluated approaches

with CONON as a very focused ontology, SOUPA brought in several valuable, higher-level concepts, whereas the situation ontology, as the latest approach, already blurs the ”frontiers” between context and situation awareness.

5 Related Surveys

In this section, closely as well as widely related surveys are identified and the corresponding contribution of this paper is declared. Since, to the best of our knowledge, no evaluation of upper ontologies for situation and context awareness currently exist, closely related work includes surveys focusing on modelling of situation or context awareness in general. Widely related work covers evaluation frameworks for general top-level ontologies, since SAW involves some very high-level concepts.

Regarding closely related work, two surveys of context-aware systems could be found. Strang et. al. [32] examine approaches to modelling context. They introduce six requirements for context models and separate the evaluated approaches into diverse categories; one of these categories are ontology-based ones. According to Strang et. al., some of the requirements stated in their survey are fulfilled by upper ontologies in any way (distributed composition, partial validation, level of formality). The requirement regarding the applicability to existing environments may be mapped to our criteria concerning the modelling characteristics. Strang et. al. additionally emphasize information quality aspects (e.g. modelling of quality indicators); these are beyond the scope of this paper, as we regard them as requirements that are not solely specific for SAW. In contrast to the evaluation framework in this paper, Strang et. al. do not go into inherent characteristics of CAW. That is, the essential concepts a context model should incorporate are not elaborated.

Another survey on context-aware systems is given by Baldauf et. al. [33]. Compared to the work by Strang et. al., this survey is more general, as it does not just focus on context modelling. However, Baldauf et. al. also state goals when modelling context, some of them being modelling requirements like simplicity, flexibility, genericity, and expressiveness. In addition, they motivate primitive kinds of entities, namely context types and context values; contexts as a whole respectively situations are not mentioned. Apart from the discussion about time, which can be regarded as a very basic counterpart of the corresponding criteria introduced in this paper, the other goals are again regarded to be rather general aspects (e.g. the incorporation of the confidence of a context information or its information source). Again, compared to this survey, our focus is on examining the concepts an upper ontology for SAW/CAW, i.e. a context model, offers.

The examination of upper ontologies for their use in the military domain by Semy et. al. [34] is the first widely related work. Semy et. al. evaluate different top-level ontologies according to a basic evaluation framework. They focus on criteria resulting from the military domain (e.g. licensing, maturity, granularity of time and space, security) and general modelling characteristics which are similar to ours. The actual content of the evaluated ontologies is not examined in depth. In contrast to Semy et. al., we evaluate upper ontologies based on their contents. A similar conclusion can be drawn when comparing our work with the evaluation of Feliu et. al. [35], who examine diverse top-level ontologies according to features like availability, the existence of management tools, expressiveness, etc. As with the survey by Semy et. al., they do not focus on the contents of the candidates.

Subsuming the contribution of this paper, it is, compared to the identified related work, the only approach to evaluate upper ontologies for SAW (to some extent also CAW) according to the inherent characteristics of the faced problem. Our main goal and at the same time our contribution is to cover the essence of SAW respectively CAW in the proposed evaluation framework.

6 Conclusion

In this paper, an evaluation framework for upper ontologies for SAW has been introduced. In the course of the compilation of this evaluation, we focused on the inherent characteristics of SAW respectively CAW. Then, four upper ontologies from diverse areas have been compared according to the established criteria. Although it was especially difficult to evaluate CAW approaches, as they are on a lower level of abstraction, it became evident that there are lots of concepts which could be beneficial for SAW and the other way round.

In future work, the findings from this evaluation are incorporated into a corresponding upper ontology which should incorporate both SAW and CAW aspects. In the long term, this upper ontology is going to be applied to the domain of road traffic telematics, in order to support traffic operators achieving situation awareness.

References

[1] Mica R. Endsley, Theoretical Underpinnings of Situation Awareness: A Critical Review, in Mica R. Endsley and Daniel J. Garland (Ed.), *Situation Awareness Analysis and Measurement* (New Jersey, USA: Lawrence Erlbaum Associates, 2000) 3-33.

[2] Heribert Kirschfink, Josefa Hernandez, and Marco Boero, Intelligent traffic management models, *Proc. European Symposium on Intelligent Techniques*, Aachen, Germany, 2000, 36-45.

[3] James Llinas, Christopher Bowman, Galina Rogova, and Alan Steinberg, Revisiting the JDL data fusion model II, *Proc. of the 7th International Conference on Information Fusion*, Stockholm, Sweden, 2004, 1218-1230.

[4] Raymond A. Liuzzi, Gerard T. Capraro, and Michael C. Wicks, Semantic web technologies — not just for the web, *Proc. of the IASTED International Conference on Knowledge Sharing and Collaborative Engineering*, St. Thomas, US Virgin Islands, USA, 2004, 219-224.

[5] Gheorghe Tecuci, Antonio M. Lopez, and Michael Bowman, Ontology development for military applications, *Proc. of the 39th Annual ACM Southeast Conference*, Athens, GA, USA, 2001, 112-117.

[6] Anne-Claire Boury-Brisset, Ontology-based approach for information fusion, *Proc. of the 6th International Conference on Information Fusion*, Cairns, Queensland, Australia, 2003, 522-529.

[7] Paul R. Smart, Nigel R. Shadbolt, Leslie A. Carr, and Monica C. Schraefel, Knowledge-based information fusion for improved situational awareness, *Proceedings of the 8th International Conference on Information Fusion*, Philadelphia, USA, 2005, 8-15.

[8] Natalya Fridman Noy, Semantic integration: A survey of ontology-based approaches, *SIGMOD Rec.*, 33(4), 2004, 65-70.

[9] Adam Pease, Raymond A. Liuzzi, and David Gunning, Knowledge Bases, in J. Marciniak (Ed.) *Encyclopedia of Software Engineering, Second Edition* (New York, USA: Wiley & Sons, 2001).

[10] G. Kappel, H. Kargl, G. Kramer, T. Reiter, W. Retschitzegger, W. Schwinger, and M. Wimmer, Lifting metamodels to ontologies: A step to the semantic integration of modeling languages, *Proc. of the ACM/IEEE 9th International Conference on Model Driven Engineering Languages and Systems*, Genova, Italy, 2006.

[11] John F. Sowa, *Knowledge Representation — Logical, Philosophical, and Computational Foundations* (Pacific Grove, California, USA: Brooks/Cole, 2000).

[12] I. Niles and A. Pease, Towards a standard upper ontology, *Proc. of the 2nd International Conference on Formal Ontology in Information Systems*, Ogunquit, Maine, USA, 2001, 2-9.

[13] Jon Barwise and John Perry, *Situations and Attitudes* (Cambridge, USA: MIT Press, 1983).

[14] Keith Devlin, *Logic and Information* (New York, USA: Cambridge University Press, 1991).

[15] International Society of Information Fusion. `http://www.isif.org`.

[16] Inc Cycorp, The Cyc Project, `http://www.cyc.com`, 2006.

[17] Ascunión Gómez-Pérez, Mariano Fernández-López, and Oscar Corcho, *Ontological Engineering: With Examples from the Areas of Knowledge Management, e-Commerce and the Semantic Web* (London, UK: Springer-Verlag, 2004).

[18] Ubbo Visser, *Intelligent Information Integration for the Semantic Web* (Berlin, Germany: Springer-Verlag, 2004).

[19] James F. Allen, Maintaining knowledge about temporal intervals, *Communications of the ACM*, 26(11), 1983, 832-843.

[20] Anthony G. Cohn and Shyamanta M. Hazarika, Qualitative spatial representation and reasoning: An overview, *Fundamenta Informaticae*, 46(1-2), 2001, 1-29.

[21] Anind K. Dey, *Providing Architectural Support for Building Context-Aware Applications*, PhD thesis, Georgia Institute of Technology, USA, 2000.

[22] Seng W. Loke, Representing and reasoning with situations for context-aware pervasive computing: A logic programming perspective, *Knowledge Engineering Review*, 19(3), 2004, 213-233.

[23] W3C recommendation, OWL web ontology language overview, `http://www.w3.org/TR/owl-features`, 2004.

[24] C. Matheus, M. Kokar, K. Baclawski, J. Letkowski, C. Call, M. Hinman, J. Salerno, and D. Boulware, SAWA: An assistant for higher-level fusion and situation awareness, *Proc. of SPIE Conference on Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications*, Orlando, Florida, USA, 2005, 75-85.

[25] Stephen S. Yau and Junwei Liu, Hierarchical situation modeling and reasoning for pervasive computing, *Proc. of the 3rd Workshop on Software Technologies for Future Embedded and Ubiquitous Systems*, Gyeongju, Korea, 2006, 5-10.

[26] Xiao Hang Wang, Da Qing Zhang, Tao Gu, and Hung Keng Pung, Ontology based context modeling and reasoning using OWL, *Proc. of the 2nd IEEE Annual Conference on Pervasive Computing and Communications Workshops*, Orlando, Florida, USA, 2004, 18-22.

[27] Harry Chen, Philip Perich, Tim Finin, and Anupam Joshi, The SOUPA Ontology for Pervasive Computing, in Valentina Tamma, Stephen Cranefield, Tim Finin, and Steven Willmott (Ed.), *Ontologies for Agents: Theory and Experiences* (London, UK: Springer-Verlag, 2005).

[28] Harry Chen, Timothy W. Finin, and Anupam Joshi, Using OWL in a pervasive computing broker, *Proc. of the Workshop on Ontologies in Agent Systems*, Melbourne, Australia, 2003, 9-16.

[29] C. J. Matheus, M. M. Kokar, and K. Baclawski, A core ontology for situation awareness, *Proc. of the 6th International Conference on Information Fusion*, Cairns, Queensland, Australia, 2003, 545-552.

[30] K. Baclawski, M. Kokar, J. Letkowski, C. Matheus, and M. Malczewski, Formalization of situation awareness, *Proc. of the 11th OOPSLA Workshop on Behavioral Semantics*, Portland, Oregon, USA, 2002, 1-15.

[31] W3C member submission, SWRL: A semantic web rule language, `http://www.w3.org/Submission/SWRL`, 2004.

[32] Thomas Strang and Claudia Linnhoff-Popien, A context modeling survey, *Proc. of the First International Workshop on Advanced Context Modelling, Reasoning and Management*, Nottingham, UK, 2004.

[33] Matthias Baldauf, Schahram Dustdar, and Florian Rosenberg, A survey on context-aware systems, *International Journal of Ad Hoc and Ubiquitous Computing*, forthcoming, 2006.

[34] Salim K. Semy, Mary K. Pulvermacher, and Leo J. Obrst, *Toward the use of an upper ontology for U.S. government and U.S. military domains: An evaluation*, Technical report MTR 04B0000063, The MITRE Corporation, Massachusetts, USA, 2004.

[35] J. Feliu, J. Vivaldi, and M. T. Cabré, *Ontologies: A review*, Technical report IULA/INF034/02, University Pompeu Fabra, Institute for Applied Linguistics, Barcelona, Spain, 2002.