Application Scenarios of Ontology-Driven Situation Awareness Systems

Exemplified for the Road Traffic Management Domain

Norbert BAUMGARTNER [a;1], Werner RETSCHITZEGGER [b] and Wieland SCHWINGER [b]

[a] *team Communication Technology Management Ltd., Vienna, Austria*
[b] *Johannes Kepler University, Linz, Austria*

Abstract. Large-scale control systems, as encountered in the domain of road traffic management, typically deal with highly-dynamic environments providing information about a large number of real-world objects, which stem from multiple heterogeneous sources and are anchored in time and space. Human operators of such systems face information overload which endangers the recognition of critical situations. Situation awareness systems should support operators fulfilling their tasks by leveraging their awareness of the ongoing situations. However, current approaches to SAW miss a common conceptual model necessary for various aspects of SAW. Although the application of ontologies for filling this gap has been proposed in recent years, ontology-driven SAW systems are nevertheless still in their infancy. In this paper, we shape the vision of an ontology-driven SAW system by the analysis of application scenarios facilitating the features of formal ontologies. We illustrate the suggested scenarios with examples from the field of road traffic management and argue that an ontology-driven SAW system does not replace but may actually enhance traditional probabilistic approaches to SAW.

Keywords. Ontologies, Situation Awareness, Context Awareness, Road Traffic Management

Introduction

Large-scale control systems, as, for example, in use in the domains of road traffic management or air traffic control, operate in geographically wide-spread environments and involve - partly incomplete - information about mainly physical objects (e.g. traffic jams, accidents, roadworks) from heterogeneous information sources. Human operators of such systems face an increasing amount of information to be incorporated in order to timely and correctly resolve or even prevent critical situations. *Situation awareness* (SAW) applications support human operators by pinpointing their attention to these sit-

[1]Corresponding Author: Norbert Baumgartner, team Communication Technology Management Ltd., Goethegasse 3/3, 1010 Vienna, Austria; E-mail: norbert.baumgartner@te-am.net.

uations. In the field of situation awareness, a situation is usually defined as s set of interrelated physical objects, i.e., situations aggregate information resulting in a decrease of information overload. Because this abstraction also entails a shift from numeric to rather symbolic information, ontologies have been proposed to provide the missing conceptual model of SAW in recent work (e.g., [1]). In this paper, we contribute an analysis of potential application scenarios of ontologies for SAW toward an ontology-driven SAW system and briefly discuss their integration with traditional approaches to situation awareness. The application scenarios are illustrated with examples from the field of road traffic management.

The paper is structured as follows: After an introduction to our running example road traffic management in section 1, we provide an overview of situation awareness in general and present the corresponding state of the art in section 2. In section 3, we investigate application scenarios of ontology-driven SAW and provide an overview of current approaches including our work BeAware!, a framework for ontology-driven SAW. We conclude the paper in section 4 with a summary of our contribution and an overview of further prospects.

1. Road Traffic Management

In the field of road traffic management (RTM), the overall goals a road traffic operator has to achieve are the reduction of traffic jams and the prevention of accidents. The tools a traffic operator may resort to are direct control measures (e.g., the restriction of speed limits) or indirect control measures (e.g., via warning messages) [2]. In order to correctly take these measure in time, the traffic operator has to be aware of the ongoing or evolving traffic situations. However, with the recent advances in sensor technology and information systems, the information a traffic operator has to incorporate has dramatically increased—leading to the problem of information overload. Fig. 1 provides an illustrative example for the induced problems.

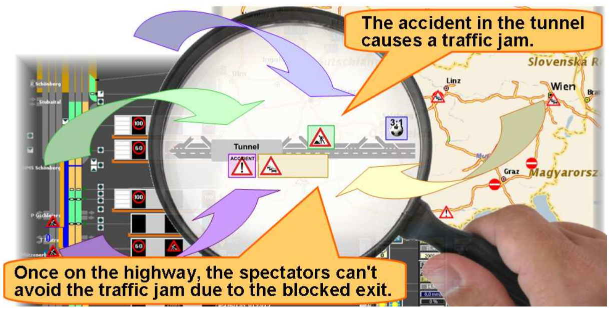

Figure 1. An illustrative example for a critical road traffic situation

The information, which have been arranged within the magnifying glass for our example, are ususally scattered across various graphical user interfaces and come from different heterogeneous information sources. Though the human operator may be aware of the accident in the tunnel and the resulting traffic jam, it may be difficult for him to realize that the exit blocked by roadworks would obstruct the soon leaving spectators of the football game from avoiding the traffic jam—cancelling the roadworks will be too late. Though this example may be exaggerated it illustrates the dangers of missing SAW in RTM.

In the next section, we are going to have a more general look on these problems by introducing SAW and providing a brief overview of the state of the art in this area of research.

2. Situation Awareness

In this section, we have a look at the notion of SAW and its multiple origins in order to highlight its cross-border significance. Subsequently, we provide an overview of current approaches and shortly state the gaps they leave for ontologies.

2.1. Different Views of a Single Problem

The original notion of SAW has been coined by Endsley in the field of human-computer interaction and cognitive sciences [3]. She stated that SAW is '*the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*'. From this definition, Endsley derived three layers of SAW: perception, comprehension, and projection. Though information overload implies that the amount of perceptible information increases, comprehension and projection tend to be more difficult because of the large quantities of information. Endsley's definition has been embraced and refined by the area of information fusion, in which the process of gaining SAW in a computational way has been denoted *situation assessment*. Because of its ranking in the processing chain of a typical large-scale control system (cf. the JDL Data Fusion Model [1]), situation assessment is also referred to as *high-level* information fusion. The following example from the field of RTM should clarify this kind of layered separation of processing steps:

1. *Signal assessment*—on the lowest level, signals measured by sensors (e.g., magnetic fields) are interpreted as numeric features like the traffic flow or the average velocity.
2. *Object assessment*—physical objects (i.e. 'the elements in the environment within a volume of time and space' in Endsley's definition) are identified based on the numeric features of the lower level; e.g., a detected traffic jam or accident.
3. *Situation assessment*—by the derivation of relations between the identified objects, relevant situations are assessed, e.g. an accident that *causes* a traffic jam or a blocked exit that *obstructs* motorists. Note that the prior levels must not be present for each object, e.g. scheduled roadworks are also relevant for situation assessment, but are rather manually entered than automatically assessed.
4. *Impact assessment*—once the traffic operator is aware of the relevant situations, the impact can be deduced in order to select the actions to be taken, e.g. cancel roadworks.

Apart from the fields of cognitives sciences and information fusion, also the field of pervasive computing has introduced a notion which is similar to SAW: Context awareness. Though there are striking similarities, research in both areas is quite separated. One of the most significant differences is that SAW (at least in large-scale control systems) focuses on the human operator who *observes* relevant situations in contrast to the agent in the realm of context awareness which is typically *part of* the situations of interest. Thus, we rank SAW on a higher level of abstraction than context awareness.

Summarizing this subsection, the notion of SAW may be found in various research areas like cognitive sciences, information fusion, or pervasive computing, which highlights its cross-border significance and which will provide the basis for motivating the application scenarios of ontology-driven SAW.

2.2. State of the Art

In this subsection, we provide a brief overview of the main approaches to SAW which are relevant for our work. Thus, we largely omit the field of cognitive sciences for the following discussion, since we are mainly interested in computational approaches to SAW[2].

In recent years, a shift of focus from the lower levels of information fusion to situation assessment has been observable. Whereas there is agreement that this shift implies the introduction of rather symbolic in contrast to the numeric information on lower levels (e.g., [4]), there is no agreed approach on how to actually handle these different requirements. Traditional approaches to SAW are of rather probabilistic nature and reach, for example, from the application of bayesian belief networks [5] to belief fusion by Dempster-Shafer models [6]. The common understanding is that SAW is not about objects, it is about relations, which is one of the most important differences from the lower levels of information fusion. A further common assumption is related with the focus of SAW system development—the success of a SAW system is determined during design time, e.g., during the analysis which traffic situations can occur, rather than on run time [7]. This assumption is supported by the fact that most related work reporting on the application of different situation assessment approaches rest on some conceptual model of the application domain—which is often taken for granted in related work. Moreover, a common abstraction of these conceptual models is missing or work in progress, which makes research results difficult to discuss (cf. [8], [4]). This is the moment when (formal) ontologies enter the stage. As promoted in related work (e.g. [1], [9]), ontologies could fill the important gap of providing a conceptual model for SAW.

Also in the area of pervasive computing the usage of ontologies has been proposed—for example, Strang et. al. [10] suggest the usage of ontologies due to their formality and the accompanying reasoning capabilities (especially in contrast to object-oriented models).

In the following section we point out for which SAW application scenarios we believe ontologies are beneficial. As mentioned above, we advocate the view that ontologies 'just' fill gaps and do not substitute traditional approaches. However, if one commits to an *ontology-driven* system as envisioned by Musen [11], the ontology becomes an integral part of of the system architecture. Thus, we also outline how to integrate traditional approaches to SAW in such architectures when presenting the application scenarios in the next section.

[2] Nevertheless, at least one application scenario of ontologies for SAW is going to be closely related to human-computer interaction.

3. Application Scenarios of Ontology-Driven Situation Awareness

The application scenarios presented in this section should point out the advantages of formalizing the conceptual model of a SAW system using an ontology. The application scenarios are illustrated by examples from the domain of RTM and are depicted at a glance in Fig. 2. The assumed ontology definition language is OWL-DL[3] which is recommended by the W3C and should constitute the basis of the Semantic Web. The section is concluded by an overview of current approaches in the field of ontology-driven SAW.

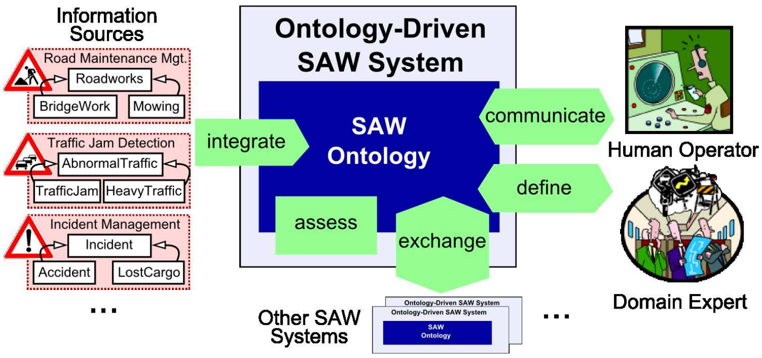

Figure 2. The application scenarios at a glance

3.1. Integrate Information Sources

One motivation for the usage of ontologies is that they may be used to integrate heterogeneous information sources (e.g., [12]). With the advent of the Semantic Web, the number of ontologies available for diverse domains is constantly increasing. The benefit of using such ontologies is that they provide an agreed specification of the concepts of a domain which can be used to describe the different information sources of a SAW system. Referring to our illustrative example from Sect. 1, each information source may be represented by a separate ontology (e.g. one for public events containing an individual representing our football game). Within the SAW system, these information sources could be mapped to a more abstract, domain-independent ontology that, as suggested in various related work (e.g., [13], [14]), fits the tasks of SAW. Note that this application scenario is especially important in the field of pervasive computing, in which it should be possible to integrate information sources on the fly.

3.2. Communicate with Human Operators

Another application scenario is to use ontologies for communicating the results of situation assessment to human operators. First of all, ontologies can provide human-understandable information about complex relations among objects. For example, an appropriate ontology may be in a position to express that 'an accident causes a traffic jam' based on the assumption that 'accident' and 'traffic jam' are individuals of the corre-

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

sponding classes and ’causes’ is a property that has been derived during situation assessment. Moreover, current approaches to construct semantic (or even geographic) mashups of arbitrary information enable new ad hoc user interfaces (cf. [15]). Another related application scenario is the exploitation of the query mechanisms ontologies provide, which has already been analyzed for SAW systems by Kokar et. al. [9]. For example, a human operator may be interested in all traffic situations in which the visitors of a ’public event’ are obstructed by a ’traffic jam’. Employing an appropriate ontology, ’football game’ could be inferred to be a subclass of ’public event’ and included in the answer of the query.

3.3. Exchange Knowledge About Situations

SAW systems are not isolated; for example, the Austrian highways agency regularly exchanges traffic information with its neighboring counterparts. Especially if traffic control strategies should be determined across jurisdictional boundaries, it is necessary to exchange all the available knowledge about occurring situations between potentially heterogeneous SAW systems. General advantages of ontologies enabling such a exchange are that they are machine-readable, platform-independent, and easily exchangeable via the Internet. Furthermore, an agreed domain-independent SAW ontology could provide the necessary common base for knowledge transfer between two systems. Nevertheless, the assessment of individuals, e.g., how the ’causes’ relation between an ’accident’ and a ’traffic jam’ is derived, has to be system-dependent, which is, however, obvious—think of a traffic jam in an urban area and a traffic jam on a highway, both have completely different characteristics from a traffic engineer’s point of view.

The application scenarios, which have been described so far, not necessarily induce a system-wide ontology-based conceptual model. Though tediously to implement, they may just represent the interfaces of a SAW system to information sources, the human operator, and other SAW systems. The last two, not less important application scenarios require, however, the SAW system to be completely ontology-driven. Thus, also the integration with traditional approaches to SAW as indicated in the previous section is discussed.

3.4. Define Situation Types

Following the notion introduced by Barwise and Perry [16], we view a situation type as an abstract state of affairs that may be instantiated during situation assessment. As already mentioned, we believe that the focus of successful SAW has to reside on the design time of a SAW system which particularly involves the definition of interesting situation types. Domain experts who have the task of designing a SAW system should be given a working language to define the characteristics of situation types. In fact, we are speaking of the common conceptual model which is missing in current approaches to SAW. A domain-independent ontology implementing this conceptual model for SAW could enable domain experts share their views as well as experiences across SAW systems and even domains, thereby laying the cornerstone for successful system behaviour at run time. However, such an ontology must not be reduced to a mere vocabulary. The value of this application scenario rather depends on the possibility to formally define the constraints of an SAW system (e.g. the situation types of interest) and check whether the design is consistent with the agreed conceptual model the ontology provides. Regarding such a formalization using Semantic Web ontologies, we have to use a rule language on top of OWL-DL, because its instance classification features do not suffice for describing situation types. Examples are the application of the SWRL[4] as discussed in [17] or the a logic-programming-like rule engine as provided by the Jena Semantic Web Framework[5] which we applied in our previous work [18].

Whereas we have a look at such existing approaches below, we proceed our discussion about the definition of situation types by inspecting the, as already mentioned, most important aspect of SAW: Relations. Let us revisit the illustrative example from Sect. 1 and assume that traffic engineers have the task to define a situation type which captures the essence of the situation the human operator has been unaware of. An immediate question is how to define that an accident 'causes' a traffic jam. Of course, one could provide some proprietary interpretation of this relation, but it would be difficult to discuss the situation type without a common understanding of 'causes'. As suggested in our previous work (cf. [19], [20]), we believe that a common SAW ontology should incorporate spatio-temporal *primitive relations* like 'proper part', 'before', etc. which could provide the basis for defining relations like 'causes', 'obstructs', and so on. Although the concrete interpretation of these primitive relations would also be dependent on the domain or even on the SAW system, they are easier to understand and straight-forward to implement.

The consequence of such an application scenario, i.e. the definition of situation types based on a SAW ontology, implies that the ontology must be consulted for situation assessment turning it into an integral part of the a SAW system. We argue that the effect on the applicability of traditional approaches is negligible. Traditional probabilistic approaches could, for example, be used for refining and learning situation types. Given that our common SAW ontology contains relations and situations, they could also be regarded as nodes in a bayesian belief network. Thereby, we may define the relations a situation depends on based on the definition of the situation type. Based on the results of situation assessment, the network could incorporate actual evidence of co-occurring relations respectively situations and even find new structures (e.g. an unnoticed dependency between a relation and a situation). These results could again be incorporated into the definition of situation types.

3.5. Assess Situations

As indicated above, situation assessment is about pattern matching—in our case, the pattern is specified as a rule which should be instantiated by individuals in the common SAW ontology. The question is how to exploit the ontology for effective situation assessment. In fact, the a priori knowledge encoded in an ontology can be used to perform some efficient reasoning steps. Some examples, which we have introduced in previous work (cf. [20], [21]), are inferring of relations, representing incomplete information, or even reasoning about evolutions of situations. However, we again stick to the claim that such an ontology-driven approach does not inhibit traditional approaches. For example, one could use fuzzy sets in order to cope with uncertain information from the lower levels

[4] Semantic Web Rule Language, http://www.w3.org/Submission/SWRL/

[5] http://jena.sourceforge.net

of information fusion and equip individuals of the ontology with membership measures during situation assessment.

To sum up, if the above application scenarios of ontologies are implemented for a SAW system, the system is indeed ontology-driven. However, ontology-driven does not mean that traditional approaches to SAW cannot be integrated. Rather, the SAW system and its users would benefit from having an ontology serve as the conceptual model of SAW and the advantages stated above.

3.6. Current Approaches

There are a number of domain-independent ontologies for SAW which we have evaluated in previous work (cf. [14]). The results of our evaluation indicated a feature which almost all ontologies neglected: The discussion about universally applicable relations, especially regarding the aspects of space and time. Moreover, to the best of our knowledge, we found just one approach that addresses all of the application scenarios stated above. SAWA, the Situation Awareness Assistant by Matheus et. al. [13], originates from the military domain and is a set of tools developed by a commercial company[6]. The basis of SAWA is a domain-independent ontology for situation awareness. In addition to OWL, SAWA employs SWRL for deriving relations among objects using rules. In SAWA, each situation type has a goal, the so-called 'standing relation', for constraining the number of relations which have to be determined. Although the standing relations are supposed to instantiate a situation, they can not be used for defining situation types as envisioned in subsection 3.4. Moreover, SAWA also misses universally applicable, spatio-temporal relations.

These shortcomings have been the motivation for starting our research project BeAware! which features an ontology-driven framework for SAW system. Whereas the basic concepts of BeAware!'s core ontology are similar to SAWA's ontology, we have extended it by primitive spatio-temporal relations from the fields of qualitative spatio-temporal reasoning (cf. [19], [20]). Thereby, we are in a position to define situation types and assess situations according to the application scenarios motivated above [21]. To show its real-world applicability, we implemented a proof-of-concept implementation for the RTM domain which we are currently deploying in the context of the Austrian highways agency's traffic management and information system[7].

4. Conclusions

In the scope of this paper, we have focused on application scenarios of ontology-driven SAW systems. The identified scenarios are the integration of heterogeneous information sources, the communication with the human operator, the exchange of knowledge about situations, the definition of situation types, and the actual situation assessment. We argue that the implementation of an ontology-driven SAW system based on a domain-independent SAW ontology resolves a shortcoming of traditional approaches to SAW, namely the missing formal conceptual model for SAW. In addition, such an ontology-

[6] Versatile Information Systems, Inc., http://www.vistology.com
[7] ASFINAG, http://www.asfinag.at

driven SAW system entails all the advantages identified in the corresponding application scenarios without replacing traditional probabilistic approaches to SAW.

One problem regarding the implementation of this vision is the missing standardized rule language on top of OWL, because especially the definition of situation types and the exchange of knowledge about situations depend on an interoperable and universal standard. We hope that the results of the W3C RIF Working Group[8] will close this issue. Although our own framework BeAware! is already finished, the factual incorporation of traditional approaches to SAW is also an open issue. Potentially starting with fuzzifying relations, we are optimistic to implement the sketches outlined in this paper.

Regarding the commercial exploitation of BeAware!, we are currently in talks with a leading German manufacturer of RTM systems aiming at the integration of the framework into their product which will hopefully be another example for a successful industrial application of formal ontologies.

References

[1] James Llinas, Christopher Bowman, Galina Rogova, and Alan Steinberg. Revisiting the JDL data fusion model II. In *Proc. of the 7th Intern. Conference on Information Fusion, Stockholm, Sweden*, pages 1218–1230, June 2004.

[2] Heribert Kirschfink, Josefa Hernandez, and Marco Boero. Intelligent traffic management models. In *ESIT 2000 - European Symposium on Intelligent Techniques, Aachen, Germany*, AC-01, pages 36 – 45, Aachen, Germany, September 2000.

[3] M. R. Endsley. Design and evaluation for situation awareness enhancement. In *Proceedings of the Human Factors Society 32nd Annual Meeting*, pages 97–101, Santa Monica, CA, USA, 1988. Human Factors Society.

[4] Joachim Biermann. Challenges in High Level Information Fusion. In *Proceedings of the Seventh International Conference on Information Fusion, Stockholm, Sweden*, pages 526–527, June 2004.

[5] S. Das, R. Grey, and P. Gonsalves. Situation assessment via bayesian belief networks. In *Proceedings of the International Conference on Information Fusion*, pages 664–671, Annapolis, MD, 2002.

[6] Glenn Shafer. *A Mathematical Theory of Evidence*. Princeton University Press, Princeton, NJ, USA, 1977.

[7] M. M. Kokar and Z. Korona. A formal approach to the design of feature-based multi-sensor recognition systems. *International Journal of Information Fusion*, 2(2):77–89, 2001.

[8] Vladimir Gorodetsky, Oleg Karasaev, and Vladimir Samoilov. On-Line Update of Situation Assessment: A Generic Approach. *International Journal of Knowledge-Based and Intelligent Engineering Systems*, 9(4):361–365, November 2005.

[9] Mieczyslaw M. Kokar, Christopher J. Matheus, Kenneth Baclawski, Jerzy A. Letkowski, Michael Hinman, and John Salerno. Use Cases for Ontologies in Information Fusion. In *Proceedings of the Seventh International Conference on Information Fusion, Stockholm, Sweden*, June 2004.

[10] Thomas Strang and Claudia Linnhoff-Popien. A context modeling survey. In *Proceedings of the First International Workshop on Advanced Context Modelling, Reasoning and Management, Nottingham, England*, September 2004.

[11] M.A. Musen. *Knowledge Engineering and Agent Technology*, chapter Ontology-Oriented Design and Programming, pages 3–16. Frontiers in Artificial Intelligence and Applications. IOS Press, 2004.

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

[13] 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. In *Proc. of SPIE Conference on Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications, Orlando, USA*, pages 75–85, March 2005.

[8] Rule Interchange Format, http://www.w3.org/2005/rules/wiki/RIF_Working_Group

[14] Norbert Baumgartner and Werner Retschitzegger. A survey of upper ontologies for situation awareness. In *Proc. of the 4th IASTED International Conference on Knowledge Sharing and Collaborative Engineering, St. Thomas, U.S. VI*, pages 1–9, Nov. 2006.

[15] Amit Sheth, Kunal Verma, and Karthik Gomadam. Semantics to energize the full services spectrum. *Commun. ACM*, 49(7):55–61, 2006.

[16] Jon Barwise and John Perry. *Situations and Attitudes*. MIT Press, USA, 1983.

[17] Christopher J. Matheus, Mieczyslaw M. Kokar, Kenneth Baclawski, and Jerzy Letkowski. An application of semantic web technologies to situation awareness. In *Proceedings of the International Semantic Web Conference*, pages 944–958, 2005.

[18] Norbert Baumgartner, Werner Retschitzegger, and Wieland Schwinger. A software architecture for ontology-driven situation awareness. In *To appear in Proceedings of the 23rd Annual ACM Symposium on Applied Computing, Track Semantic Web and Applications, Fortaleza, Ceará, Brazil*, 2008.

[19] Norbert Baumgartner and Werner Retschitzegger. Towards a situation awareness framework based on primitive relations. In *Proceedings of the IEEE Conference on Information, Decision, and Control (IDC), Adelaide, Australia*, pages 291–295, February 2007.

[20] Norbert Baumgartner, Werner Retschitzegger, and Wieland Schwinger. Lost in time, space, and meaning—an ontology-based approach to road traffic situation awareness. In *Proc. of the 3rd Workshop on Context Awareness for Proactive Systems (CAPS), Guildford, UK*, June 2007.

[21] Norbert Baumgartner, Werner Retschitzegger, Wieland Schwinger, Gabriele Kotsis, and Christoph Schwietering. Of situations and their neighbors—evolution and similarity in ontology-based approaches to situation awareness. In *Proc. of the 6th International and Interdisciplinary Conference on Modeling and Using Context, Roskilde, Denmark*, Aug. 2007.