Situation Tracking: The Concept and a Scenario

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Abstract

Situation Awareness makes a step forward from the previous focus on Level 1 information processing and fusion, as defined by the JDL Model. However, in most approaches the meaning of 'situation awareness' is limited to knowing whether a particular relation holds or not. In our approach, situations are considered as entities that can affect, exhibit and participate in various behaviors. This requires a clear understanding of the meaning of a new concept – 'behavioral situation'. We use the term 'situational behavior' to refer to a collective response to an event generated by a collection of objects in a situation. This in turn leads to the notion of 'behavioral situation modeling' that refers to the activity of modeling situational behaviors. In this paper we show an ontology that can be used to capture abstract behaviors. This ontology is an extension of the ontology for situation awareness. Here behavioral situations are considered as dynamic entities having states, with transitions from one state to another resulting from events generated by entities participating in a specific behavior, and thus can be tracked. In this paper we discuss a scenario that will show examples of 'situational states' as well as 'events'. The whole scenario is embedded in the formalism of State Machines, where particular states are modeled as 'situation types'. All models are expressed in terms of an ontology for situational behaviors.

1 Introduction

Situation Awareness has recently become the attention of various research efforts, marking a step forward from the previous focus on Level 1 information processing and fusion, as defined by the JDL Model [i]. However, most approaches so far have treated situations as simply relations, i.e., the meaning of 'situation awareness' essentially has been limited to knowing whether a particular relation (relevant to a goal) among some objects holds or not. This interpretation is consistent with Endsley's definition of situation awareness [ii]. It is clear, however, that there is a need for a much more refined and innovative view of the term 'situation', i.e., a view in which situations should be considered as entities that can affect, exhibit and participate in various behaviors. This requirement constitutes a new challenge to the information fusion community. The handling of this challenge requires a clear understanding of the meaning of a new concept – 'behavioral situation', referring to the notion of a situation that has a behavior, as opposed to a situation being just a static collection of objects and relations among them. We then can use the term 'situational behavior' to refer to a collective response to an action by a collection of objects in a situation. This in turn leads to the notion of 'behavioral situation modeling' that refers to the activity of modeling situational behaviors.

A behavior model can be conceptualized in a number of ways - as an abstract concept that is independent of any physical or conceptual entity, as a feature of a specific entity, or as an abstract concept that is associated with one or more physical or conceptual entities. Various knowledge representation mechanisms including State Machines, Hidden Markov Models, Petri Nets, Game Theoretic Models and Bayesian Networks have been used extensively for behavior modeling. Most of the studies have been focusing on modeling behavior of a specific type of entity. For instance, organizational behavior modeling considers an organization as a system of interrelated entities (humans) and then develops models for behavior of humans within an organization. Behavior modeling for military applications needs to consider systems in which all kinds of entities participate – machines, humans, human organizations (like platoons or companies) as well as such complex entities like countries, industries and societies. The variety and the structure of entities participating in behaviors in the military domain require the use of representations and tools appropriate for this kind of complexity. Ontological modeling seems to be the best match for this domain. However, there are no known results in the literature on modeling and tracking of behaviors using an ontological approach.

In the approach presented in this paper, behavior is treated as being associated with a *situation*, i.e., with a number of objects (e.g., an organization) being in some relations with each other. While situation objects will normally have some basic behaviors associated by default, they will be able to participate in complex behaviors involving multiple situation objects. Those complex behaviors can occur *in a situation*, and not just as inherent features of a specific object. Thus behaviors will be treated as situation objects. In this paper we will show an ontology that can be used to capture abstract behaviors. This ontology can be considered as an extension of the ontology for situation awareness.
The new approach to behavior modeling requires the development of models, techniques and tools that can support both the analyst and the developer in the process of employing this new concept in operational scenarios. With such tools, not only will the analyst be able to employ a system for monitoring whether a specific situation has occurred, but also to track situations. While the term 'tracking situations' has been used in the information fusion community, it has been used primarily in the sense of generating indicators and warnings when the situation occurs. In the concept presented in this paper, behavioral situations will be considered as dynamic entities having states, with transitions from one state to another resulting from actions executed by entities participating in a specific behavior.

In this paper we will discuss a concrete scenario that will be considered as a proof-of-concept for situational behavior modeling and situation tracking. This scenario will show examples of 'situational states' as well as 'events'. Events will cause state transitions. The whole scenario will be embedded in the formalism of State Machines, where particular states will be modeled as 'situation types'. All models will be expressed in terms of an ontology for situational behaviors.

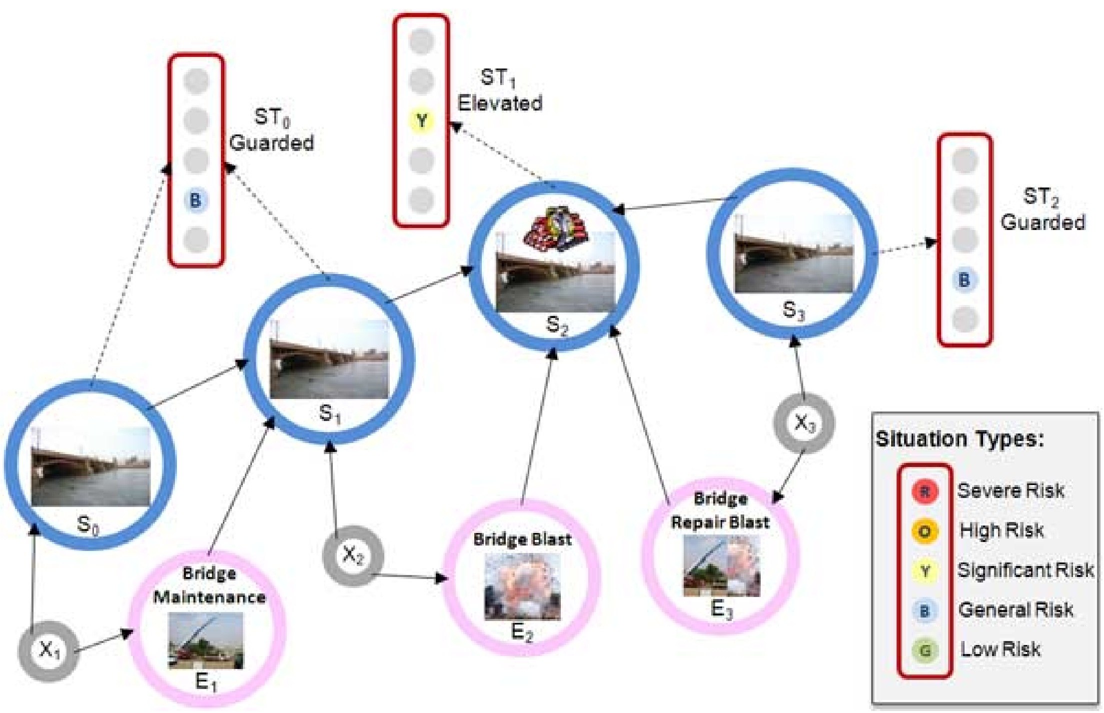

Figure 1 The Scenario

2 Scenario

To explain the main ideas of our approach we present a relatively simple scenario. In this scenario an analyst poses a query related to the 2008 Boston Marathon: "Will there be a bridge explosion during the 2008 Boston Marathon?" The goal is then to support the analyst in not only answering such a query at the time the query is posed, but most importantly, to track the status of this query as new evidence is gathered. The objective of this paper is to indicate how such tracking can be implemented.

Once such a query is posed, the system supports the analyst with expressing the query in the language defined by the Behavioral Situation Theory Ontology (STO-B). This is followed by an interactive process of accepting new evidence (events), resolving ambiguities in the representation of the current situation and the incoming events, merging of new events with the current situation and automatic derivation of consequences of new evidence and particular representational decisions.

A graphical depiction of the scenario is shown in Figure 1. Only major phases of the whole process are shown in this figure. The left-most circle represents the situation that the system is aware of after the analyst posts the query. Since the analyst is already concerned about some danger of the potential situation, the lights above the circle indicate that the situation type can be classified as "General/Guarded Risk" (or code *Blue*). The circle labeled "Bridge Maintenance" represents the event that arrives at some later time. This event includes a relation (*undergoes*) between the bridge and the activity of Repair. The system needs to combine the current description of the situation (S_0) with this new event (E_1). In order to resolve possible ambiguities, a mapping needs to be provided that indicates which of the terms in the description of the current situation and in the event are different names for the same concepts. The mapping is indicated by the arrows from a smaller circle to the two large circles. The meaning of the small circles is that these are sets of terms. The meaning of the arrows from the small circles is that a pair of arrows originating from the same terms in a small circle point to two terms in the large circles that need to be unified, i.e., must be treated as the same term. The merging creates a new description of the current situation, however, since this event describes bridge maintenance, the type of the situation does not change; it still remains at the same level of dangerousness. The second event, "Bridge Blast", includes the *isPlaceOf* relation between Bridge and Blast, and is processed in the same way as the previous event. Since *isPlaceOf* relates bridge to an explosion, the level of danger (type of situation) is raised to "Significant/Elevated Risk " (or code *Yellow*). Finally, the third event delivers a message that the blast was actually related to the repair. At

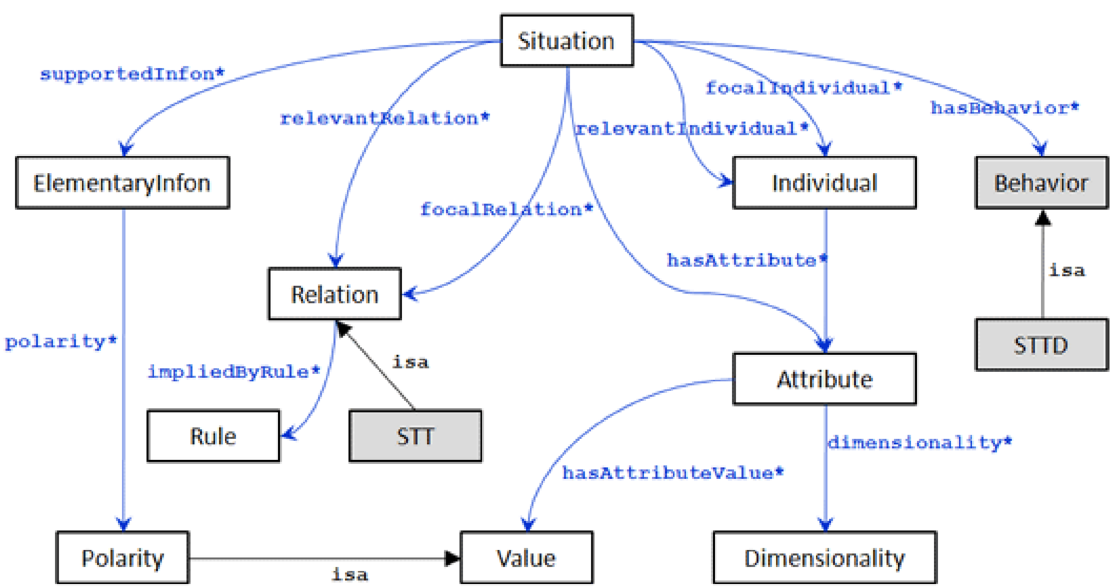

Figure 2 Behavioral Situation Theory Ontology (STO-B)

this point, some information is actually subtracted from the current description of the situation. Note that the direction of the arrows in this case is different than in the previous two events. This time the arrows point towards the previous situation, indicating that the sum of the event and the new situation add up to the previous situation.

3 Behavioral Situation Theory Ontology (STO-B)

In our previous research we have developed a Situation Theory Ontology, called STO [iii]. The intent there was to capture, as closely as possible, the Situation Theory developed by Barwise and Perry [iv] and later by Devlin [v]. However, that ontology was only for static situations. In order to be able to capture dynamic situations we had to extend it by adding some classes and relations to STO. The resulting ontology (STO-B) is shown in Figure 2. As can be seen in this figure, Situation is the central class. Instances of this class represent specific situations. ElementaryInfon is the class whose main role in this ontology is to capture the focus of attention of a situation. A situation object can have relationships with other instances of class Individual, capturing the participants in a situation. Situations also satisfy some relations – instances of class Relation. Situations are first-class objects and thus can have Attributes of their own, in additional to the attributes of the participants.

To be able to represent behaviors, the Behavior class has been added to STO. Typically, a behavior is represented by a State Transition Diagram (STD). However, since we are dealing with behaviors of situations we had to decide what should be state of a situation. Our proposal was to use Situation Type for this role. Consequently, we have a Situation Type Transition Diagram (STTD) in our ontology. The transitions themselves are instances of the class STT (for Situation Type Transition). Each such transition links two situation types. Thus the STT class is a sub-class of Relation.

4 Subtypes of Situation in STO-B

In terms of Situation Theory of Barwise [vi], an analyst's query would represent an *utterance*, which in turn would give rise to what Barwise calls an *utterance situation*. It captures the fact that in the real world the analyst is performing the act of *uttering*. The utterance refers to another situation, the one of the Boston Marathon, which in ST is called the *resource situation*. The utterance situation and the resource situation determine the focus for the analyst, i.e., they establish the focus for the current analysis session. Consequently, the situation that the analyst is interested in is called the *focal situation* (also referred to as *described situation*). All these types of situation are shown in Figure 3. As this figure indicates, a situation (the top box) can be related to another situation (FocalSituation, UtteranceSituation, ResourceSitutation) via the appropriate relations (*focalSituation*, *utteranceSituation*, *resourceSituation*). Additionally, a link *referringSituation* is provided to capture the reverse relationship between a situation that refers to a ResourceSituation and the situation being referred to.

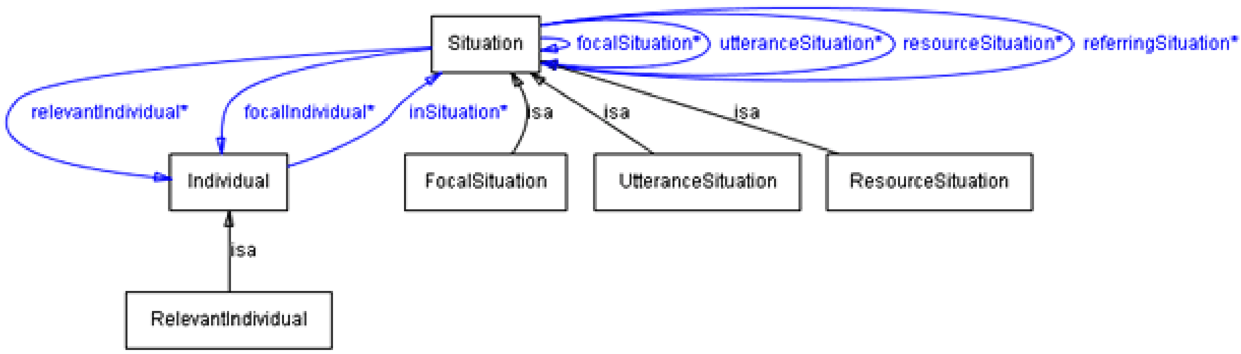

Figure 3 Situation types in Situation Theory

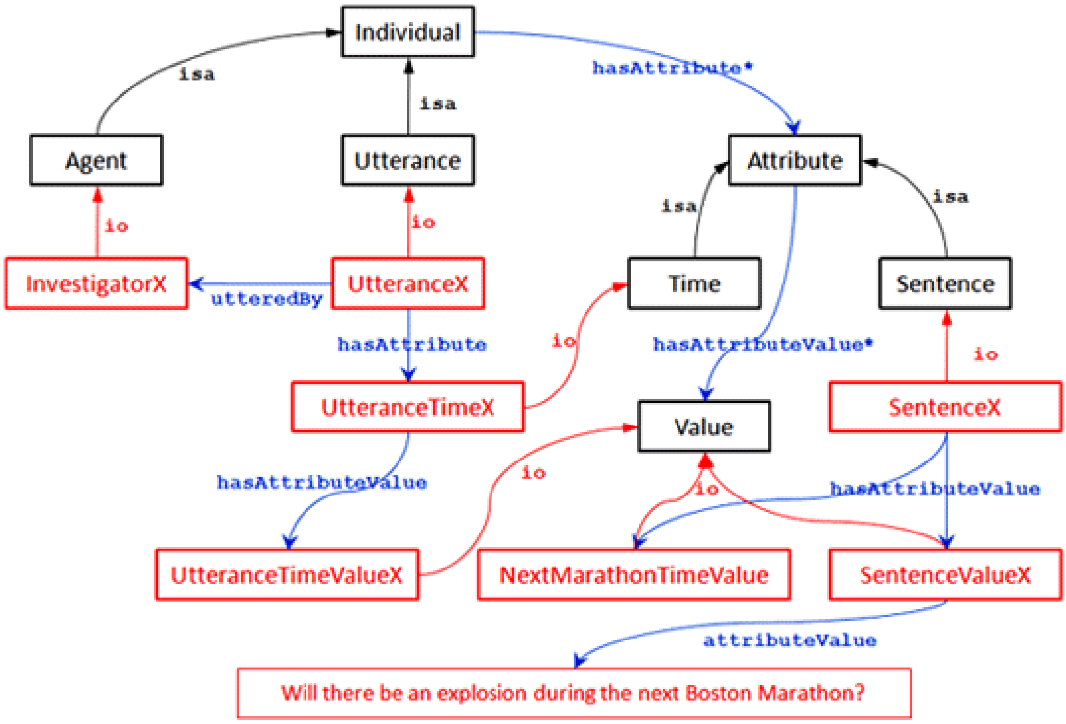

Figure 4 Boston Marathon utterance in STO-B

5 Scenario in STO-B

The scenario presented in Section 3 may be understandable to a human, but since our goal was to develop computer processing of behavioral situations, we had to represent it in computer processable form. By "computer processable" we understand such a representation in which a computer program (an inference engine) can infer facts that are not explicitly represented in the computer's memory, but are implicit in the representation. An example of information explicitly represented in a computer is an entry in a database table. A value returned as a result of a query regarding database-stored information can be viewed as computer processable, however it can be done only for explicitly stored information. We, on the other hand, are also interested in values that are not explicit in the database but that can be inferred from knowledge of the domain. For example, a database may have an entry for X being father of Y; a computer with semantic processing capabilities and an appropriate ontology could then infer that X is a male.

Returning to our Boston Marathon scenario, the utterance can be represented in STO-B as shown in Figure 4. An utterance is an instance of the class Utterance, which is a subclass of Individual in STO-B. An utterance is uttered by an instance of Agent, a subclass of Individual. An instance of utterance is linked to an instance of Agent by the relation *utteredBy*.

To capture the sentence itself, the class Sentence (a subclass of Attribute) is added to STO-B. So a specific utterance (UtteranceX) is related to a specific sentence (SentenceX) via the relation *hasAttribute*. The attribute then is related through *hasAttributeValue* with an instance of Value (SentenceValueX), which in turn is related through *attributeValue* with the sentence "Will there be an explosion during the next Boston Marathon?"

As we can see, the representation of a simple utterance (a sentence) is rather cumbersome. This is, however, a one-time investment done at the time or constructing such a representation. This representation can then be used in various contexts, which are impossible to foresee at the time of developing such a representation. An important thing to understand about such representations is that an item of information, like "UtteranceX" in this example, is given semantics by the links that capture the relationships that the item participates in.

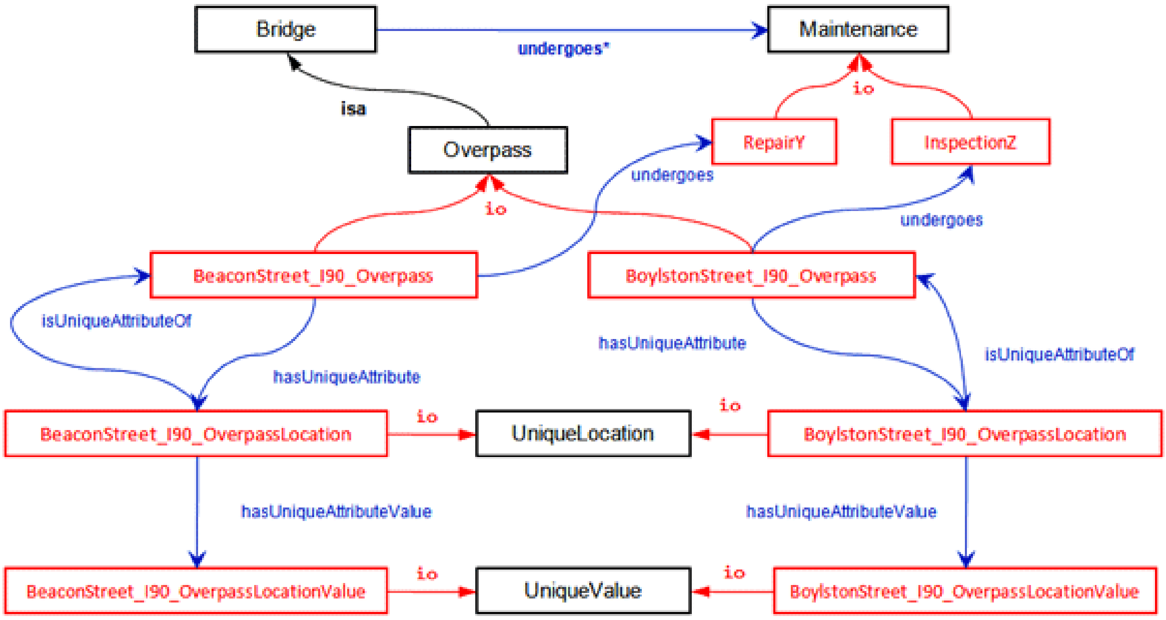

Figure 5 A Bridge Maintenance scenario

6 Understanding Situations

To discuss situation understanding we use the example of automatic inference of the fact that two individuals referred to in two different places (e.g., event and current situation) by different names are actually the same individuals. Suppose that the agent focuses on a situation that involves some bridge maintenance activity in Boston. This event brings information about maintenance activities (repair and inspection) of two overpasses in Boston (Figure 5) [vii]. Suppose one of the overpasses in the Bridge Maintenance situation has the same location value as the bridge mentioned in the Boston Marathon situation. Is it possible that these two individuals, an overpass and a bridge, are actually the same individual, just referred to by two different names? In order to test such a hypothesis we can use an inference engine. Towards this end, we add assertions to the Focal annotation of the situation [viii], using the OWL-based *sameAs* property. In other words, we make a statement that these two individuals are the same. It is theoretically possible, since in our ontology, the class Overpass is a subclass of Bridge.

Since the locations of the bridges (overpasses) are defined by OWL object and data-type properties (as shown in the STO-B), our

```
<rdf:Description rdf:about="&bm;#BridgeX">
  <owl:sameAs rdf:resource="&bmt;#BeaconStreet_I90_Overpass"/>
</rdf:Description>
<rdf:Description rdf:about="&bm#BridgeXLocation">
  <owl:sameAs rdf:resource="&bmt;#BeaconStreet_I90_OverpassLocation"/>
</rdf:Description>
<rdf:Description rdf:about="&bm;#BridgeXLocationValue">
  <owl:sameAs rdf:resource="&bmt#BeaconStreet_I90_OverpassLocationValue"/>
</rdf:Description>
```

where:

```
&bm;=http://vistology.com/ont/2008/STO/BostonMarathon.owl
&bmt;=http://vistology.com/ont/2008/STO/BridgeMaintenance.owl
```

are the abbreviations of the full name spaces.

Figure 6 A test for identity of two objects (bridges).

assertions must be specified for each instance that is used to specify the locations. Consequently, we add the statements shown in Figure 6 to the annotation. Next, we use the consistency-checking program, ConsVISor [ix], to test these assertions. It turns out that the assumption of the two individuals being the same is consistent. However, if we replace the *sameAs* statement with the statement that one of these individuals is *differentFrom* the other individual, the running of ConsVISor results in inconsistency. Thus the final answer is that these two individuals are the same.

Checking (querying) a situation for consistency should be considered as an initial step in the agent's situation analysis. Depending on the outcome of the consistency checking, some event-situations may be eliminated as not feasible. However, the most important aspect of this example is that a computer agent can begin to "understand" situations since it can infer facts from a description of a situation even when such facts are not explicit in the description. A generic reasoner such as BaseVISor [**Error! Bookmark not defined.**,**Error! Bookmark not defined.**] can and will be used to perform a wider variety of inferences and answer more complex queries.

7 Conclusions

In this paper we discussed the problem of representation and automatic inference about dynamically changing situations. Situation has been defined as a first-class item, one that can have its own properties and can participate in various relations. Moreover, the Situation Theory ontology has been extended to incorporate behaviors. We showed examples of representations of situations and events. We also showed a simple example of inferring facts that are not explicit in the representation. This is suggestive of how a computer agent might begin to "understand" situations more fully through the use of semantic capabilities.

In our ongoing work, we are focusing on development of automated and semi-automated approaches to situation tracking. Situations expressed in OWL will be embedded in a higher-order representation that will allow for automated inference and reasoning about transitions among the different situation states (Situation Types).

8 Acknowledgments

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