Of Situations and Their Neighbors

Evolution and Similarity in Ontology-Based Approaches to Situation Awareness

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Abstract. Ontology-based approaches to situation awareness have gained increasing popularity in recent years. However, most current approaches face two inherent problems. First, they lack sufficient support for assessing evolutions of situations, which is crucial for informing (human) agents about emerging instances of interesting situation types. Second, they are confronted with the problem of recognizing situations that are just similar to a situation type an agent is interested in. Our approach contributed in this paper is based on conceptual neighborhoods of relations which we generalize to conceptual neighborhoods of situations. These conceptual neighborhoods turn out to be the basis for addressing both problems, the assessment of evolving as well as similar situations. The applicability of our approach is demonstrated by an in-depth case study in the domain of road traffic management.

1 Introduction

A profound basis for decision making of (human) agents in highly-dynamic, heterogeneous environments—like operators in the field of road traffic management—has to provide a perception of the available information that is tailored to the decision maker's context. *Situation awareness* (SAW) aims at providing such a perception based on *situations*, which describe a state of affairs adhering to a partial view of the world. Our conceptualization of situations, which is motivated by Situation Theory [1], involves physical *objects*, their intrinsic *attributes*, and their *relations* to other objects, which altogether may potentially contribute to *relevant* situations, i.e. the ones an agent is interested in. These relevant situations are defined by abstract *situation types* that should be instantiated during situation assessment. In recent years, *ontologies*, i.e. their interpretation coined by Gruber [2],

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have been regarded to be suitable for providing the vocabulary for describing situations and their involved concepts (e.g. [3]).

Endsley [4] points out that SAW also involves the estimation of the future of recognized situations, meaning that also the *evolution* of situations has to be assessed. Consequently, agents should be informed of an emerging relevant situation, in order to take pro-active action. A further problem is to inform agents about situations that are just *similar* to the relevant situation types (e.g. sensors still just capture a very limited image of the real world). Unfortunately, ontology-based SAW approaches face the problem inherent to the mainly symbolic representation of situations. This leaves the questions how to determine that a situation is on its way to turn into a relevant situation or that a situation is similar to a situation type? At first sight, both problems, assessing evolving and similar situations, are unrelated. In the scope of this paper, we contribute an approach based on conceptual neighborhoods of relations, which, generalized to conceptual neighborhoods of situations, turn out to be the basis for addressing both problems. Our approach is established as a case study in the road traffic management domain, which is, as indicated above, a prominent candidate for applying SAW systems. Road traffic operators have to control road traffic based on the assessed traffic situations using, for example, speed controls or warning messages. In order to elaborate a realistic setting, we collaborate with ASFINAG Traffic Telematics Ltd., a subsidiary of Austria's highways agency, regarding the interesting types of traffic situations and the actions taken by a traffic operator upon their occurrence.

The paper is structured as follows. First, we introduce an ontology for road traffic SAW and a formalism to specify situation types in Sect. 2. Next, we elaborate our approach in Sect. 3 and subsequently, in Sect. 4, apply it in the scope of a case study involving various traffic situation types and their occurrences in a complex scenario. Finally, we provide an overview of related work in Sect. 5 and conclude the paper in Sect. 6, in which we critically discuss our contribution and indicate further prospects of our work.

2 Road Traffic Situation Awareness

In order to explain our approach elaborated in Sect. 3 by means of illustrative examples, we introduce an ontology for road traffic SAW and, thereupon, a formalized description of an interesting but simple situation type in this section. The ontology and the according formalism to describe situations and situation types are also the basis for our case study in Sect. 4.

2.1 An Ontology for Road Traffic Situation Awareness

The ontology depicted in Fig. 1 is based on our previous work which focused on spatio-temporal extensions to a simple, OWL[1]-DL-based ontology for road

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

traffic SAW [5]. Whereas the road traffic concepts are extended, the SAW concepts, which are the core of the ontology, are simplified in the scope of this paper. In short, the classes `WrongWayDriver`, `BlackIce`, etc. are traffic-relevant entities and are combined in the package `roadTraffic`. The SAW concepts on top of these traffic-relevant entities have various origins. The basic components, essentially the classes `Object`, `Situation`, and `Attribute` are motivated by the top-level concepts we have identified in our survey of domain-independent ontologies for SAW [6]. The class `Object` subsumes all traffic-relevant entities and is associated with all subclasses of `Attribute`, like, for example, `Lifespan` and `Location`. Relations, which are deduced from attributes, relate objects and are subject to the largest simplification of the original SAW ontology [5]. In contrast to a class taxonomy, we use derivatives of the object property `isRelatedWith` for relating objects, assuming that properties of these relations are modeled outside of OWL-DL. Instances of the class `Situation` are constituted of objects as well as the relations that contribute to the situation. Situations have, like relations, an implicit time interval of validity. Evolutions of situations are represented as sequences using the object property `hasNextState`.

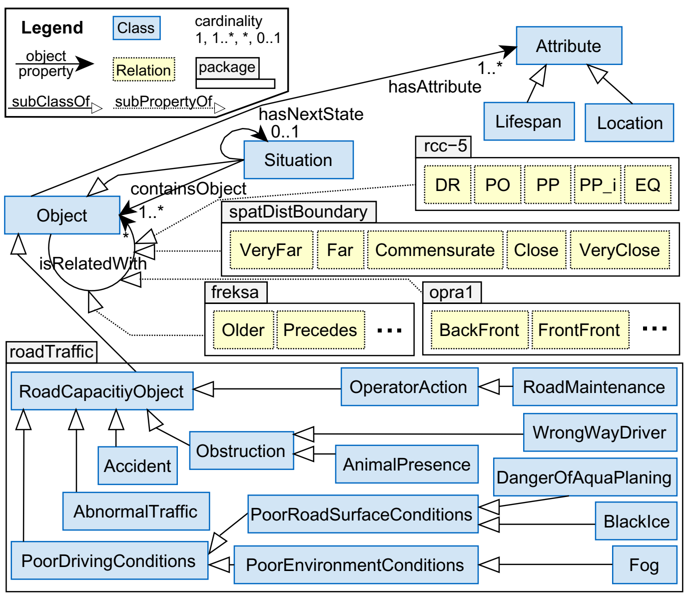


Fig. 1. An ontology for road traffic SAW

The depicted derivatives of the object property `isRelatedWith` are primitive relations which provide the concepts for defining situation types or more complex relations [7]. The different relations are again organized into packages. We call each package a *family of relations* because all contained relations model a specific *aspect* of the relationships between two objects. The currently incorporated families, which are based on well-known calculi from the field of qualitative spatio-temporal reasoning, originate from our previous work [5] and have been chosen for this paper because they provide the minimal spatio-temporal aspects for defining the traffic situation types introduced in the following sections.

The family (1) `rcc-5` [8] models the mereo(topo)logical relationships between the spatial regions occupied by two objects (e.g. `DR` means 'discrete from'). (2) `spatDistBoundary` [9] models a simple interpretation of qualitative distance between two objects based on the minimal distance between their boundaries on the road network. (3) `freksa` [10] models temporal relationships between time intervals, i.e. the lifespans of two objects. (4) $\texttt{opra}_1$ [11] models the aspect orientation in an intrinsic way without a reference point. Two objects are regarded to be oriented points with respect to the road network (e.g. `BackFront` indicates one object being in front of another object travelling in the same direction on the same road).

Note that one may also define more complex families of relations, like, for example, the level of obstruction between two traffic objects. In the rest of this paper, however, we stick to the above families of spatio-temporal relations and their interpretation with respect to road traffic management [5].

2.2 Formalizing Traffic Situation Types

A situation type defines an abstract state of affairs an agent, i.e. a road traffic operator in our domain, is interested in. In accordance with our previous work [5], we use a simple formalism to define such situation types based on the above ontology. We describe the formalism using a simple traffic situation type, which will also serve as the running example in the following section. The traffic situation type 'Fog in the border area of a chunk of abnormal traffic (traffic jam)', shortly denoted as S_0, is specified as follows:

```
roadTraffic:AbnormalTraffic(?a) ∧ roadTraffic:Fog(?b) ∧
rcc-5:PO(?a, ?b) ∧ spatDistBoundary:VeryClose(?a, ?b)
```

This rule can be seen as the left-hand side of an implication, i.e. it represents a formalization of the trigger for situation type S_0. To improve readability, we apply a very simple formalism based on the human-readable syntax of SWRL[2]. For the specification of OWL class and object property membership we use unary and binary predicates. For reasons of brevity, we suppose that the valid time intervals corresponding to the time instant of situation assessment are implicitly chosen. The rule should be read as follows. If between instances of the classes `roadTraffic:AbnormalTraffic` and `roadTraffic:Fog` the relations `rcc-5:PO` (partly overlapping) as well as `spatDistBoundary:VeryClose` hold, an instance of S_0, i.e. an instance of a subclass of `Situation`, is created.

Although such rules allow us to recognize instances of situation types, they are restricted to exact matches of the *most critical* instant in the evolution of a situation. Our approach to counter this restriction is introduced in the next section.

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

3 Assessing Evolving and Similar Situations

Whereas a situation type is a template for a *state of affairs*, the evolution of a situation or a situation type may be seen as a *course of events* [1]. Let us consider the *possible* courses of events between two arbitrary situations. With our current knowledge based on the formalization of situation types, we just know that there are—even if regarding just the contributing relations—possibly infinite variations between these two situations. That is, we have no a priori knowledge about the evolution of situations and we, consequently, can not determine for a situation, whether it may evolve into or it is similar to an instance of a most-critical situation type. Our approach to handle both problems is elaborated in the following subsections, in which we describe the notion of *conceptual neighborhoods* of relations and situations, and, thereon, provide a method to model evolutions of situations using *landmark situation types*.

3.1 Conceptual Neighborhoods of Situations

We elaborate our approach based on two assumptions. First, two relations are, according to Freksa [10], '*conceptual neighbors*, if a direct transition from one relation to the other can occur upon an arbitrarily small change in the referenced domain'. We assume that for each family of relations, a directed graph specifying the *conceptual neighborhood* is given. This conceptual neighborhood graph (CNG) is defined by a set of vertices, the relations, and a set of edges, the direct neighborhoods of the relations in the corresponding family. This leads us to the second assumption—a relation between two objects evolves in the form of *smooth transitions* with respect to the CNG of its corresponding family. Fig. 2 shows an exemplary CNG for `rcc-5`. For example, if between two objects the relation `DR` (discrete from) holds, it can only evolve to `EQ` (equals) by traversing over `PO` (partly overlapping).

In fact, these two assumptions are very common in the field of qualitative spatial and temporal reasoning, because they restrict the complexity of reasoning calculi. However, we suggest that the assumptions can be interpreted as requirements for general families of relations that are modeled in a SAW application. For example, the level of obstruction between two traffic objects also adheres to our premises.

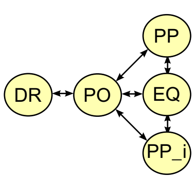


Fig. 2. The CNG of `rcc-5`

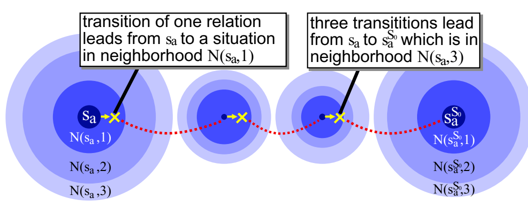


Fig. 3. The evolution of s_a into $s_a^{S_0}$

The generalization from one relation to all relations that contribute to a situation is straight-forward and has already been investigated with respect to relation-based similarities between spatial scenes (e.g. [12]). We generalize this work to relation-based similarities between situations and apply it to define the possible situations on the way from one situation to another. What follows is the direct *neighborhood of a situation*—the *set of situations* containing the same objects and the relations that are reachable by a single transition of one relation that contributes to the situation. The neighborhood of a situation type is defined analogously by the substitution of concrete object instances with unified variables. In the following, we denote an arbitrary situation a being an instance of a situation type S_i as $s_a^{S_i}$. We omit S_i if s_a is an anonymous situation, i.e. it is just an instance of the most general situation type `Situation`. Moreover, we designate the conceptual neighborhood of a situation, which is reachable by a transition of n relations, as $N(s_a^{Si},\ n)$.

Let us demonstrate the concept using the exemplary situation type S_0, 'Fog in the border area of a chunk of abnormal traffic', which we have defined in the previous section. Assume we got the following formalization of a concrete, anonymous situation s_a that involves the two objects `obj1` and `obj2`:

```
roadTraffic:AbnormalTraffic(obj1) ∧ roadTraffic:Fog(obj2) ∧
rcc-5:DR(obj1, obj2) ∧ spatDistBoundary:Commensurate(obj1, obj2)
```

We want to determine whether s_a may evolve into an instance of S_0. Based on the CNGs of the families `rcc-5` and `spatDistBoundary`, we know that s_a is, at minimum, three transitions away from being an instance of S_0 (`DR`→`PO`, `Commensurate`→`Close`→`VeryClose`). Hence, $s_a^{S_0} \in N(s_a, 3)$. Fig. 3 depicts an exemplary evolution of s_a into $s_a^{S_0}$ across anonymous situations in its neighborhoods visualized by means of concentric circles around each evolution. The different sizes of the circles indicate that the number of reachable situations in a neighborhood differs (e.g. in `rcc-5`, we got one possible transition from `DR` in contrast to four transitions from `PO`; cf. Fig. 2). Note that the neighborhoods need not necessarily be symmetric as it may be assumed from Fig. 3, i.e. a CNG with asymmetric neighborhoods of relations may lead to cases in which an instance of S_0 is in the neighborhood of s_a, but not the other way round.

If we investigate the example in detail, we find an approach to tackle both our problems. First, we are now in a position to determine the *minimal distance* between two situations or situation types regarding the number of necessary transitions of their contributing relations. Note that we do not talk about the likelihood of the minimal distance—we simply know each possible path from the contributing relations' CNGs. Second, given a situation s_a and a to-be-matched situation type S_0, we know that s_a is similar to an instance of S_0, if one of both is in the direct neighborhood of the other one.

Though the example in Fig. 3 and the elaborated approach are rather intuitive, we believe that, in a real-world setting, counting the number of hops in a CNG (cf. [12]) is a too simplistic distance measure. For example, concurrent transitions may occur, or the relevance of transitions may vary across families or situations. Nevertheless, the elaboration of such a distance measure is beyond the scope of this paper. Rather, we assume that a function $D : (s_a, s_b) \rightarrow [0..1]$, which maps a pair of situations or situation types to the interval between 0 and 1, is given. D corresponds to the normalized, minimal distance between both situations or situation types. Regarding the application of our approach to the scenario in the following section, we will provide a simple heuristic for D.

While we are now in a position to assess for any situation, whether it may evolve into or it is similar to a most-critical situation, a situation may still have many evolutions from which just a few are relevant for an agent. Hence, we want to provide further means for modelling the *relevant* courses of events.

3.2 Landmark Situation Types

Landmarks are used in various domains for highlighting significant entities of interest (e.g. robot navigation [13]). We follow these examples and introduce *landmark situation types* in order to delineate the relevant states of affairs in a course of events. Moreover, we separate these landmark situation types into three categories. The situation types discussed and explicitly modeled up to now, which represent the most-critical types of situations agents are interested in, are further on called *climax* situation types. In addition, there may be various *trigger* situation types before a climax situation type, i.e. situations that are likely to evolve into a climax situation. After a climax situation type, we add various *clearance* situation types. Although their formalization equals climax situation types, trigger and clearance situation types match, unlike climax situation types, situations in a fuzzy way—they mark the beginning and the end of a matching *phase*. That is, once a trigger situation type is instantiated, the evolutions of the situation towards the climax situation stay instances of the trigger situation type. The other way round, with the first deviation of a climax situation towards a clearance situation type, all evolutions of the situation are instances of the clearance situation type. Accordingly, we call the evolutions before and after a climax situation type the *trigger phase* and *clearance phase*.

Fig. 4 shows such an exemplary course of events based on our climax situation type S_0 which we have extended by the trigger situation type S_0T_0 and the clearance situation type S_0C_0. Once we have assessed a situation $s_a^{S_0T_0}$, the situation's successive states towards the climax belong to the trigger phase. In the given example, s_a evolves to an instance of the climax situation type by two transitions, i.e. $s_a^{S_0} \in N(s_a^{S_0T_0}, 2)$. The climax situation is valid as long as it matches, whereby the first deviation causes an instantiation of S_0C_0 which marks the beginning of the clearance phase. If the clearance situation type finally matches, the course of events ends.

The clearance situation type S_0C_0 indicates a further problem when dealing with evolving situations—one may define a landmark situation type that consists of a different number of objects than the subsequent landmark situation type. In case we are dealing with a trigger situation, the distance to the following landmark situation can just be determined with respect to the remaining relations. In fact, a trigger situation may, in case the remaining relations already match, spontaneously evolve into a climax situation without further relation transitions—

S_0T_0: roadTraffic:AbnormalTraffic(?a) ∧
roadTraffic:Fog(?b) ∧
rcc-5:DR(?a, ?b) ∧
spatDistBoundary:Close(?a, ?b)
S_0C_0: roadTraffic:Fog(?b)

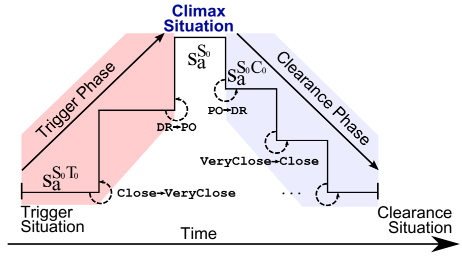


Fig. 4. An exemplary course of events based on landmark situation types

the object just 'pops up' at the adequate position. Such circumstances may be smoothed, for example, by the provision of distance measures for the co-occurrence of subclasses of `Object` in our ontology. Furthermore, following the course of events, the trivial *default* clearance situation types are determined by the drop out of *any* or *every* object that contributes to a climax situation type. The first case, i.e. the drop out of any object, may be overridden by a specific clearance situation type like, for example, S_0C_0. This clearance situation type means that the chunk of `AbnormalTraffic` determines the length of the clearance phase; if it drops out, and just the `Fog` remains, the course of events ends.

The final approach to assess evolving and similar situations shapes up as follows. At every time instant of situation assessment, we search for evolutions of previously assessed landmark situations. If an evolution finally matches the last clearance situation type, the situation ends. In addition, when trying to match a climax situation type without prior evolution, we follow our approach to assess situations similar to situation types, i.e. a situation also matches if it is in the near neighborhood of the climax situation type.

4 A Case Study in Road Traffic Management

We demonstrate our approach to assess evolving and similar situations by means of a case study which is made up of a formalization of exemplary traffic situation types and their assessment in a concrete scenario.

The exemplary traffic situation types shown in Table 1 are motivated by typical tasks of a road traffic operator and will be the basis for showing different aspects of the assessment of evolving and similar situations in the subsequent scenario. Apart from the formalization introduced in Sect. 2, the informal descriptions of the four climax situation types and their corresponding trigger or clearance situation types indicate exemplary workflows of traffic operators that are triggered by the occurrence of such situations in a real-world setting. In case a trigger or clearance situation type is missing, there is no interesting evolution of the corresponding situation from a traffic operator's point of view.

The scenario presented below serves as a test bed for our approach and consists of five states of affairs at consecutive, but not contiguous time instants (t_0 to t_4). Table 2 lists the four states of affairs with their corresponding results of

Table 1. A description and formalization of the four relevant courses of events

$S_i[T_i\|C_i]$	**Description – Formalization**
S_1T_0	An `OperatorAction` (for reasons of brevity, we omit the name of the package `roadTraffic`), i.e. a capacity-restricting action taken by the road operator occurs. Examples are roadworks or blocked lanes. `OperatorAction(?a)`
S_1	An `OperatorAction` causes `AbnormalTraffic`. The restricted capacity causes abnormal traffic, i.e. a traffic jam. The main workflow of this type of situation is the mitigation of the abnormal traffic by stopping the corresponding operator action. `OperatorAction(?a)` ∧ `AbnormalTraffic(?b)` ∧ `rcc-5:PO(?a, ?b)` ∧ `freksa:Older(?a, ?b)` ∧ `opra1:BackFront(?a, ?b)`
S_1C_0	The `AbnormalTraffic` disperses. After the dispersion, a traffic operator may consider the resumption of a previously cancelled operation action. Note that this situation type overrides the default clearance situation type, i.e. the `AbnormalTraffic` determines the extent of the situation. `OperatorAction(?a)`
S_2	`PoorDrivingConditions` cause an `Accident`. Typical workflows triggered by this climax situation type would be the alarm of local authorities and the publication of special warnings to road drivers. Note that we have not defined a trigger for this climax situation type, since there are no specific actions in case of poor driving conditions without an accident. `PoorDrivingConditions(?a)` ∧ `Accident(?b)` ∧ `(rcc-5:PO(?a, ?b)` ∨ `rcc-5:PP(?b, ?a))` ∧ `freksa:Older(?a, ?b)` ∧ `spatDistBoundary:VeryClose(?a, ?b)`
S_2C_0	The area of `PoorDrivingConditions` moves away from the `Accident`. `PoorDrivingConditions(?a)` ∧ `Accident(?b)` ∧ `rcc-5:DR(?a, ?b)` ∧ `spatDistBoundary:Commensurate(?a, ?b)`
S_3T_0	`AbnormalTraffic` potentially grows together with `AbnormalTraffic`. `AbnormalTraffic(?a)` ∧ `AbnormalTraffic(?b)` ∧ `rcc-5:DR(?a, ?b)` ∧ `spatDistBoundary:Close(?a, ?b)`
S_3	`AbnormalTraffic` grows together with `AbnormalTraffic`. Two chunks of abnormal traffic that grow together should be treated as a single object. Hence, the single, more critical traffic jam would result in a different control strategy. `AbnormalTraffic(?a)` ∧ `AbnormalTraffic(?b)` ∧ `rcc-5:DR(?a, ?b)` ∧ `spatDistBoundary:VeryClose(?a, b?)`
S_3C_0	Grown-together chunks of `AbnormalTraffic` split. `AbnormalTraffic(?a)` ∧ `AbnormalTraffic(?b)` ∧ `rcc-5:DR(?a, ?b)` ∧ `spatDistBoundary:Commensurate(?a, ?b)`
S_4T_0	A `WrongWayDriver` heads toward a chunk of `AbnormalTraffic`. `WrongWayDriver(?a)` ∧ `TrafficJam(?b)` ∧ `rcc-5:DR(?a, ?b)` ∧ `opra1:FrontFront(?a, ?b)` ∧ `spatDistBoundary:Commensurate(?a, ?b)`
S_4	A `WrongWayDriver` rushes into `AbnormalTraffic`. An instance of this situation type would be very critical, because it would imply an accident at an already congested part of the road network. Again, such a situation would trigger the alarm of local authorities. `WrongWayDriver(?a)` ∧ `AbnormalTraffic(?b)` ∧ `rcc-5:PO(?a, ?b)` ∧ `opra1:FrontFront(?a, b?)` ∧ `spatDistBoundary:VeryClose(?a, ?b)`

situation assessment. For each state of affairs, a simple graphic depicts the valid objects, which are, for reasons of brevity, located on the same carriageway of the same highway. Note that the driving direction is from the right to the left and there are several junctions at which one may leave or enter the highway. The object classes are represented by classic traffic signs and different shadings. The spatial extent of all objects is indicated by the boxes surrounding them.

Below each state of affairs, Table 2 provides the assessed situations followed by a description of the aspects covered by the example. The first column *Id*, which contains the identifier for a situation, is followed by the instantiated situation type and the column *Concrete Match*—the formalization of the assessed situation. The last three columns provide three distance measures based on our function D. For this scenario, D is the average distance of all relations that contribute to a situation. The distance per relation, i.e. the number of transitions from one relation to another, is normalized by the length of the longest non-cyclic path between any pair of relations in the corresponding CNG (e.g. `DR` to `PO` takes one hop, the length of the longest path in `rcc-5` is 2, thus, the normalized distance is $1\ /\ 2\ =\ 0.5$). D is not defined for situations with different objects. $D_{\leftarrow}$ and $D_{\rightarrow}$ indicate the distance from the previous and to the next landmark situation type in a course of events; both are just determined for trigger or clearance phases, whereas $D_{\sim}$, the distance from a climax situation type, just applies to climax situations.

Summing up the core of our case study, we have demonstrated our approach by applying it to a scenario involving all the previously defined, relevant traffic

Table 2. The scenario and the corresponding results of situation assessment

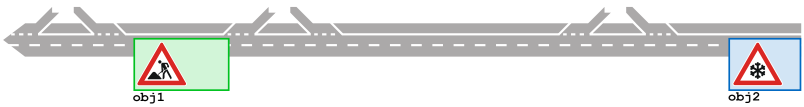
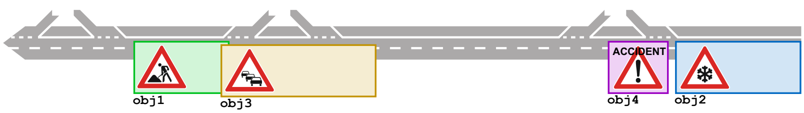
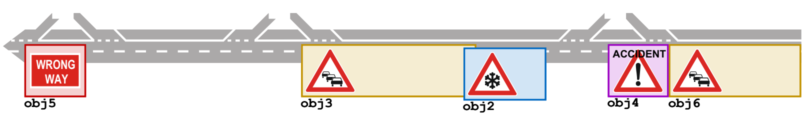
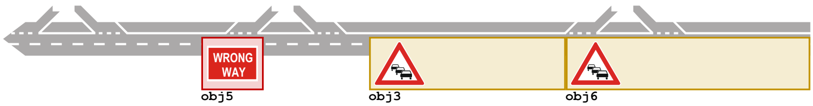
<table>
<tr><th>t_i</th><th colspan="6">Scenario</th></tr>
<tr><th></th><th>Id</th><th>$S_i[T_i|C_i]$</th><th>Concrete Match</th><th>$D_{\leftarrow}$</th><th>$D_{\rightarrow}$</th><th>$D_{\sim}$</th></tr>
<tr><td>t_0</td><td colspan="6">
</td></tr>
<tr><td></td><td>s_a</td><td>$S_1 T_0$</td><td>RoadMaintenance(obj1)</td><td>0</td><td>n.d.</td><td>–</td></tr>
<tr><td></td><td colspan="6">This state of affairs is an example for an assessed trigger situation with a missing object (the AbnormalTraffic). The triggered course of events is brought to the operator's attention, although we can not determine the minimal distance to the climax situation. Contrarily, the area of BlackIce is consciously not instantiated, because we have not defined a corresponding trigger situation type for S_2.</td></tr>
<tr><td>t_1</td><td colspan="6">
</td></tr>
<tr><td></td><td>s_a</td><td>S_1</td><td>RoadMaintenance(obj1) ∧ AbnormalTraffic(obj3) ∧ rcc-5:PO(obj1, obj3) ∧ freksa:Older(obj1, obj3) ∧ opra1:BackFront(obj1, obj3)</td><td>–</td><td>–</td><td>0</td></tr>
<tr><td></td><td>s_b</td><td>S_2</td><td>BlackIce(obj2) ∧ Accident(obj4) ∧ rcc-5:DR(obj2, obj4) ∧ freksa:Older(obj2, obj4) ∧ spatDistBoundary:VeryClose(obj2, obj4)</td><td>–</td><td>–</td><td>0.17</td></tr>
<tr><td></td><td colspan="6">Whereas s_a has evolved to its climax, an Accident has been reported near an increasing area of BlackIce. Although the actual situation is just similar to the corresponding climax situation type, it matches with some deviation. The situation causes the traffic operator to dispatch a warning to motorists advising them to drive with extreme caution.</td></tr>
<tr><td>t_2</td><td colspan="6">
</td></tr>
<tr><td></td><td>s_a</td><td>$S_1 C_0$</td><td>AbnormalTraffic(obj3)</td><td>0</td><td>n.d.</td><td>–</td></tr>
<tr><td></td><td>s_b</td><td>$S_2 C_0$</td><td>BlackIce(obj2) ∧ Accident(obj4) ∧ rcc-5:DR(obj2, obj4) ∧ freksa:Older(obj2, obj4) ∧ spatDistBoundary:Close(obj2, obj4)</td><td>0.25</td><td>0.08</td><td>–</td></tr>
<tr><td></td><td>s_c</td><td>$S_3 T_0$</td><td>AbnormalTraffic(obj3) ∧ AbnormalTraffic(obj6) ∧ rcc-5:DR(obj3, obj6) ∧ spatDistBoundary:Close(obj3, obj6)</td><td>0</td><td>0.13</td><td>–</td></tr>
</table>

Table 2. (*continued*)

t_i	Id	$S_i[T_i \vert C_i]$	Concrete Match	$D_{\leftarrow}$	$D_{\rightarrow}$	$D_{\sim}$
	s_d	S_4T_0	`WrongWayDriver(obj5) ∧ AbnormalTraffic(obj3) ∧ rcc-5:DR(obj5, obj3) ∧ opra1:FrontFront(obj5, obj3) ∧ spatDistBoundary:Commensurate(obj5, obj3)`	0	0.33	–

The operator has reacted and cancelled the `RoadMaintenance`. Thus, s_a is in its *clearance* phase which will eventually end when the chunk of `AbnormalTraffic` *disperses*. At the same time, the area of `BlackIce` has moved and, because of winter maintenance, shrunk. Therefore, s_b has evolved—in this case due to the *transition* of its contributing *relations*—to a state of affairs shortly before final *clearance*. Moreover, the `Accident` has caused `AbnormalTraffic`, which seems to be growing together with the existing chunk of `AbnormalTraffic`. In addition, a `WrongWayDriver` suddenly emerges. The operator informs police of the detected `WrongWayDriver` and the imminent large chunk of `AbnormalTraffic` (s_c, s_d). Both situations *may evolve* to their climax by a *transition* of their contributing *relations*, what is reflected by the available distance measures.

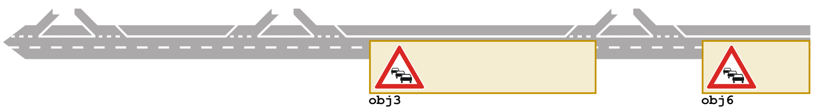
t_3



t_i	Id	$S_i[T_i \vert C_i]$	Concrete Match	$D_{\leftarrow}$	$D_{\rightarrow}$	$D_{\sim}$
t_3	s_a	S_1C_0	`AbnormalTraffic(obj3)`	0	n.d.	–
	s_c	S_3	`AbnormalTraffic(obj3) ∧ AbnormalTraffic(obj6) ∧ rcc-5:DR(obj3, obj6) ∧ spatDistBoundary:VeryClose(obj3, obj6)`	–	–	0
	s_d	S_4T_0	`WrongWayDriver(obj5) ∧ AbnormalTraffic(obj3) ∧ rcc-5:DR(obj5, obj3) ∧ opra1:FrontFront(obj5, obj3) ∧ spatDistBoundary:Close(obj5, obj3)`	0.08	0.25	–

Thanks to the previously notified fire department, the `Accident` and, hence, situation s_b have been finally cleared. Whereas s_c has evolved to its *climax* by a *transition of relations*, s_d is not yet there. Note that especially s_d reveals the shortcomings of the simple distance function—although just two possibly concurrent transitions are left, the distance measure to the climax situation is rather high.

t_4



t_i	Id	$S_i[T_i \vert C_i]$	Concrete Match	$D_{\leftarrow}$	$D_{\rightarrow}$	$D_{\sim}$
t_4	s_a	S_1C_0	`AbnormalTraffic(obj3)`	0	n.d.	–
	s_c	S_3C_0	`AbnormalTraffic(obj3) ∧ AbnormalTraffic(obj6) ∧ rcc-5:DR(obj3, obj6) ∧ spatDistBoundary:Close(obj3, obj6)`	0.13	0.13	–

Finally, the `WrongWayDriver` has vanished, what causes s_d to disappear as a result of the *trivial clearance* situation types. Moreover, in anticipation of the `WrongWayDriver` rushing into the already large chunk of `AbnormalTraffic`, the operator has diverted road traffic away from the highway what resulted in the diminution of `AbnormalTraffic`. In fact, situation s_c is in its clearance phase, because of the transition of the contributing relations.

situation types. Although the scenario as a whole will scarcely happen in this compact form in real-life, the single situations are typical for road traffic management. During situation assessment, both our goals, i.e. the notification of operators of emerging and similar climax situations, have been demonstrated by corresponding examples. Moreover, various distinguishable aspects of evolution have been illustrated. In short, we have dealt with courses of events involving missing objects as well as evolutions based on transitions of relations.

5 Related Work

Searching for the notion *situation* in related work from different research communities, one discovers that, although many of them—intentionally or not—share some common grounding, the actual conceptualization is payed varying attention. For example, whereas the information fusion community has identified situations as the key to informed decision making [3] more than a decade ago, explicit representations of situations have not such a long tradition in approaches to SAW for ubiquitous computing (e.g. [14]).

Starting with closely related work, it is first of all interesting to note that there are currently, to the best of our knowledge, no specialized, formal ontologies for the area of SAW in road traffic management. Thus, we increase the scope of related work beyond the road traffic management domain and examine domain-independent *ontology-based* approaches to SAW. Our previous survey of such approaches [6] revealed that SAWA by Matheus et. al. [15] is the only approach which at least partly addresses evolving situations by incorporating temporal concepts. However, the actual assessment of evolving or similar situations is not yet elaborated.

Having a still wider look at *non*-ontology-based approaches to SAW, Mayrhofer et. al. [16] provide an approach to context prediction for ubiquitous computing. Although their generic approach is different to ours, because it lacks a conceptualization of situations and their involved concepts, they also analyze the evolution of context information over time. Regarding this characteristic, our work stresses the a priori knowledge which is encoded in an ontology or is provided by a domain expert in contrast to the probabilistic approach followed by Mayrhofer et. al. Widely related is also the work by Padovitz et. al. (e.g. [17]). Again with respect to ubiquitous computing, they propose context spaces, a generic, multi-dimensional approach to model situations. Though being similar to Mayrhofer et. al., their work focuses on dealing with imprecise information rather than on context prediction, what resembles our problem to assess similar situations. Having different goals in mind, however, our ontology-based solution should be regarded as the *basis* for, e.g., probabilistic methods as suggested by Mayrhofer et. al. or Padovitz et. al.

Another non-ontology-based work we examine is BABY-SIT—a logic programming environment based on *Situation Theory* by Akman and Tin [18]. In their work, they give an overview of systems akin to BABY-SIT and make ontological commitments that are closely related to our conceptualization of situations. Although they do not mention the assessment of similar situations, they use methods alike forward chaining in order to model and infer evolutions of situations. On the one hand, this approach is, like ours, based on the a priori knowledge about situation types. On the other hand, we further lift this a priori knowledge from situation types to the constructs available for defining them, i.e. the conceptual neighborhoods of relations. This leads to an implicit definition of evolution which results in simpler specifications of situation types. Similarly related is McCarthy's *Situation Calculus* and its derivative by Reiter [19] which focus on planning actions and inferring their effects. Although we may clearly face these problems if, for example, we want to plan the actions of a traffic operator in order to avoid climax situations, it is currently beyond the scope of our work—we just deal with the perception of situations and their possible evolution without any *explicit* actions.

Only recently, similarity measures for instances of ontology concepts, which is the final and farthest related work, have been proposed (e.g. [20]). In short, our approach substantiates parts of these domain-independent similarity measures with respect to SAW by the provision of conceptual neighbors of situations.

6 Discussion and Future Work

In this paper, we have proposed a method to assess evolving and similar situations in ontology-based approaches to SAW. Subsequently, our approach, which is mainly based on conceptual neighborhoods of relations that contribute to situations, has been demonstrated in form of a case study in the road traffic management domain. The case study involved an ontology for road traffic SAW, a formalization of relevant situation types, and the application of our approach to assess these situation types in a complex, real-world scenario. Although our approach performs as expected, we want to point out that we just regard it as a novel basis for traditional approaches to SAW. The bottom line is that one should incorporate the a priori knowledge encoded in ontologies or available from domain experts in situation assessment processes.

In the course of our work, we have also identified some open issues. The most prominent one is the distance function D which should be more sophisticated in order to obtain a more realistic behaviour. For example, it should provide distances for the co-occurrence of objects or should enable weights indicating the contribution of a family of relations to a situation type. A further issue is the current focus on evolutions of relations. A complete approach should also consider evolutions of intrinsic attributes for situation assessment. Another matter are interdependencies between families of relations (e.g. externally connected objects imply zero distance between their boundaries) which may result in inconsistent, not reachable neighborhoods that could further restrict the search space. The final issue is the incorporation of scheduled or forecast information which would raise the evidence that a situation actually evolves into a subsequent landmark situation. Thus, statements about the probability of a concrete evolution would be possible.

Regarding future prospects of our work, we are currently developing a software framework for SAW which is based on the approach proposed in this paper. In the near future, we are going to deploy a prototypical implementation of this framework for the road traffic domain in order to support traffic operators achieving SAW in complex road traffic management scenarios.

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