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Formalizing Reasoning About Change: A Temporal Diagnosis Approach

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Abstract. In this paper we describe a framework for reasoning about temporal explanation problems, which is based on our previous work on model-based diagnosis of dynamic systems. We use an explicit representation of qualitative temporal information which provides a simpler and more natural representation than the situation calculus. We show how to generate more specific explanations by instantiating explanations and assuming an Open World Assumption. We argue that a framework for reasoning about action should be able to deal with concurrent and durative actions and show how they can be represented in our system.

1 Introduction

Reasoning about action has been a very active topic since Hanks and McDermott showed surprising weaknesses of conventional non-monotonic reasoning formalisms to handle simple problems like the Yale Shooting Problem. The last years have seen formalizations of various complexities, which often seemed intuitive, only to be contradicted by simple extensions of the same examples they handled. It can be argued, that finally formalizations have been found for these examples, but difficulties and uncertainties remain even in the latest papers.

Different styles of reasoning can be distinguished. Given some observations about an initial situation, what might be true in some later situation? This style of forward reasoning in time is called *temporal prediction*. The opposite direction is reasoning backward in time and is called *temporal explanation*. Given some observation we are interested in what happened in previous situations.

In this paper, which extends our work in [5], we focus on the problem of temporal explanation in reasoning about action examples, and discuss an approach strongly related to our recent formalism for doing temporal diagnosis in a model-based reasoning system [12]. In particular, we tackle the following issues: what do we want to explain, how do we want it to be explained (what are the abducibles), how can we formalize persistence of fluents, how can we generate more specific explanations, and how can we represent concurrent actions. Our formalism is based on a interval-based temporal logic which we argue is a more suitable representation than conventional situation calculus based formalisms.

2 Introductory Example

One of the most important representational frameworks for reasoning about action and change is the *Situation Calculus* [11]. A situation s is considered to represent a snapshot of the world. The function $Result(a, s)$ represents the situation resulting from performing action a in situation s. The predicate $Holds(p, s)$ asserts that fluent (property) p holds in situation s.

Example 1 (The Stolen Car Problem). The most famous temporal explanation problem is Kautz's Stolen Car Problem (SCP) [7]. In the initial situation, $S0$, a car is not stolen. After waiting two times, $S2$, the car is stolen. What happened?

$$\neg Holds(Stolen, S0), \tag{1}$$
$$S2 = Result(Wait, Result(Wait, S0)), \tag{2}$$
$$Holds(Stolen, S2) \tag{3}$$

The intended model is that the car has been stolen during either of the two waiting phases, there is no reason to prefer one over the other. □

Recently, Shanahan [13] described an interesting approach to formalize temporal explanation within the situation calculus using the SCP as an example. The key point in Shanahan's work is that the axioms (1), (2) and (3) do not constitute a good representation for the SCP. In particular, axiom (2) states that $S2$ is the situation after waiting two times in $S0$, nothing else. As waiting actions have no effects and we assume persistence of properties, the car should still be parked in $S2$ contradicting the observation (axiom 3). The point is that we do not know exactly what actions occured between $S0$ and $S2$. Shanahan's alternative representation states only that $S2$ follows $S0$ and that there must be a sequence of actions leading from $S0$ to $S2$. The task is to find this sequence of actions, which represents an explanation for the observation in $S2$. Shanahan studied a deductive and an abductive approach for temporal explanation using the standard and the alternative representation.

The situation calculus is a simple framework and rather expressive. However, several problems and counterexamples have been identified. The aim of this paper is to show how temporal explanation problems can be formalized in our model-based diagnosis framework for dynamic systems and that this formalization yields clearer and more intuitive results. We will use the SCP and the extensions introduced in [13] as examples throughout the paper.

3 The Basic Temporal Diagnosis Approach

In this section we develop the basic framework for temporal explanation problems by extending our temporal diagnosis approach [12], which is based on explicit representation of qualitative temporal information.

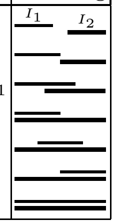
Basic relation	Inverse relation	Meaning
I_1 *before* I_2	I_2 *after* I_1	
I_1 *meets* I_2	I_2 *met* I_1	
I_1 *overlaps* I_2	I_2 *overlapped* I_1	
I_1 *starts* I_2	I_2 *started* I_1	
I_1 *during* I_2	I_2 *contains* I_1	
I_1 *finishes* I_2	I_2 *finished* I_1	
I_1 *equal* I_2	I_2 *equal* I_1	

Table 1. The 13 basic relations that hold between two intervals.

3.1 Temporal Framework

We use a subset of the interval-based temporal logic described by Allen and Hayes in [1]. The basic temporal primitives are *time intervals* with a positive duration. *Time points* are introduced as unique meeting places of intervals having zero duration. Based on these primitives the following mutually exclusive *qualitative temporal relations* are defined: 13 relations between two intervals (see table 1), 5 relations between a point (an interval) and an interval (a point), {*before*, *starts*, *during*, *finishes*, *after*} ({*before*, *finished*, *contains*, *started*, *after*}) , and 3 relations between two points, {*before*, *equal*, *after*}. Indefinite knowledge is expressed as disjunction of basic relations.

Properties are used to denote that something is true over a time period. We do not allow for properties to hold at time points. An important characteristic of properties is homogeneity: a homogeneous property holds during a time interval I iff it holds during each subinterval of I. Intuitively, the notion of properties captures the static behavior of the world.

Events are classified as durative and instantaneous. *Durative* events occur during time intervals and are intended to take time. *Instantaneous* events occur at time points and are durationless. Intuitively, they can be considered as causing transitions of properties, and thus represent the dynamic behavior of the world. The most important type of events in this paper are actions.

3.2 Formalizing the Domain Theory

We use a sorted First Order Language and a Prolog-like notation: Variables begin with an upper case letter, constants and predicates with a lower case letter. Unless stated otherwise, time intervals are denoted by I (i) (possibly indexed), time points by P (p) (possibly indexed). Qualitative temporal relations are represented by 2-ary predicates with the obvious meaning.

Definition 1. An *Action Model* for an action α is defined as a first order formula, $\alpha \wedge \beta \rightarrow \gamma$, where β represents the preconditions and γ the effect of α.

To describe the *temporal behavior* of an action, both preconditions β and the effect γ may contain qualitative temporal relations.

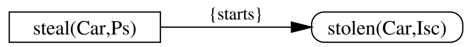


Fig. 1. Temporal behavior of the steal action.

Example 2. Following Shanahan's alternative representation of the SCP we have an action *steal* (axiom (AR5) in [13]) represented by the action model

$$\forall Car \forall P_s \exists I_{sc}\ steal(Car, P_s) \rightarrow stolen(Car, I_{sc}) \wedge starts(P_s, I_{sc})$$

Stealing a car *Car* at time point P_s starts an interval, I_s, during which the car is stolen. This action has no preconditions. □

We use a graphical representation for the temporal behavior of an action model. The nodes represent the temporal extent of the actions and properties. The arcs are labeled with the qualitative temporal relation between them and are denoted as a set of basic relations. The temporal behavior of the steal action is shown in figure 1. For clarity, the nodes are denoted by the whole action (property) expression rather than by the corresponding temporal extent, rectangular boxes represent time points, and rounded boxes represent time intervals. We follow this convention through the rest of the paper.

The steal action in the above example is an instantaneous action with an immediate effect. In general, we allow for durative actions as well as more complex, possibly indefinite temporal relationships between the action and its effects. Sometimes the effect of an action is delayed which is easily represented in our framework, e.g. *overlaps*. The representation of delayed effects in the situation calculus is not straightforward, as it requires the representation of time and the assumption of an additional action taking place after the real action which would lead to the situation where the effect holds [6]. In the event calculus [8] the effects of events take place immediately corresponding to the *starts*-relation.

3.3 Observations and Abstract Observations

Observations describe what we know about the actual behavior of the world and are usually given in terms of properties at time points. This is difficult to imagine from a cognitive point of view, as time points are durationless entities. A more intuitive interpretation of observations in dynamic systems is to interpret them over time periods "around" the observation time point. This is captured by the concept of an abstract observation, which represents the assumption that there exists a time interval during which a property holds. Usually, we neither determine exactly the extent of an abstract observation nor its location on the real time line, rather we only constrain it using qualitative temporal relations.

Definition 2. An *Abstract Observation* is defined as a formula $\exists I\ o(I) \wedge \rho(I)$, where o is a predicate which states that a property holds during a time interval I, and the *(temporal) anchor* ρ is a conjunction of qualitative temporal relations constraining I relative to the real time line and/or other abstract observations.

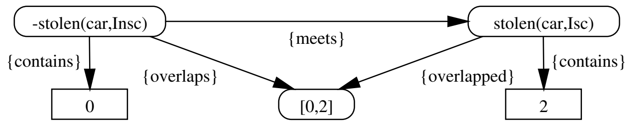


Fig. 2. Abstract observations in the SCP.

Example 3. The two observations, the car is not stolen in $S0$ (axiom (1)) and the car is stolen in $S2$ (axiom (3)), are represented by the abstract observations $\exists I_{nsc}\ \neg stolen(car, I_{nsc}) \wedge contains(I_{nsc}, 0)$ and $\exists I_{sc}\ stolen(car, I_{sc}) \wedge contains(I_{sc}, 2)$, stating that the time period over which the car is not stolen (stolen) contains time 0 (2). We represent time by the real numbers and assume the ordering axioms of real numbers. This avoids to state explicitly that $S2$ follows $S0$, as through axiom (2), or in [13] through axiom (AR3). □

Exclusiveness of abstract observations. The temporal constraints in the above example do not prevent I_{nsc} from including time 2, which contradicts the second observation. From the homogeneity assumption of properties it follows that two intervals I_1 and I_2 during which a property and its negation hold are exclusive. This can be expressed as $before(I_1, I_2) \vee meets(I_1, I_2) \vee met(I_1, I_2) \vee after(I_1, I_2)$. In particular, in the above example we get $before(I_{nsc}, I_{sc}) \vee meets(I_{nsc}, I_{sc})$.

Maximality of abstract observations. An abstract observation is *maximal* iff it persists as long as possible in both direction of time, into the past and the future. From this assumption follows that consecutive maximal abstract observations which represent that a property holds and that it does not hold, are constrained by the relation *meets*. Maximal abstract observations capture the persistence assumption of properties: properties persist unless there is some reason to assume otherwise. We make this assumption throughout most of the paper. This concept of maximal abstract observations is different from chronological minimization [14], which assumes persistence of properties only forward in time, and in the SCP would conclude that the car has been stolen during the second waiting action.

Example 4. Given that we use homogeneous properties and maximal abstract observations, we get the final set of abstract observations in the SCP

$$AOBS = \{\ \exists I_{nsc}\ \neg stolen(car, I_{nsc}) \wedge contains(I_{nsc}, 0) \wedge meets(I_{nsc}, I_{sc}),\\ \exists I_{sc}\ stolen(car, I_{sc}) \wedge contains(I_{sc}, 2) \wedge met(I_{sc}, I_{nsc})\ \}$$

A graphical representation of $AOBS$ is shown in figure 2. To make the temporal relationships clearer we added the interval $[0, 2]$. □

The concept of abstract observations allows also to represent exact knowledge about the temporal extent of properties. For instance, we represent the fact that property f holds during the time interval $[0, 2]$ as $\exists I\ f(I) \wedge equal(I, [0, 2])$.

3.4 Abstract Temporal Diagnosis

The aim of temporal diagnostic reasoning is to find an explanation in terms of abducible expressions for the actual abstract observations [12].

Abducible Expressions. Intuitively, an abducible expression is one for which no further explanation can be generated. This is the case for the truth-value *true*, as well as for all expressions occuring only on the left-hand side of action models, in particular actions itself. To get a temporal diagnosis additionally the qualitative temporal relations must be abducible even if they appear also in the right-hand side of action models. Later we will discuss the need for additional abducible expressions if one assumes an Open World Assumption.

Similar to [4] we use a combination of abductive and consistency-based diagnosis: a diagnosis must abductively explain a "subset" of abstract observations, $AOBS^+$, while being consistent with the set of all abstract observations, $AOBS$.

Definition 3. A set D of abducible expressions is an *Abstract Temporal Diagnosis* for a theory T and a set of abstract observations $AOBS$ iff

- D covers $AOBS^+$, i.e. $T \cup D \models AOBS^+$.
- D is consistent with $AOBS$, i.e. $T \cup D \cup AOBS$ is consistent.

The set $AOBS^+$ consists basically of the *abnormal* abstract observations. Assuming persistence of properties, each change of a property without known cause is abnormal. In general we cannot entail the temporal extent of abstract observations and their temporal location on the real time line. We define $AOBS^+$ to consist of the abnormal abstract observations without their temporal anchors relative to the real time line and relative to normal abstract observations. This gives an explicit notion about what to include in $AOBS^+$, in contrast to the vague characterization in [13].

The basic procedure to compute an abstract temporal diagnosis is a backward-chaining procedure. Starting from the initial set $AOBS^+$ we choose an action model which predicts a non-empty set of abstract observations in $AOBS^+$ not yet explained. In first order logic we would unify the explained observations with the effects predicted by the chosen action model. In our temporal logic, we instead cover them by adding an equal relationship between the explained observations and the predicted effects, which leads to an instantiation of variables and connects the temporal networks of the chosen action model with $AOBS^+$. The left-hand side of the instantiated action model represents the abductive hypothesis. The connection of networks leads to additional temporal relationships between action model, abstract observations and hypothesis. Similar to first order logic, where the unified literals are dropped, we can also drop the covered literals and the corresponding temporal relations, though we need additional assumptions to avoid losing information in this step. Specifically, we have to assume maximal persistence of properties[1]. An action with preconditions can

[1] This is similar to the assumption of maximal abstract observations.

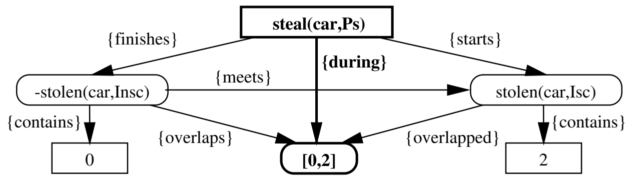


Fig. 3. Explanation (in boldface) and $AOBS$ in the SCP.

give rise to new abnormal property changes, in which case we extend $AOBS^+$ accordingly (see example 5). If all abstract observations in $AOBS^+$ are covered, the conjunction of the generated hypotheses represents an abstract temporal diagnosis.

Example 5. The theory T for the SCP contains the action model for steal, $\forall Car \forall P_s \exists I_{sc}\ steal(Car, P_s) \rightarrow stolen(Car, I_{sc}) \wedge starts(P_s, I_{sc})$. The set of abstract observations, $AOBS$, is calculated as in example 4. Initially the car is not stolen and due to the persistence assumption we should be able to conclude that it is still not stolen at time 2. However, we observe the contrary, indicating an abnormal property change which needs an abductive explanation, so $AOBS^+ = \{\exists I_{sc}\ stolen(car, I_{sc})\}$[2]. We cover this abstract observation with the effect $stolen(Car, I_{sc})$ of the steal action, which instantiates the variable Car to car and unifies the interval variables from action model and observation giving $stolen(car, I_{sc})$. In the consistency based step, which includes the temporal anchors of $AOBS$, we then get the additional temporal relation $during(P_s, [0, 2])$. We can now drop $stolen(car, I_{sc})$. All abstract observations in $AOBS^+$ are covered and we get the abstract temporal diagnosis (see figure 3)

$$\exists P_s\ steal(car, P_s) \wedge during(P_s, [0, 2])$$

This is the intended explanation and corresponds to Shanahan's one. □

Even if the above explanation is the intended one and it is not very probable that the car has been brought back and stolen again, we should at least not be forced to exclude it. If we do not use maximal abstract observations, i.e. constrain the two abstract observations by $before \vee meets$ instead of $meets$, we can consistently assume several steal actions between time 0 and 2. To explain the abstract observations abductively one steal action still suffices.

4 Extending the Basic Approach

Additional problems in reasoning about action and change arise, when preconditions for actions are introduced. Following Shanahan [13] we extend the SCP.

[2] $meets(I_{nsc}, I_{sc})$ is a relation to a normal abstract observation, $overlapped(I_{sc}, [0, 2])$ is a relation to the real time line. Both of them are excluded from $AOBS^+$.

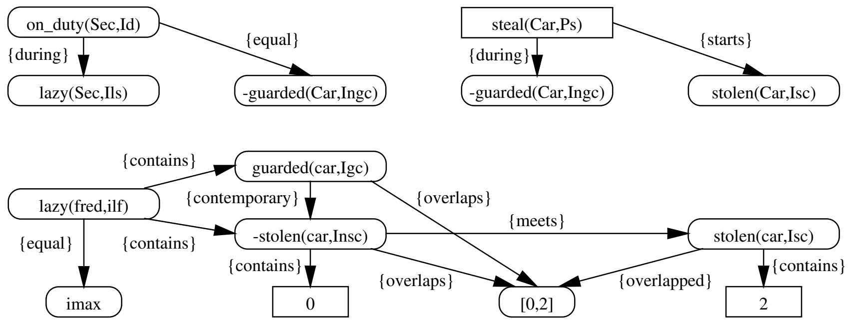


Fig. 4. Action models and abstract observations in the extended SCP.

Example 6 (Axioms AR7 through AR10 in [13]). In order for a steal action to be successful, the car must be unguarded. This action has a precondition and is represented by the action model $\forall Car \forall P_s \forall I_{ngc} \exists I_{sc}\ steal(Car, P_s) \land \neg guarded(Car, I_{ngc}) \land during(P_s, I_{ngc}) \rightarrow stolen(Car, I_{sc}) \land starts(P_s, I_{sc})$. A second action is introduced for a security guard to be on duty. If a lazy security guard comes on duty, he immediately falls asleep, and the car will be unguarded for the time he is on duty. Initially the car is guarded, and Fred is known to be a lazy security guard. The actions and the abstract observations of the extended SCP are shown in figure 4 (*contemporary* is an abbreviation for the disjunction of the basic relations *overlaps*, *starts*, *during*, *finishes*, *equal* and their inverses). Properties which are always true, such as Fred being lazy, are represented by abstract observations, whose temporal extent is equal to a maximal interval i_{max}.

Turning to the generation of an explanation, we start with the same set $AOBS^+$ as before and hypothesize $\exists I_{ngc} \exists P_s\ \neg guarded(car, I_{ngc}) \land steal(car, P_s) \land during(P_s, I_{ngc})$. Testing consistency with $AOBS$ yields $during(P_s, [0,2])$ and $during(I_{ngc}, [0,2]) \lor finishes(I_{ngc}, [0,2]) \lor overlapped(I_{ngc}, [0,2])$. This hypothesis contains the non-abducible $\neg guarded(car, I_{ngc})$ representing an abnormal property change violating the persistence assumption. We add $\exists I_{ngc}\ \neg guarded(car, I_{ngc})$ to $AOBS^+$ and continue the diagnostic process. The action *on_duty* predicts the desired property, and we cover the effect $\neg guarded(Car, I_{ngc})$. From this and the *equal*-relation in the action model we get $contains(I_d, P_s)$, which we include in the final explanation, and drop $\neg guarded(Car, I_{ngc})$ and the corresponding temporal relationships

$$D = \exists Sec \exists I_d \exists I_{ls} \exists P_s\ on\_duty(Sec, I_d) \land lazy(Sec, I_{ls}) \land steal(car, P_s) \land during(I_d, I_{ls}) \land contains(I_d, P_s)$$

— while a lazy security was on duty the car has been stolen. In this and the following examples we leave out constraints stating that all this happens between time 0 and 2. This explanation corresponds to Shanahan's one in his deductive approach. □

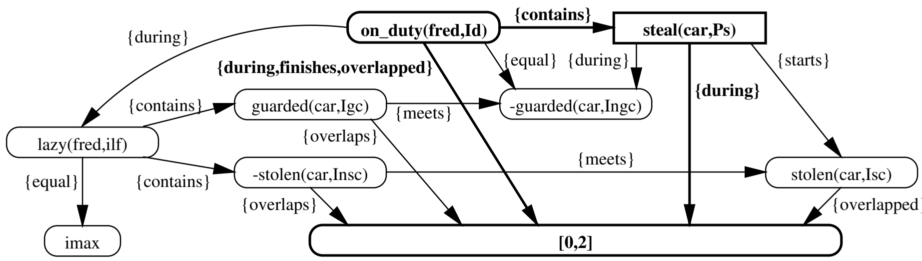


Fig. 5. Explanation D_1 — while Fred was on duty the car has been stolen.

4.1 Specifying Explanations

The explanation in the last example is not satisfactory as it does not exploit the fact that Fred is a lazy security guard, and it contains the non-abducible expression $lazy(Sec, I_{ls})$.

Instantiating Explanations. As we know that Fred is a lazy security guard, we want to specify the explanation and instantiate the variable *Sec* to *fred*. To formalize this we represent a fact f as a formula $true \to f$, and extend the abduction policy by instantiating variables and eliminating non-abducibles in an explanation by using known facts, i.e. abstract observations not in $AOBS^+$.

Example 7. Fred is a lazy security guard is represented as $true \to lazy(fred, i_{lf}) \wedge equal(i_{lf}, i_{max})$. Using this rule we instantiate the variable *Sec* in D to *fred*, eliminate the non-abducible $lazy(Sec, I_{ls})$ and get the first intended explanation

$$D_1 = \exists I_d \exists P_s \; on\_duty(fred, I_d) \wedge steal(car, P_s) \wedge contains(I_d, P_s)$$

— while Fred was on duty the car has been stolen (see also figure 5) □

Open World Assumption. The Open World Assumption (OWA) admits the existence of objects not currently known. This allows us to generate explanations on the existence assumption of such objects rather than on known facts. Using the OWA we must extend the set of abducible expressions accordingly.

Example 8. We hypothesize the existence of a lazy security guard other than Fred by adding the rule $\exists Sec \exists I_{ls} \; lazy(Sec, I_{ls}) \wedge Sec \neq fred \to lazy(Sec, I_{ls})$ to the theory. We add the left-hand side of this rule to the set of abducible expressions and generate the second intended explanation

$$D_2 = \exists Sec \exists I_d \exists I_{ls} \exists P_s \; on\_duty(Sec, I_d) \wedge lazy(Sec, I_{ls}) \wedge Sec \neq fred \wedge steal(car, P_s) \wedge during(I_d, I_{ls}) \wedge contains(I_d, P_s)$$

— while a lazy security guard other than Fred was on duty the car has been stolen. □

Shanahan's deductive approach can only generate the general explanation D, while his abductive approach only provides the specific explanation D_1. We generate in each case explanation D_1. If we use the OWA we additionally generate the specific explanation D_2. Hence, we always are more specific than Shanahan.

Unknown Actions. One might argue that our approach just encodes the solution as all actions used in the explanation are explicitly represented. In the original formulation of the SCP through axioms (1), (2) and (3) we have only the waiting action which, however, does not change the truth value of stolen. In order to get a model we have to introduce unknown changes which in [9] are called miracles. While it is arguable, if we should include the steal action in our theory or not, miracles seem to be too abstract. We know at least, that some action has taken place which results in our car to be stolen, and we should include this knowledge in our theory. We exploit once again the OWA and hypothesize the existence of an unknown action. We use a slightly modified representation of actions, and represent the steal action as $\forall Car \forall P_s \exists I_{sc}\ action(steal, Car, P_s) \rightarrow stolen(Car, I_{sc}) \wedge starts(P_s, I_{sc})$. Then the unknown action U is represented as $\forall Car \forall P_u \exists I_{sc} \exists U\ action(U, Car, P_u) \wedge U \neq steal \rightarrow stolen(Car, I_{sc}) \wedge starts(P_u, I_{sc})$ and leads to an additional explanation — an unknown action other than the steal action caused the car to be stolen. If we do not use the steal action at all we remove the precondition $U \neq steal$, and we get exactly one explanation — an unknown action caused the car to be stolen.

4.2 Concurrent and Durative Actions

Shanahan's approach is based on the observation that $S2$ cannot be the situation from just waiting two times in $S0$. He goes on to assume a sequence of actions between $S0$ and $S2$, and only states that $S2$ follows $S0$. Now he cannot express anymore that we already know an action sequence characterizing the interval between $S0$ and $S2$ (while not sufficient to explain the changed properties).

Example 9. We extend the story again. The owner of the car, after parking the car at time 0, goes to lunch. He comes back at time 2 and the car is stolen. The new action *lunch* is durative and takes place from time 0 to time 2, i.e. $\exists I_{lo}\ lunch(owner, I_{lo}) \wedge equal(I_{lo}, [0, 2])$. As going to lunch hardly affects the properties used so far, this is consistent with all our explanations and we can conclude, for example, that the theft of his car occured during lunch. □

Now Shanahan can assume some other action between $S0$ and $S2$ without affecting the explanation, which however has to be instantaneous and not concurrent with another action. Because of this restriction caused by the situation calculus, Shanahan has to say that the owner went to lunch between $S0$ and $S2$, either before or after the steal action. This is one of the major drawbacks of the situation calculus that concurrent actions as well as durative actions cannot be represented without introducing major extensions [6, 10] leading to quite complex formalisms. Aside from really concurrent actions we can represent various other complex temporal relationships between actions in a very natural fashion.

5 Discussion

Even if the situation calculus is rather simple and expressive, the underlying ontology is problematic for many problems. The notion of a situation representing an instantaneous snapshots of the world, which is originally defined as a sequence of actions, has been criticized by several authors. Shanahan [13] proposed an alternative representation for temporal explanation within the situation calculus and studied in detail a deductive and an abductive approach. Even if his alternative representation improves the standard approach, we have shown that our temporal diagnosis approach leads to better results. In particular, by instantiating explanations and allowing to use an Open World Assumption we can always give more specific explanations. Moreover, we have shown the need for concurrent and durative actions, which cannot be represented in the situation calculus without major extensions [6].

An alternative framework to deal with action and change is the event calculus [8]. The basic primitives are events which start or finish a time period, while in our framework the primitives are time intervals and time points derived from intervals [1]. In the event calculus properties persist until they are clipped by some contradicting event. This behavior is realized in our approach by the concept of maximal abstract observations. If we do not use maximal abstract observations, properties can cease to hold earlier, for example depending on quantitative temporal information. While we allow arbitrarily complex temporal relationships between actions and their effects, events in the event calculus have immediate effects corresponding to the *meets*-relation in our framework.

6 Conclusion

In this paper we propose a framework for temporal explanation based on our model-based temporal diagnosis approach. We focus mainly on the expressive power of our framework and on the natural and easy representation of temporal knowledge in reasoning about change. We use an explicit representation of qualitative temporal relations between properties holding during time intervals and actions occuring at time points or during time intervals. This provides a powerful language for modeling actions with preconditions and effects. The concept of maximal abstract observations capture the persistence assumption of properties and can easily be extended to various forms of persistence assumptions. Temporal explanations are generated by using abduction and testing additional consistency constraints. We give a concise characterization of what needs to be explained and what can be used in an explanation. We show how our framework deals with an open world assumption and how this leads to additional, more specific explanations. Finally, we argue that concurrent and durative actions are useful in reasoning about action and change, and can be handled in a very natural way in our framework.

Current and future work include an exact formalization of our approach in first order logic as well as detailed complexity analysis and a detailed comparison to abductive reasoning in first order logic, such as worked out for example in [3, 2]. We are also investigating which kind of temporal knowledge is required to abductively explain various temporal relations. Another important topic is how to exploit temporal knowledge in order to reduce the computational complexity inherently in abductive reasoning. Finally we consider various forms of persistence assumptions for different properties, such as adding quantitative temporal information.

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