Using Causal Relationships to Deal with the Ramification Problem in Action Formalisms Based on Description Logics

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Abstract. In the reasoning about actions community, causal relationships have been proposed as a possible approach for solving the ramification problem, i.e., the problem of how to deal with indirect effects of actions. In this paper, we show that causal relationships can be added to action formalisms based on Description Logics (DLs) without destroying the decidability of the consistency and the projection problem. We investigate the complexity of these decision problems based on which DL is used as base logic for the action formalism.

1 Introduction

For action theories represented in the situation or fluent calculus \[13,16\], important inference problems such as the projection problem are in general undecidable since these calculi encompass full first-order logic (FOL). One possibility for avoiding this source of undecidability is to restrict the underlying logic from FOL to a decidable Description Logic \[1\]. The main argument for using DLs in this setting is that they offer considerable expressive power, going far beyond propositional logic, while reasoning is still decidable. An action formalism based on DLs was first introduced in \[3\], and it was shown that important reasoning problems such as the projection problem become decidable in this restricted formalism.

An action theory basically consists of three components: (i) a (possibly incomplete) description of the initial state; (ii) a description of the possible actions, which specifies the pre-conditions that need to be satisfied for an action to be applicable as well as the post-conditions, i.e., the changes to the current state that its application causes; and (iii) domain constraints, which formulate general knowledge about the functioning of the domain in which the actions are executed, and thus restrict the possible states. In a DL-based action formalism, the initial state is (incompletely) described by an ABox, pre-conditions are ABox assertions that must hold, post-conditions are ABox assertions that are added or removed, and domain constraints are specified using TBox axioms. Given a finite sequence of actions \(\alpha_1 \ldots \alpha_n\), an incomplete description \(A_0\) of the initial state,

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and a formula $\varphi$ specifying a (desired or unwanted) property of states, projection \cite{13} is the inference problem that asks whether $\varphi$ holds in all states that can be reached from a possible initial state (i.e., a state satisfying $\mathcal{A}_0$) by applying this sequence of actions. The formula $\varphi$ may, for example, be the prerequisite of an action $\alpha$ to be applied after the last action of the sequence, or a condition used in the control structure of an agent’s program. In \cite{3}, it was shown that the projection problem is decidable in action theories based on DLs between $\text{ALC}$ and $\text{ALCQIO}$. However, this paper did not deal with the so-called ramification problem \cite{8,15}.

The ramification problem is caused by the interaction of the post-conditions of an action with the domain constraints. To be more precise, when applying an action, it may not be enough to make only those changes to the current state that are explicitly required by its post-conditions (direct effects) since it might happen that the resulting state does not satisfy the domain constraints, in which case one needs to make additional changes in order to satisfy these constraints (indirect effects). For example, assume that we have a hiring action, which has the direct effect that the person that is hired is then an employee, and that we have a domain constraint that says that any employee must have a health insurance. If John does not have health insurance, then just applying the hiring action for John would result in a state that violates the health insurance domain constraint.

One approach for solving the ramification problem is trying to find a semantics for action theories that automatically deals with such indirect effects, i.e., somehow makes additional changes to the state in order to satisfy the domain constraints, while taking care that only “necessary” changes are made. An example of such an attempt is the possible models approach (PMA) \cite{18,7}. However, without additional restrictions, the PMA and all the other approaches in this direction can lead to unintuitive results. It is not clear how to construct a general semantics that does not suffer from this problem. In our example, assume that there are only two insurance companies that offer health insurance: AOK and TK. In order to satisfy the health insurance domain constraint, John must get insured by one of them, but how should a general semantic framework be able to decide which one to pick.

A second approach is to avoid rather than solve the issues raised by the ramification problem. This is actually what is done in \cite{3}: the domain constraints are given by an acyclic TBox and post-conditions of actions are restricted such that only primitive concepts and roles are changed. Since, w.r.t. an acyclic TBox, the interpretations of the primitive concepts and roles uniquely determine the interpretations of the defined concepts, it is then clear what indirect effects such a change has. The semantics obtained this way can be seen as an instance of the PMA. It is shown in \cite{3} that the use of the PMA in a less restrictive setting (use of more general TBoxes as domain constraints or of non-primitive concepts in post-conditions) leads to unintuitive results.

A third approach is to let the user rather than a general semantic machinery decide which are the implicit effects of an action. In our example, assume that