Deductive Plan Generation*

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Understanding and modeling the ability of humans to reason about actions, change, and causality is one of the key issues in Artificial Intelligence and Cognitive Science. Since logic appears to play a fundamental rôle for intelligent behavior, many deductive methods for reasoning about change were developed and thoroughly investigated. It became apparent that a straightforward use of classical logic lacks the essential property that facts describing a world state may change in the course of time. To overcome this problem, the truth value of a particular fact has to be associated with a particular state. This solution brings along the famous technical frame problem. It amounts to the difficulty of expressing that the truth values of facts not affected by some action are not changed by the execution of this action [20].

The problem of classical logic is that propositions are not treated as resources [13]. A proposition cannot be produced and consumed in the course of time. To handle this problem J. McCarthy, P. Hayes [20], and C. Green [10] introduced *frame axioms*; one for each action and each atomic fact. The obvious problem with this solution is that the number of frame axioms rapidly increases when many actions and many facts occur. R. Kowalski reduced the number of frame axioms to become linear with respect to the number of different actions [17]. Some years later, it was again J. McCarthy who proposed the use of nonmonotonic inference rules to tackle the frame problem [19]. He uses a default rule called *law of inertia* which states that a proposition does not change its value when executing an action unless the contrary is known.

Some years ago we developed a modified version of the connection method to solve the frame problem without the need of any frame axioms [2]. In the *linear* connection method proofs are restricted such that each literal is connected at most once [2, 4, 3]. Thus, connecting a literal during the inference process simulates consumption of the corresponding fact. Conversely, if the conditions of an implication are fulfilled then the conclusion can be used and, thus, the literals occurring in the conclusion are produced. This treatment of literals resembles the concept of resources.

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A different approach to deductive planning which is based on equational Horn logic and also avoids frame axioms, was developed at our institute and presented in [14]. Its most significant feature is that a complete situation is represented by a single term using a special binary function symbol which connects the various atomic facts (the resources) that hold in this situation.

A third deductive planning method which models the concept of resources is based on linear logic, which is a Gentzen-style proof system without weakening and contraction rules [9]. In the multiplicative fragment of the linear logic, literals and formulas cannot be copied or erased, which also provides the idea of resources [18]. In [12, 23, 11] we proved the formal equivalence of these three resource-oriented approaches [2, 18, 14] for *conjunctive* planning problems, where situations as well as the conditions and effects of actions are conjunctions of atomic facts. Moreover, in [6, 7] we revised and extended the linear connection method and the equational logic approach in order to include the treatment of disjunctions of facts. We showed that these extended approaches and a similar extension of the linear logic approach are equivalent wrt. a unique semantics of *disjunctive* planning problems where situations as well as the conditions and effects of actions are disjunctions of conjunctions of atomic facts.

Recently, we substantially extended the expressiveness of the equational logic approach by introducing the concept of specificity which allows to handle several descriptions of one and the same action, depending on the particular situation in which this action is performed [15, 16]. Specificity originates in the problem of overloading methods in object oriented frameworks but can be observed in general applications of actions and change in logic.

In order to provide a uniform semantical framework for methods to reason about actions, M. Gelfond and V. Lifschitz developed the *Action Description Language* [8] and, independently, E. Sandewall defined his *Ego-World-Semantics* [21, 22]. Both methodologies are generalizations of former work in so far as they support reasoning about the past as well as handling partial information about situations. In [25], we showed the adequacy of the equational logic approach, including the notion of specificity, wrt. the Action Description Language. Furthermore, we extended this language to express non-deterministic actions, and we established a similar adequateness result concerning our equational logic based framework. In [5], another recent extension [1] of this language was used to provide a semantics for an extension of our method that allows to express the concurrent execution of actions. Finally, in [24] we related both the Action Description Language as well as its extension concerning non-deterministic actions, to E. Sandewall's semantics. We established two formal equivalence results of slightly restricted versions of both languages wrt. two particular ontological problem classes in the latter framework. In conjunction with the relationship between our equational Horn logic approach and the Action Description Language, this result implies the adequacy of our method regarding these two classes within the hierarchy of the Ego-World-Semantics as well.

The purpose of this talk is to give an overview of our various contributions to the field of deductive planning.

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