Mapping mental states into propositional planning

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Abstract

Most BDI agent architectures rely on plan libraries in order to ensure bounded time for means-ends reasoning. Nevertheless, the usage of fast planning algorithms to provide the agent with runtime planning capabilities is an alternate approach to augment agent autonomy and flexibility. This paper proposes an autonomous agent architecture based on the integration of a logic-based BDI model with propositional planning algorithms through a mapping process.

1. Introduction

Among the main requirements of an autonomous agent is the ability to perform *means-end* reasoning, *i.e.* the ability to select a course of actions that ultimately achieves the goals of the agent [2]. Thus, methods to accomplish such a requirement have long been a major research issue in Artificial Intelligence, the most recognized result of these pursuits lying in the field of planning algorithms. Planning problems are very complex in the general case [3]. This shortcoming in solving planning problems limits the usage of planning when it comes to long-term goals, resulting in the development of many approaches to *practical reasoning*, the most notorious of which is the agent model known as *Beliefs, Desires and Intentions* or BDI [2]. Such an approach allows an agent to break down its goals so that the agent can commit itself to achieving only a subset of its entire goal universe. Yet, the agent still have to perform means-end reasoning to determine how he is to accomplish this subset of his goals, *i.e.* the agent must determine a plan to fulfill his selected goals.

Most implementations of BDI agent architectures tend to avoid the inherent complexity of creating complete plans at run-time [5], exceptions to that rule, to the best of our knowledge, are very few [6, 7]. On the other hand, advances on propositional planning have resulted in a series of planning algorithms capable of very efficient planning for a large class of problems [9, 5]. Therefore, it is an important implementation advantage for BDI agents to be allowed to use such algorithms in order to perform their process of means-end reasoning [5]. Agent languages such as 3APL [4] and Dribble [8] demonstrate a particular interest in using run-time planning strategies in order to provide an agent with greater autonomy than it would otherwise be possible should plan libraries be used in the deliberation process. Nevertheless, these languages do not yet address planning efficiency so that an agent can deal with complex problems in a timely manner.

2. The $\mathrm{X^2BDI}$ Agent Model

Considering the goals set forth in the introduction, an extension of X-BDI was defined. Such an extension maps the agent's mental state into propositional planning problems during its deliberation process in order to use a planning function to perform means-end reasoning. This agent model is called *Extended X-BDI* or $\mathbf{X^2BDI}$.

The cognitive structure of $\mathbf{X^2BDI}$ has the traditional components of a BDI agent, *i.e.* a set of Beliefs, Desires and Intentions. It also has a set of time axioms inherited from X-BDI. An $\mathbf{X^2BDI}$ is composed of the same components as an X-BDI agent plus a propositional planning function conforming to the formalism described in [5].

The set of beliefs is a formalization of facts in ELP [1], whose consistency is maintained by means of the program revision process performed in ELP by the SLX procedure. From the agent's point of view, it is assumed that its beliefs are always consistent. Every desire in an $\mathbf{X^2BDI}$ agent is conditioned by a conjunction of literals called $Body$, which specifies the pre-conditions that must be satisfied in order for an agent to desire a property. Desires may be specified to be valid only in a specific moment, or whenever its pre-conditions are valid. Desires also have a priority value used in the formation of an order relation among desire sets. There are two possible types of intentions: Primary Intentions, which refer to the intended properties, and Relative Intentions, which refer to actions able to bring about these properties. An agent may not intend something in the past, that is already true, or is impossible, *i.e.* there must be at least one plan available to the agent whose result is a world state where the intended property is true.

In X-BDI the possibility of a property was verified through the abduction of an Event Calculus theory that would make the property true. In $\mathbf{X^2BDI}$ the planning process is abstracted from the operational definition of the agent, allowing any planning process that conforms to the propositional planning formalism of [5] to be used. Thus, the notion of possibility of a desire is associated with the existence of a plan to satisfy it.

The reasoning process performed by X-BDI initiates with the selection of Eligible Desires, which represent the unsatisfied desires whose pre-conditions have been satisfied. The elements of this set are not necessarily consistent among themselves. Candidate Desires are then generated, which represent a set of Eligible Desires that are both consistent and possible and will be later adopted as Primary Intentions. In order to satisfy the properties represented by Primary Intentions, the planning process generates a sequence of temporally ordered actions that constitute the Relative Intentions.

The process of selecting Candidate Desires seeks to choose a subset of Eligible Desires that contains only those that are internally consistent and possible, *i.e.* desires of properties P that can be simultaneously satisfied through a sequence of actions. Candidate Desires represent the most significant modification regarding the abductive planning in the original X-BDI [6]. In $\mathbf{X^2BDI}$ we use an external planning function, thus separating the planning process previously hard-coded within X-BDI. We define that a set of Candidate Desires is the subset of Eligible Desires with the greater priority value, and whose properties can be satisfied. Satisfiability is verified through the execution of a propositional planner that processes a planning problem where the initial state contains the properties that the agent believes at the time of planning. The P properties present in the Candidate Desires are used to generate the set Primary Intentions. Primary Intentions represent the agent's commitment to achieving a set of objectives for which a course of action has been found. Relative Intentions correspond to the temporally ordered steps of the concrete plans generated to satisfy the agent's Primary Intentions. The notion of agent commitment results from the fact that Relative Intentions must be non-contradictory regarding Primary Intentions. The computational effort and the time required to reconsider the whole set of intentions of a resource-bounded agent is generally significant regarding the environment change ratio. Therefore, intention reconsideration should not occur constantly, but only when the world changes in such a way as to threaten the plans an agent is executing or when an opportunity to satisfy more important goals is detected. As a consequence, X-BDI uses a set of reconsideration "triggers" generated when intentions are selected, and causes the agent to reconsider its course of action when activated. Such modifications should alter X-BDI functioning so that it uses propositional planning algorithms as the underpinning of the means-end reasoning and as possibility verifiers in the practical reasoning process.

3. Conclusions

In this paper we described the relationship between propositional planning algorithms and the process of means-end reasoning in BDI agents. Such a relationship is defined in terms of a mapping between the BDI mental states of an X-BDI agent and planning problems. In order to verify the viability of such an approach we modified the X-BDI agent model to cope with the usage of an external planning module that uses a Graphplan implementation. Through the merger of BDI agents and fast planning algorithms, we expect the class of problems whose runtime resolution speed is feasible to be expanded towards that of planning algorithms used. Considering that the majority of known BDI agent implementations use a plan library in the process of means-end reasoning in order to avoid the inherent complexity of planning at runtime, $\mathbf{X^2BDI}$ provides an innovative way of implementing autonomous agents. Moreover, even though the original X-BDI did possess runtime planning capabilities, its planning algorithm was very inefficient, therefore, the mapping defined in this paper allows X-BDI to use any propositional planning algorithm, thus the agent model is able to use future planning algorithms [5].

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References

[1] J. J. Alferes and L. M. Pereira. *Reasoning with Logic Programming*. Springer Verlag, 1996.

[2] M. E. Bratman, D. J. Israel, and M. E. Pollack. Plans and resource-bounded practical reasoning. *Computational Intelligence*, 4(4):349-355, 1988.

[3] D. Chapman. Planning for conjunctive goals. *Artificial Intelligence*, 32(3):333-377, 1987.

[4] M. Dastani, F. de Boer, F. Dignum, and J.-J. Meyer. Programming agent deliberation: an approach illustrated using the 3apl language. In *Proc. of AAMAS'03*, p 97-104. ACM Press, 2003.

[5] F. R. Meneguzzi, A. F. Zorzo, and M. D. C. Móra. Propositional planning in BDI agents. In *Proc. of SAC'04*, p 58-63. ACM Press, 2004.

[6] M. C. Móra, J. G. Lopes, R. M. Viccari, and H. Coelho. BDI models and systems: Reducing the gap. In J. P. Müller, M. P. Singh, and A. S. Rao, editors, *Proc. of ATAL-98*, LNCS 1555. Springer Verlag, 1999.

[7] N. Nide and S. Takata. Deduction systems for BDI logics using sequent calculus. In *Proc. of AAMAS'02*, p 928-935. ACM Press, 2002.

[8] B. van Riemsdijk, W. van der Hoek, and J.-J. C. Meyer. Agent programming in dribble: from beliefs to goals using plans. In *Proc. of AAMAS'03*, p 393-400. ACM Press, 2003.

[9] D. S. Weld. Recent advances in AI planning. *AI Magazine*, 20(2):93-123, 1999.