Augmenting BDI Agents with Deliberative Planning Techniques

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Abstract. Belief-Desire-Intention (BDI) agents are well suited for autonomous applications in dynamic environments. Their precompiled plan schemata contain the procedural knowledge of an agent and contribute to the performance. The agents generally are constrained to a fixed set of action patterns. Their choice depends on current goals, not on the future of the environment. Planning techniques can provide dynamic plans regarding the predicted state of the environment. We augment a BDI framework with a state-based planner for operational planning in domains where BDI is not well applicable. For this purpose, the requirements for the planner and for the coupling with a BDI system are investigated. An approach is introduced where a BDI system takes responsibility for plan monitoring and re-planning and the planner for the creation of plans. A fast state-based planner utilizing domain specific control knowledge retains the responsiveness of the system. In order to facilitate integration with BDI systems programmed in object-oriented languages, the *planning problem* is adopted into the BDI conceptual space with object-based domain models. The application of the hybrid system is illustrated using a propositional puzzle and a multi agent coordination scenario.

1 Introduction

BDI is a well established model of agency [1] based on the Theory of Practical Reasoning [2]. Early BDI-systems have been devised with the idea in mind to overcome the poor performance of propositional planners controlling agents in dynamic environments at that time. The systems are based on two central ideas. One of them is the reactive planning, comparable with hierarchical planning systems [3], the other is deliberation [4,5].

Planning, an approach central to Artificial Intelligence (AI) research, is substantial for rational agent behavior. It is a method that aids agents in solving complex problems in synthetic and natural environments. Although planning systems are devised for means-end reasoning and are capable to find actions that achieve goals, they are less useful to decide, which goals to pursue [6].

Due to advances in planning techniques and understanding of *planning problems*, it seams reasonable and interesting to combine the strength of flexible means-end reasoning given by deliberative planners with the timely reactivity

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and goal deliberation capabilities carried by BDI systems. It is also interesting to analyze suitability of planning approaches to BDI agents in real world applications.

In order to benefit from both paradigms one needs to consider the strengths of both paradigms. There are multiple ways to compose the systems and the outcome is different dependent on their properties and features. As stated above, hierarchical planning techniques are comparable with BDI. Their strength lies in the evaluation of future environmental states and a constructed proof that a course of action will achieve goals under the preconditions. On the other hand, BDI systems handle dynamic environments more efficiently and are capable of both: reactive behavior, and maintenance of long term goals. They sacrifice the optimality and correctness of their planning algorithms for performance.

Both paradigms deal with generation of actions and share common ideas, so there are concerns which parts of a control and planning problem will be delegated to a planner and which to the BDI subsystem. This determines the choice of the BDI component and the planning algorithm. The overall architecture depends strongly on those choices.

A hybrid system can be built twofold. The planner may be applied to produce long term plans and to hand over single parts to a reactive BDI subsystem for the execution. This approach invokes serious performance concerns especially in dynamic environments where continuous changes force the planner to re-plan - a process with performance penalties comparable to planning itself. Generally, planning algorithms have been devised for one shot planning and are well suited for a solution of a single planning problem. They are rather less useful to maintain long term intentions of an agent.

The other way round is to augment the BDI system with a relatively simple planner that is invoked from the BDI controller and used for the purpose of creating short-term plans that need a proof of correctness. The last approach is used in this work to join the best from both paradigms.

The remainder of this paper proceeds as follows. In Section 2 we define the concept of a *planning problem* used for this work. Section 3 discusses the choice of a planning algorithm. In Section 4 we propose a way to integrate a planning component into a BDI framework. Section 5 presents two application examples of the hybrid system. Related work is presented in Section 6 and a conclusion is given in Section 7.

2 Planning Concepts

The basis for planning is given in the form of a *planning problem*. In order to represent a planning problem one needs at least to describe states of the world and how these states may change due to agent's actions. In a restricted classical view, this can be given by a model of a state-transition system $\Sigma = (S, \mathbb{A}, \gamma)$ where S is the set of states, A is the set of actions and $\gamma : S \times \mathbb{A} \rightarrow S \cup \{\perp\}$ is the transition function mapping a state and action to another state. $\perp$ is the illegal state being a result of a not applicable action. The planning problem is