OBDD-Based Planning with Real-Valued Variables in Non-Deterministic Environments

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Planning for highly dynamic and uncertain real-world domains is difficult using current planning tools. These domains may be characterized by non-deterministic actions and the need to represent large real-valued state spaces. Classical planning considers only deterministic domains and sidesteps the issue of non-determinism. Real-valued variables are handled by requiring domains to either represent real variables as relative booleans (e.g. using *on-table* or *on-block* in the classical blocks world), or to explicitly enumerate each possible value for a real variable (e.g. using *at11*, *at12*, *at21*, *at22* for block position in a 2x2 blocks world). The former approach is a lossy transformation where positioning information is lost while the latter is subject to state explosion for large domains.

We are developing a planner that can efficiently handle non-determinism and real variables using neither relative values nor explicit enumeration. In doing so, we are leveraging tools and representations from ***(i)*** planning and ***(ii)*** logic synthesis for computer-aided verification.

We propose the use of OBDDs (Ordered Binary Decision Diagrams) to deal with the large amounts of space required to represent domains and plans. OBDDs have recently been shown to be effective in modeling non-deterministic domains and provide a concise representation for state diagrams because their size (number of nodes) is not necessarily related to the size of the state space (Cimatti et al., 1998). OBDDs are currently used to represent gate-level logic for logic synthesis and computer-verification problems and have a wealth of prior research and tools available for manipulation and searching (Goel et al., 1998). These tools can be extended to handle non-determinism and real-variable based plan generation.

Recent work in the use of un-interpreted functions with OBDDs has outlined a method for modeling and interpreting real variables (Goel et al., 1998). A full explanation of this technique is beyond the scope of this abstract. However, this methodology allows real variables to be used without requiring relative boolean values or explicit enumeration. The real variables are directly represented and used to calculate the satsifiability of the OBDDs. A satisfiable path through an OBDD represents a statement supported by the information in the OBDD.

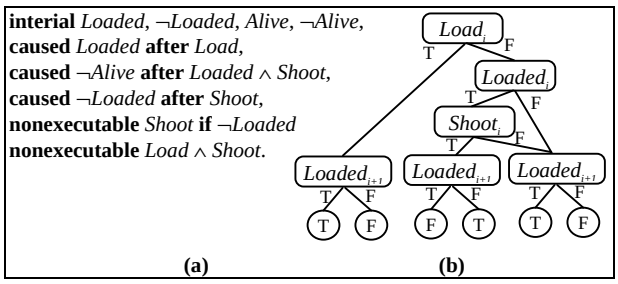

Figure 1: Example Shooting Domain

This method can be used as a tool to analyze OBDD-based domain and plan characterizations. This will allow us to provide mappings between various domain and action representation languages. Among those being considered are: ***(i)*** the Planning Domain Definition Language (PDDL) and ***(ii)*** ***C***, a new causal representation language (McCain and Hudson, 1997). An example specification in ***C*** and one sample OBDD is shown in Figure 1. In Figure 1.b, $Load_i \wedge Loaded_{i+1}$ is a satisfying path. Thus, finding and executing a plan is equivalent to finding a set of satisfiable paths that is consistent across all the OBDDs representing a domain and achieves the desired goal state.

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