Refinement-based *Planning As Satisfiability*

Amol D. Mali
Department of Computer Science & Engineering,
Arizona State University, Tempe, AZ 85287-5406
amol.mali@asu.edu

(Appears in the proceedings of AAAI, 1998, Madison, p. 1194)

A classical planning problem is the problem of computing a sequence of actions that transforms one state of the world into the desired. Traditional planners cast planning as a "split & prune" type search. These are called "refinement planners" since they start with a null plan and refine it by adding constraints. It has been shown recently that planning problems are far easier to solve when they are cast as model finding problems [2]. Some schemes for automated generation of the encodings of the planning problems in propositional logic have been designed [1]. However these schemes lack several of the refinements and preprocessing that traditional planners use. Since no single encoding has been shown to have the smallest size and the best performance, it is necessary to know what the space of the encodings is, to make a more flexible and efficient exploration of the encodings possible.

The plan refinements can proceed either in the forward direction (from initial state) or in the backward direction (from goal) or both. The steps of a plan can either be totally ordered (state space planning) or partially ordered (plan space or least commitment planning). The direction of refinement affects the branching factor in the search space and the nature of step ordering affects the completeness of the knowledge of the world state (complete world state is known in forward state space planning and causal planning is devoid of this knowledge). One can also do pre-processing to prune irrelevant information. These three dimensions show that many more novel plan encodings [4] exist.

We discuss some encodings from this space here. **1. State Space Encodings -** There are two categories of these encodings - linear and parallel. In linear encodings, only one action occurs at a time step. In parallel encodings, multiple actions can occur at the same time step, if they do not interfere. The state space encoding in [1] is not sensitive to the direction of refinement. Our encodings are sensitive to the direction of refinement (to enforce directional control in the declarative representation like a propositional encoding, we assign weights to the clauses). **a. Linear Forward Encoding** is based on forward state space refinement. We state that if the preconditions of an action are true at a time, that action or null action can occur at that time. We also say that if some precondition of an action is false at a time, the action cannot occur at that time. **b. Linear Backward Encoding** is based on backward state space refinement. **c. Linear Bidirectional Encoding** is formed for k step plans, where first k_1 steps are based on the linear forward refinement, and the remaining k_2 steps are based on the linear backward refinement. **2. Parallel Encodings -** These too can be forward, backward and bidirectional. **3. Hybrid Encoding -** This encoding is inspired by the idea that a planner can do both state space and plan space refinements. The first part for k_1 steps is based on state space refinement and the remaining k_2 step part is based on plan space refinement. **4. Preprocessing -** Not all actions in a domain are generally relevant to a given planning problem. Knowing this a priori does reduce the search space and allows the planner to focus on more relevant actions. Integrating the outcome of pre-processing yields smaller plan encodings (that contain fewer clauses and variables)[4]. Our work [3][4] bridges the gap between the previous research in planning (planning as refinement search) and the recent exciting developments (planning as model finding).

[1] **Henry Kautz, David McAllester and Bart Selman**, Encoding plans in propositional logic, Proc. of Knowledge Representation & Reasoning conference (KR), 1996.

[2] **Henry Kautz and Bart Selman**, Pushing the envelope: Planning, Propositional logic and Stochastic search, Proc. of the National Conference on Artificial Intelligence (AAAI), 1996.

[3] **Amol D. Mali**, Frugal propositional encodings of planning, Dept. of computer science, Arizona state university, TR-97-042.

[4] **Amol D. Mali**, Refinement-based planning as satisfiability, Dept. of computer science, Arizona state university, TR-97-043.