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# Project 2 –Developments in Planning

Research Report

## Introduction

This paper addresses the research paper rubric item for Project 2:

*The report describes at least three key historical developments in the field of AI planning and the relationships between them. The report is at least one and no more than three US Letter- or A4-sized pages using standard margins, is double-spaced, and uses between 10- and 12-point font. The report demonstrates professionalism: it is legible, mostly free of spelling and grammatical errors, it uses appropriate tone, ...*

According to the Russell-Norvig text (Russell & Norvig, 2010), the most popular and effective approaches to automated planning are (1) Boolean satisfiability, (2) forward search with good heuristics, and (3) search using a planning graph. A representative development for each of these three major approaches is presented here.

## 1. Boolean satisfiability

Boolean satisfiability is the idea of finding a plan through a logic equation using propositional logic of all the axioms that are inferred by the initial state, goals, and possible actions for a given problem. One of the key historical developments along the way to this methodology is the work of the mathematician Ernst Schröder (Schröder, 1877). Schröder extended algebraic logic developed by others including George Boole, Augustus De Morgan, Hugh MacColl, and Charles Peirce. He is credited with describing the conjunctive normal form (CNF). The CNF makes it possible to load a knowledge base with logical sentences, a conjunction of logic statements, and in turn reduce and resolve the overall equation. This is the basis of Satplan, an algorithm for solving planning problems strictly with logic.

## 2. Forward search with heuristics

Perhaps the best know modern heuristic search algorithm is A-star, which combines path cost with a heuristic to choose its search expansion nodes during a planning search. A planning search is a search where the nodes of the graph are states and the edges (paths) of the graph are the actions that are valid between states. By providing a heuristic that estimates the true distance to goal from any given node, the A-star algorithm is able to choose actions that move closer and closer to the goal. It is optimal, and its efficiency is dependent on the quality and efficiency of the heuristic itself. Other search algorithms that used heuristics had been studied prior to A-star, but A-star takes path cost into account. This was presented by Hart et al in 1968 (Hart, Nilsson, & Raphael, 1968).

## 3. Planning graph

A planning graph is a compact graph that tracks literals, actions, and their relationship to each other in “levels”. The planning graph can be used to calculate heuristics such as “level-sum” and “set-level” for use with more traditional searches. Alternatively, it may be used directly to solve the planning problem with the Graphplan algorithm (Blum & Furst, 1997).

## 4. Conclusion

The three major directions for planning are each popular for some subset of planning problems. Logic, search with heuristics, and planning graphs will each find planning solutions. Using logic can be very fast if it is implemented in hardware, for example, but will suffer from the curse of dimensionality as the number of features is increased. Search using heuristics is straightforward and very fast if the heuristic is accurate and fast. For some problems, determining the heuristic may take a great deal of time and reduce that advantage. If the heuristic is readily available, however, such as in the case of map distances, A-start is an efficient as well as optimal method for planning. Finally, use of a planning graph is complex, but has been shown to be useful for many difficult planning problems.

## References

Blum, A., & Furst, M. (1997). Fast planning through planning graph analysis. *Artificial intelligence*, 90:281-300.

Hart, P., Nilsson, N., & Raphael, B. (1968). A formal basis for the hueristic determination of minimum cost paths. *IEEE Transactions on Systems Science and Cybernetics*, SSC-4(2), 100-107.

Russell, S., & Norvig, P. (2010). *Artificial Intelligence: a modern approach.*

Schröder, E. (1877). *Der Operationskreis des Logikkalküls.* Leipzig: B.G. Teubner.