

## Research Review

The planning search project introduced us to classical planning through an air cargo transportation problem. It very clearly demonstrated the usefulness of devising a plan of action to solve such a problem. We saw a wide range of performance demonstrated by the different methodologies used in the project and decided to focus this research review on a few recently devised powerful planning systems. We focused on three state-space search planners, Fast-Forward, FastDownward and LAMA.

Fast-Forward (FF), a state-space search planner seen as one of the most successful to date [4]. As described in [1], it relies on forward state space search and uses a heuristic that estimates goal distances. In [1], they described three approaches that showed improvements in the efficiency of planning systems in recent years, *Planning graphs*, a plan generation technique, *planning as satisfiability*, a propositional reasoning system, and *heuristic search planning* that relies on heuristic functions to guide the search through the state space. FF stood out and achieved great performance by focusing on three key features, a relaxation heuristic using GRAPHPLAN, a modified Hill-Climbing search technique by combining local and systematic search, and finally two powerful pruning techniques. The first pruning technique finds “promising successors” at each node and the second removes branches where a goal was achieved too early. Classical planning methodologies were typically derived from theory and tested on examples, however, FF was derived from examples and careful experimentation which led it to be very efficient at solving problems like these examples. This approach led them to the conclusion that the focus of planning research should not be devise a technology that many different tasks but to focus on those that can be efficiently solved.

FastDownward followed in the footsteps of FF among other planners and is also a forward state space search planner. From [2], FastDownward’s design goal was to develop an algorithm that solved general propositional planning tasks in an efficient way by focusing on the structure of causal graphs and their hierarchical aspect. In the process, they faced three major obstacles. First, typical propositional planning tasks don’t necessarily have structured causal graphs and their response was to devise an automatic algorithm to reformat them into multi-valued planning tasks. Second, planning tasks are not always structurally hierarchical in their design and to deal with this issue, they focused on relaxing the problem and using the solutions of the relaxed problem in a heuristic search algorithm. Finally, they had to overcome the PSPACE-complete difficulty and opted for a heuristic function that considers a fragment of a task at a time. In conclusion, FastDownward’s heuristic search algorithm uses *deferred heuristic evaluation* which computes the heuristic goal distance on a reduced number of states and uses a *multi-heuristic best-first search algorithm* that combines two heuristics, causal graph heuristic and FF heuristic.

LAMA was derived from FastDownward planning system but uses a finite-domain and a multi-heuristic search approach. As described in [3], LAMA is a planning system based on FastDownward in three aspects. First it replaced the causal graph heuristic with a variant of the FF heuristic based on landmarks. Second, it applies action costs to both the landmarks and FF heuristics and finally, it uses an “anytime search” approach that continues to find better solutions until the search space is fully explored or the process is interrupted. It uses a greedy best-first search first followed by a weighted A\* search with decreasing weights in an attempt to find an improved solution.

Each of these planning systems have showed outstanding performance as shown by their rankings in different competitions. While Fast Forward remains a state of the art planning system based on relaxed planning graphs [3], it led to the development of two different similarly efficient planning systems, FastDownward and LAMA. FastDownward was created by further exploring heuristic search approaches and in a sense, so was LAMA with its multi-heuristic state-space search approach and the implementation

of action costs. As stated in [1], the prediction of Kautz and Selman (1999) that advances in propositional reasoning systems would render planning technologies unnecessary, recent breakthrough like the three approaches quickly described above prove that there are still advances being made in classical planning systems with excellent performance.

## **References:**

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