

Extending the Applications of Recent Real-time Heuristic Search

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Abstract

Real-time heuristic search algorithms that precompute search space-specific databases have demonstrated exceptional performance in video-game pathfinding. We discuss the first steps towards extending these algorithms to other search spaces that also benefit from the real-time property. We present our initial progress in characterizing the performance of current algorithms based on the features of a search space, and discuss future directions of this research.

Introduction

A heuristic search problem is a weighted graph (or *search space*) with one vertex designated as the start state, and one or more vertices designated as the goal states. An agent must find a set of edges connecting the start state to a goal state. Heuristic search algorithms solve search problems by making use of a heuristic function that provides estimates of solution lengths to guide decisions made during search. A heuristic search algorithm may be classified as either optimal or suboptimal. In the former case, the agent must choose a set of edges which links the start state to a goal state with the minimum possible summed weight.

We focus our interest on real-time heuristic search algorithms. This class of suboptimal algorithms imposes an upper bound on planning time *a priori*, independent of search space size. These algorithms perform search by interleaving alternate phases of planning and execution. In the planning phase, a frontier of local states is expanded to a given depth from the agent's current state, and the agent selects a most promising state from the frontier. In the execution phase, the agent takes one step towards the most promising state. This cycle is repeated until the agent reaches a goal state.

Recent algorithms have augmented the performance of real-time search by using a subgoal database computed offline, prior to execution. This method was first used by D LRTA* (Bulitko et al. 2008) and has since been improved upon by kNN LRTA* (Bulitko, Björnsson, and Lawrence 2010) and HCDPS (Lawrence and Bulitko 2010). When a database record is available, search is directed towards a local subgoal state instead of towards the global goal state. Since heuristic functions are typically more accurate

for closer states, the provision of appropriate subgoals can greatly reduce search suboptimality.

Historically, the primary applications of real-time search have been in video-game pathfinding and robotics. However, the algorithms are formulated for search in arbitrary graphs. Given their outstanding performance in video-game pathfinding, we seek to extend the applications of these algorithms to more diverse search spaces, including general planning and general game playing. We first discuss the shortcomings of current real-time search algorithms on certain search spaces, and follow by describing how our experiments have built a better understanding of the search space features that influence algorithm performance. Finally, we discuss future directions for our research.

Real-time Search in Other Search Spaces

We have applied database-computing real-time search algorithms to search spaces outside video-game pathfinding for the first time. We performed experiments on an assortment of domains incrementally different from typical video-game maps. We began with pathfinding in randomly generated, fully-reachable mazes and continued with several classical combinatorial puzzles: the sliding-tile puzzle, towers of Hanoi and the pancake puzzle. For comparison, we also included video-game maps from the literature (Bulitko, Björnsson, and Lawrence 2010). Figure 1 contrasts a sample video-game map with a more complex maze search space.

We generated 250 random search problems for each search space and solved them using three state of the art real-time heuristic search algorithms: D LRTA*, kNN LRTA* and HCDPS. We observed that solutions in the non-video-game search spaces were considerably more suboptimal than those in video-game search spaces.¹ We also observed that suboptimality was not strongly predicted by search space size alone. Given the disparity in performance results among search spaces, we elected to perform an analytical study to determine which search space features lead to higher solution suboptimality.

¹This fact alone should not preclude these algorithms from use in these search spaces, since sufficiently large databases can guarantee optimal solutions, and database size can be managed by tuning parameters in all three algorithms.

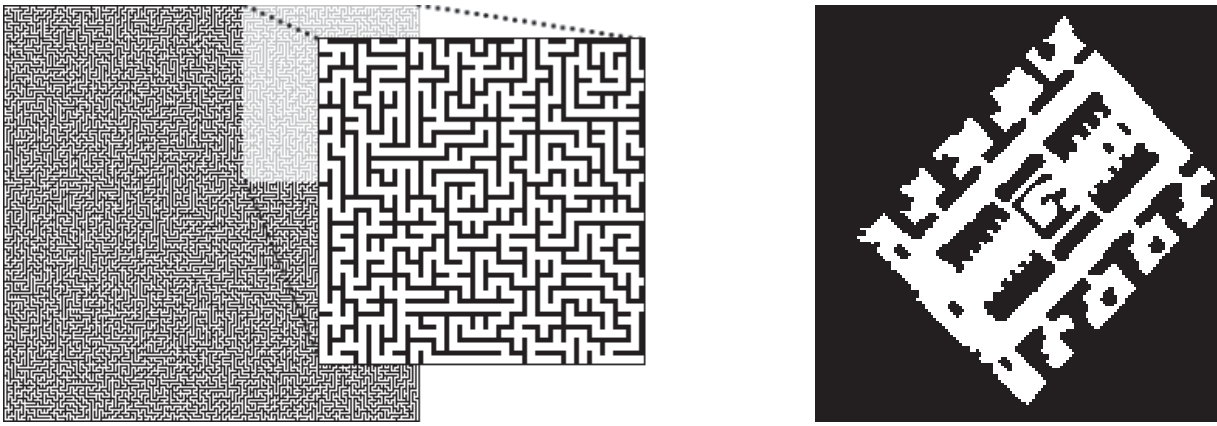


Figure 1: **Left:** a random maze with a segment enlarged for visibility. **Right:** a video-game map.

Complexity Measures

Database precomputation time for large search spaces can be in the order of days (Lawrence and Bulitko 2010), so testing performance on a search space can be an expensive proposition. Therefore, we suggest a more computationally efficient method to predict algorithm performance.

Incorporating previous work on heuristic topology (Hoffmann 2001) and real-time search complexity (Mizusawa and Kurihara 2010), we constructed a set of eight algorithm-independent complexity measures, four of which are original to this work. The measures are all domain-independent, and can thus be computed for arbitrary search spaces. Most of the measures are computed by randomly sampling problems within a given search space.

We computed the Spearman rank correlation (Spearman 1904) between the complexity measure values and the suboptimality of the three algorithms. Using these statistics, we identified which complexity measures were strong predictors of the performance of which algorithms and provided intuition for the correlations. For example, suboptimality of kNN LRTA* was observed to be most strongly correlated to the complexity measure *hill-climbing* (HC) probability, with a correlation coefficient of $\rho = -0.95$. This measure is the observed probability with which a random goal state can be reached from a random start state via simple hill-climbing alone. For a kNN LRTA* database record to be applicable in a search problem, it must be HC-reachable to and from the start and goal state of that problem. Therefore, a lower HC probability leads to a lower chance of finding an appropriate database entry. When kNN LRTA* has no suitable database entries, it performs a basic LRTA* search (Korf 1990) to the global goal, and is thus expected to produce a more suboptimal solution.

In the case of all three algorithms, we found at least one of our complexity measures to be a stronger predictor of solution suboptimality than search space size.

Future Directions

The next step for this research is to apply the algorithms in their current form to additional domains. In particular, we

would like to explore applications to single player general game playing and benchmark problems from the International Planning Competition.

Complexity analysis has previously been used to establish a hierarchy of difficulty for planning benchmark problems (Hoffmann 2001). We would like to further these results by showing that the correlation we demonstrated between real-time search performance and our collected complexity measures persist across this domain.

A future goal of our research is to develop a database-computing real-time heuristic search algorithm which addresses the limitations of the current state of the art. In particular, we would like to ensure that databases be computable for arbitrarily large search spaces while maintaining database coverage in complex search spaces.

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