Avoiding and Escaping Depressions in Real-Time Heuristic Search

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Abstract

Heuristics used for solving hard real-time search problems have regions with depressions. Such regions are bounded areas of the search space in which the heuristic function is inaccurate compared to the actual cost to reach a solution. Early real-time search algorithms, like LRTA∗, easily become trapped in those regions since the heuristic values of their states may need to be updated multiple times, which results in costly solutions. State-of-the-art real-time search algorithms, like LSS-LRTA∗ or LRTA∗(k), improve LRTA∗’s mechanism to update the heuristic, resulting in improved performance. Those algorithms, however, do not guide search towards avoiding depressed regions. This paper presents depression avoidance, a simple real-time search principle to guide search towards avoiding states that have been marked as part of a heuristic depression. We propose two ways in which depression avoidance can be implemented: mark-and-avoid and move-to-border. We implement these strategies on top of LSS-LRTA∗ and RTAA∗, producing 4 new real-time heuristic search algorithms: aLSS-LRTA∗, daLSS-LRTA∗, aRTAA∗, and daRTAA∗. When the objective is to find a single solution by running the real-time search algorithm once, we show that daLSS-LRTA∗ and daRTAA∗ outperform their predecessors sometimes by one order of magnitude. Of the four new algorithms, daRTAA∗ produces the best solutions given a fixed deadline on the average time allowed per planning episode. We prove all our algorithms have good theoretical properties: in finite search spaces, they find a solution if one exists, and converge to an optimal after a number of trials.

1. Introduction

Many real-world applications require agents to act quickly in a possibly unknown environment. Such is the case, for example, of autonomous robots or vehicles moving quickly through initially unknown terrain (Koenig, 2001). It is also the case of virtual agents in games (e.g., Warcraft, Starcraft), in which the time dedicated by the game software to perform tasks such as path-finding for all virtual agents is very limited. Actually, companies impose limits on the order of 1 millisecond to perform these tasks (Bulitko, Björnsson, Sturtevant, & Lawrence, 2011). Therefore, there is usually no time to plan for full trajectories in advance; rather, path-finding has to be carried out in a real-time fashion.

Real-time search (e.g., Korf, 1990; Weiss, 1999; Edelkamp & Schrödl, 2011) is a standard paradigm for solving search problems in which the environment is not fully known in advance.
and agents have to act quickly. Instead of running a computationally expensive procedure to generate a conditional plan at the outset, real-time algorithms interleave planning and execution. As such, they usually run a computationally inexpensive lookahead-update-act cycle, in which search is carried out to select the next move (lookahead phase), then learning is carried out (update phase), and finally an action is executed which may involve observing the environment (act phase). Like standard A* search (Hart, Nilsson, & Raphael, 1968), they use a heuristic function to guide action selection. As the environment is unveiled, the algorithm updates its internal belief about the structure of the search space, updating (i.e. learning) the heuristic value for some states. The lookahead-update-act cycle is executed until a solution is found.

Early heuristic real-time algorithms like Learning Real-Time A* (LRTA*) and Real-Time A* (RTA*) (Korf, 1990) are amenable for settings in which the environment is initially unknown. These algorithms will perform poorly in the presence of heuristic depressions (Ishida, 1992). Intuitively, a heuristic depression is a bounded region of the search space in which the heuristic is inaccurate with respect to the heuristic values of the states in the border of the region. When an agent controlled by LRTA* or RTA* enters a region of the search space that conforms a heuristic depression it will usually become “trapped”. In order to leave the heuristically depressed region, the agent will need to visit and update many states in this region, potentially several times. Furthermore, in many applications, such as games, the behavior of the agent in a depression may look irrational and thus it is undesirable.

State-of-the-art heuristic real-time search algorithms that are suitable for applications with initially unknown environments are capable of escaping heuristic depressions more quickly than LRTA* or RTA*. They do so by performing more lookahead search, more learning, or a combination of both. More search involves selecting an action by looking farther away in the search space. More learning usually involves updating the heuristic of several states in a single iteration. There are many algorithms that use one or a combination of these techniques (e.g., Hernández & Meseguer, 2005; Bulitko & Lee, 2006; Koenig & Likhachev, 2006b; Hernández & Meseguer, 2007; Rayner, Davison, Bulitko, Anderson, & Lu, 2007; Björnsson, Bulitko, & Sturtevant, 2009; Koenig & Sun, 2009). As a result, these algorithms perform better than LRTA*, spending fewer moves trapped in depressions.

Two algorithms representative of the state of the art in real-time search for initially unknown environments are LSS-LRTA* (Koenig & Sun, 2009) and RTAA* (Koenig & Likhachev, 2006a). These algorithms generalize LRTA* by performing more search and more learning in each episode. Both algorithms have been shown to perform very well in practice. However, despite the use of more elaborate techniques, they may still perform poorly in the presence of heuristic depressions. This is because they may sometimes rely on increasing the heuristic value of states inside the depressions as a mechanism to exit them.

In this paper we study techniques that allow us to improve the performance of real-time search algorithms by making them explicitly aware of heuristic depressions, and then by guiding the search in order to avoid and, therefore, escape depressions. Specifically, the contributions of this paper are as follows.

- We provide new empirical evidence that shows that RTAA* outperforms LSS-LRTA* in game map benchmarks in the first trial, which means that whenever there is a single chance to run one of those real-time heuristic search algorithms to solve a search