Synthesis of the Path-Planning of Autonomous Vehicles and Reinforcement Learning in University of Virginia Computer Science Curriculum

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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ABSTRACT

The Department of Computer Science at the University of Virginia (UVA) inadequately prepares undergraduate students for the industry of autonomous vehicles. To improve upon the quality of course materials, I propose the synthesis of the path-planning of autonomous vehicles with reinforcement learning techniques in the computer science curriculum. I propose two potential methods of applying reinforcement learning techniques to path-planning in existing classes. The first method is with an added project in the Special Topics in Computer Science course titled Autonomous Vehicles: Perception, Planning & Control that would focus on applying reinforcement learning to finding an optimal raceline for the current final project of the class. The second method is to have the professor of the Autonomous Vehicles course provide guest lectures reviewing and demonstrating the application of reinforcement learning techniques in the path-planning of autonomous vehicles for the CS course titled Artificial Intelligence. I anticipate that undergraduate students in these classes will gain a better understanding of reinforcement learning techniques and will also be better prepared for the industry of autonomous vehicles beyond the classroom. Beyond these methods, the University of Virginia should evaluate other ways students could be better prepared for the autonomous vehicles industry, such as with the further exploration of these related topics in a new graduate-level course.

1. INTRODUCTION

On the night of March 18, 2018, an Uber AV test vehicle struck and killed a pedestrian, Elaine Herzberg, who was pushing a bicycle across a four-lane road in Tempe (Wakabayashi, 2018). This marked the first known pedestrian death related to an autonomous vehicle and established the danger of testing such vehicles on public roads. As companies such as Tesla and Uber work to develop cars that can be driven without any human intervention, autonomous vehicles are a topic of increasing importance to society. Given the tangible consequences of releasing inadequate self-driving technology to the public, engineers looking to enter the industry must be properly educated and trained. It is thus integral for the UVA CS curriculum to provide experiental and practical learning that will directly prepare them for working on autonomous vehicles.

With the introduction of the special topics course of Autonomous Vehicles at UVA, students are initially taught to write programs that use Light Detection and Ranging (LiDAR) sensors on 1/10 scale RC cars to have these cars act as reflex (reactionary) agents. These cars first follow a wall and eventually make use of the “Follow The Gap” algorithm to detect and avoid obstacles. Later in the coursework, students increase the autonomy of their vehicles by using LiDAR sensors and Vedder Electric Speed Controllers (VESC) to build their own occupancy grid map of a physical track, which is a grid where each cell is marked with a number that indicates the likelihood that the cell contains an object. Once the map has been established, students use localization techniques, which are briefly mentioned in the Artificial Intelligence course, to determine where their car is on the map. Students then create their own race line for their vehicle to complete a lap in minimal time using the “Pure Pursuit” algorithm which projects the car’s location based on its speed and current localization to stay on the designated path. For the final project, students are expected to combine these strategies to race both in a time trial and against another team’s cars.

In the course Artificial Intelligence, students learn to solve non-deterministic search problems involving a grid called Markov decision processes (MDPs). A MDP is defined by a set of states (often in a grid), a set of actions determined by boundaries and obstacles, a transition function, a reward function based on the values in each state in the grid, and a start state (Kiran et al., 2020). To solve these problems, students are taught to use various reinforcement learning techniques such as value iteration and Q-learning to take the optimal path in the environment. The professor even uses navigating through a parking lot as an example of a way reinforcement learning might be used to optimize the best parking spot to achieve; however, there is no activity or assignment to apply the techniques to an autonomous vehicle. There is also a dedicated lecture on autonomous vehicles towards the end of the course, but there is no hands-on application of the techniques we learned throughout the class to provide a deeper understanding of the actual implementation.

2. RELATED WORKS

Fong and Olanie (2017) describe the occupational effects of autonomous vehicle development, highlighting the required education for jobs being lost versus jobs being created. The authors’ focus on the strong technical background and experience required by leaders of the industry demonstrates a need for students to be adequately prepared with practical learning. The article then recommends various topics for implementation within university curricula, including the integration of sensors, robotics, target tracking, object detection, and artificial intelligence. My proposal draws on these ideas to implement artificial intelligence algorithms within the Autonomous Vehicles course and to provide experiential learning within the Artificial Intelligence course by demonstrating a practical implementation of its curriculum.

Kiran, et. al. (2021) provide an overview of various reinforcement learning techniques, including algorithms taught in UVA’s Artificial Intelligence course, and describe how these techniques can be applied to autonomous driving. The authors also review the necessary state spaces, action spaces, and rewards necessary to apply reinforcement learning to autonomous driving tasks. These requirements make up an MDP which can already be formed using the current tools in the Autonomous Vehicles course. This informs my proposal to have students implement a basic reinforcement learning algorithm to determine an optimal raceline within the Autonomous Vehicles curriculum by using existing components specific to the course.

3. PROPOSED DESIGN

To improve the practical teaching of autonomous vehicles within the UVA CS curriculum, I propose two methods of change within coursework: applying reinforcement learning within the Autonomous Vehicle coursework and having a guest lecture in the Artificial Intelligence course from the professor of Autonomous Vehicles.

3.1 Method 1: Applying Reinforcement Learning Within Autonomous Vehicle Coursework

The first proposed method of improving the teaching of autonomous vehicles in the UVA CS curriculum is to have students apply a reinforcement learning algorithm to their F1Tenth car to in replacement of the Pure Pursuit algorithm currently taught in the Autonomous Vehicles course. To do this, students in the class would need an understanding of artificial intelligence and specific reinforcement learning techniques. One option would be to teach the underlying artificial intelligence knowledge necessary within the lectures of Autonomous Vehicles in place of the lectures relevant to the Pure Pursuit approach. This material would include search algorithms, MDPs, a single reinforcement learning approach chosen by the instructor, such as Q-Learning, and any other information chosen by the instructor as beneficial to teach.

Rather than teaching all of this material within the Autonomous Vehicles coursework, another option is to make the Artificial Intelligence course a prerequisite to Autonomous Vehicles in order for students to realistically apply reinforcement learning algorithms. The Autonomous Vehicles lecture material being replaced would then serve as a review of MDPs and one or more reinforcement learning approachs for students to use with their vehicle. Students could then choose their own approved algorithm taught in Artificial Intelligence to apply to their car in Autonomous Vehicles.

To use reinforcement learning to approach the problem of optimizing lap time on a racetrack, a MDP must be established. The current curriculum of the Autonomous Vehicle course already provides a state space and action space. The state space is formed by the polar occupancy grid, localized position, heading, velocity, and LiDAR sensors to detect obstacles, whereas the action space is defined by the steering angle, throttle, and brake of the vehicle. The transition function of this MDP would use the state and action spaces to determine the probability of entering a new state and may be provided by the professor or expected for the students to write. The reward function would be designed by students to minimize their lap time on the track. Some variables to be considered by students in the reward function would include distance travelled towards a checkpoint, collisions with obstacles or the track walls, speed, acceleration, and steering. With a state space, action space, transition function, and reward function, a MDP can successfully be established within the Autonomous Vehicles course framework which can be controlled for difficulty by the professor.

3.2 Method 2: Guest Lecture for Artificial Intelligence Course

The second proposed method of enhancing the teaching of autonomous vehicles in the CS curriculum is to have the professor for the Autonomous Vehicles course provide a guest lecture to demonstrate various artificial intelligence algorithms applied to a F1Tenth car. This would include reviewing how the algorithms taught within the Artificial Intelligence coursework are specifically adapted to an autonomous vehicle and demonstrating their usage on a track. Material from the Artificial Intelligence coursework that may be exhibited include the previously described MDP, robot localization using particle filtering, and reinforcement learning approaches such as value-based methods and policy-based methods taught in the coursework of Artificial Intelligence.

4. ANTICIPATED RESULTS

As a result of Method 1 of the proposed design, I anticipate that students will gain experience applying techniques that have practical usage in the workplace. While the replaced Pure Pursuit approach of the Autonomous Vehicles coursework has minimal application in self-driving outside of autonomous racing, reinforcement learning is the baseline for algorithms used on self-driving vehicles to this day. Applying these techniques should allow students to be prepared to apply more complex versions of such approaches in the field of autonomous vehicles.

As a result of the guest lecture described in Method 2 of the proposed design, I expect that students will be able to better contextualize content from Artificial Intelligence into the specific topic of autonomous vehicles. This should provide them with the ability to then better adapt the course material to more complex approaches in autonomous vehicles or other applications. Overall, I anticipate that these two methods will provide students with a more practical application of artificial intelligence and autonomous vehicles which will better prepare them for the industry beyond the classroom where they may make a greater impact.

5. CONCLUSION

Autonomous vehicles are playing an increasingly large role in society, in which inadequate design of self-driving systems have potentially dire consequences. It is thus integral that the UVA CS curriculum provide students who may work in the field of autonomous vehicles a practical and robust learning program that will allow them to push the industry forward. The addition of a reinforcement learning project in the Autonomous Vehicles course and a guest lecture on autonomous vehicles in the Artificial Intelligence course are a valuable starting point for the CS department to reach these goals. I anticipate that these proposed methods of improving the CS curriculum at UVA will give students the context they need to succeed in the workplace and design software that benefits society as a whole.

6. FUTURE WORK

To initiate this proposed design, the first step would be to propose these methods to the professors of the Artificial Intelligence and Autonomous Vehicles courses. Based upon their feedback, changes would be made to the design until one or both of the proposed methods were enacted. To examine the effectiveness of the design, professors of the courses would need to evaluate general student reception to the new elements of the coursework and study whether students were successfully able to apply reinforcement learning to their F1Tenth cars. To build from the proposed design further, it may be promising to explore the introduction of a graduate-level course exploring deep reinforcement learning and other artificial intelligence or machine learning techniques in the field of autonomous driving.

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