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Unified Path-Planning Algorithm for Traffic Participants in Multi-Agent Traffic Simulations: Part II

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Background and Objectives

Despite the advancement of autonomous driving technologies, reducing traffic accidents and associated casualties remains an urgent global issue. Multi-agent traffic simulations are increasingly utilized in feasibility studies to pre-evaluate diverse safety measures for vehicles and infrastructure. Since traffic spaces are shared by diverse entities—including cars, motorcycles, pedestrians, and emerging micro-mobility—simulations must be highly versatile. Effective multi-agent simulations require: (a) precise modeling of human cognitive and decision-making processes rather than mere mechanical vehicle control; (b) a universal, human-centered model structure independent of the specific mobility type; (c) flexibility to express diverse agent behaviors; (d) the ability to identify model parameters from real-world observation data; and (e) the capability to reproduce complex, unstructured traffic flows, such as those frequently observed in ASEAN countries where lane discipline is loose. Previous studies exploring the Cross Nested Logit (CNL) model for these purposes relied on aggregate parameter estimations, failing to capture individual characteristics and achieve a universal simulation framework. While our prior report proposed a CNL-based unified path-planning simulation, it exhibited behavioral instability under certain environments. This study aims to overcome these challenges by refining the algorithm, modifying the utility function, and validating the model through specific traffic interactions.

Methodology

This study proposes a unified path-planning algorithm that is fundamentally independent of the operated mobility type. Instead of relying on conventional approaches that utilize separate, isolated models for each transport mode, we focus on the common decision-making structure inherent to human beings. The core methodology is the implementation of a discrete choice model based on the CNL structure. In this framework, movement is formulated as a selection from a set of path candidates. Specifically, a fan-shaped traversable area predicted one second into the future is discretized to generate multiple path candidates. Each candidate is evaluated using a comprehensive utility function that accounts for interaction risks with other vehicles, obstacles, and road boundaries. To address the correlation among similar path candidates, a nested structure concerning movement direction and acceleration is introduced. By calculating the selection probability based on utility, the agent's next state is stochastically determined. This approach seamlessly translates complex environmental stimuli into a mathematically rigorous format, allowing behavioral differences to be expressed solely by adjusting parameters within this common utility framework.

Numerical Example

To validate the refined algorithm, numerical simulations were conducted focusing on representative traffic interactions. The modified utility functions were tested on a straight road segment under two primary scenarios: (a) obstacle avoidance, including zigzag maneuvers around static obstacles and complete stops, and (b) dynamic interactions with leading agents, specifically "car-following" and "overtaking" behaviors. The results confirmed that the proposed algorithm consistently reproduces these diverse behaviors. In the presence of obstacles, agents successfully avoided static objects and road boundaries while maintaining appropriate lateral margins, which varied logically when weighting parameters were adjusted. In dynamic scenarios, the decision to follow or overtake switched smoothly based on parameter settings reflecting positional preferences and risk tolerance. All generated behaviors satisfied kinematic constraints while avoiding collisions. These findings demonstrate that modifying parameters within a unified utility function is sufficient to simulate a wide spectrum of realistic, complex traffic phenomena accurately.

Conclusion

This study established a unified path-planning algorithm for multi-agent traffic simulations, proving that diverse behaviors can be integrated within a single framework. By utilizing a common utility function rather than mobility-specific models, this approach provides a flexible, robust foundation for the pre-evaluation of advanced driving assistance systems. Future work will focus on incorporating qualitative characteristics, such as driver psychology, into the utility function. By defining qualitative states as binary dummy variables and linearly combining them into the utility function, we will quantify their impact on decision-making trade-offs and dynamically reflect these shifts in the simulation. Furthermore, we will expand the model to encompass universal road environments, like intersections, and universal behaviors such as pausing and checking surroundings. Ultimately, utilizing dynamic utility functions to represent multi-factor trade-offs transcends deterministic if-then rule-based models. This paradigm shift from rigid rules to probabilistic choices will enable more realistic representations of human driving in complex urban networks.

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