

Game-Theoretic Integration in Imitation Learning for Safe Lane-Changing

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Background

- **Imitation learning (IL)** is commonly used in autonomous driving to learn from expert demonstrations.
- IL models are trained on fixed datasets, which often **fail in rare, safety-critical scenarios**.
- **Game theory** can complement IL by modeling vehicle interactions as a game.
- This work proposes a **game-theoretic framework** to improve safety in lane-changing scenarios and compares it to a state-of-the-art IL model.

Research questions: Can a game-theoretic framework improve safety in vehicle-to-vehicle interactions compared to the state-of-the-art IL model?

Experiment

We evaluated the performance of both TransFuser [1] and the integrated game-theoretic framework in CARLA Town05. Surrounding vehicles' trajectories are predicted using the kinematic bicycle model. Collision risks trigger the game-theoretic module, which decides to yield or compete.

We tested the models on two scenarios: (1) Rear vehicle slower than the ego-vehicle. (2) Rear vehicle faster than the ego-vehicle.

The performance of both models is evaluated using CARLA Offline Leaderboard, where they are measured with *driving score (DS)*, *route completion (RC)* and *infraction score (IS)*.

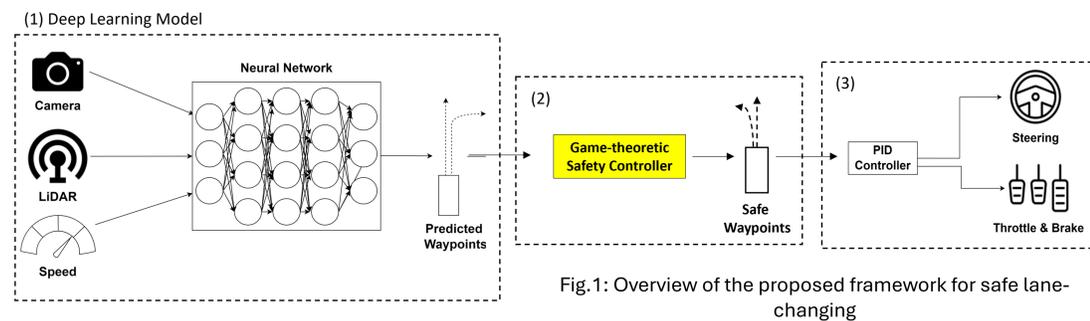
Findings

- TransFuser performed well overall but collided in unseen lane-changing scenarios (Fig. 2), or otherwise left small gap to rear vehicles (Fig. 3)
- The game-theoretic framework achieved **collision-free lane changes**, correctly **yielding** for fast vehicles (Fig. 4) and **competing** safely for slower vehicles (Fig. 5), maintaining safe gaps without compromising driving performance.

Conclusions

- **Integrated game-theoretic safety controller** in TransFuser pipeline helps to improve safety in **lane-changing**.
- The experiment serves as a proof-of-concept, proving the effectiveness in **reducing collision risks** during lane-changing.
- Limitation: Simple heuristics was used and tested in lane-changing scenarios only.

Methodology



Goal: Ensure **safe lane-changing** by integrating deep learning with a **game-theoretic framework**.

(1) **Deep Learning Model (TransFuser)** predicts ego-vehicle waypoints based on perception input

(2) **Game-theoretic Safety Controller** filters unsafe trajectories using a simplified two-player game: ego-vehicle vs. a surrounding vehicle.

Strategies:

- **Compete:** Accelerates if the surrounding vehicle is slower.
- **Yield:** Maintains speed if the surrounding vehicle is faster
- Decisions also consider **collision risk** and a **safe gap**.

(3) **PID Controller** generates steering, throttle, and brake commands to drive the ego-vehicle from the filtered trajectories.



Fig.2: Baseline TransFuser (no game-theory): ego-vehicle (circled) performs **unsafe lane-changing**.

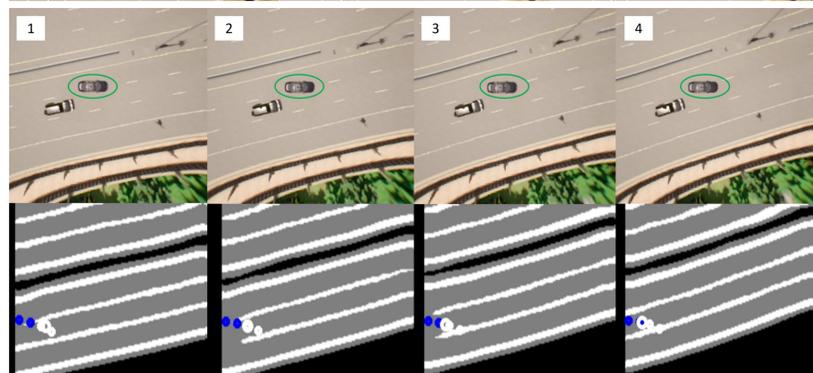


Fig.3: Baseline TransFuser: ego-vehicle changes lane against a slower vehicle **without safe distance**.

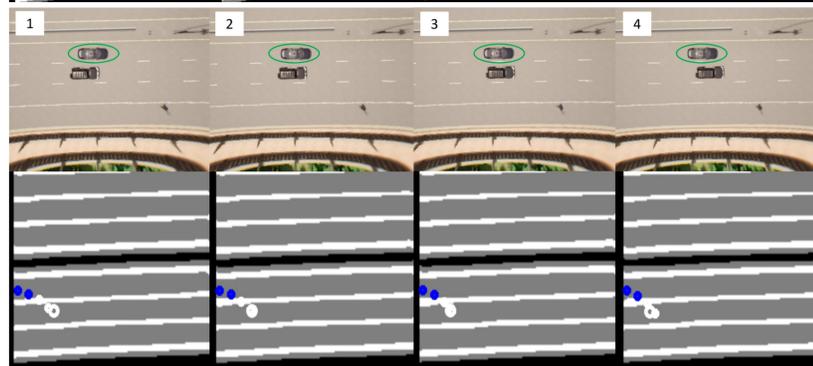


Fig.4: Game-theoretic (GT-inspired): **yielding ego-vehicle** over 4 time steps.

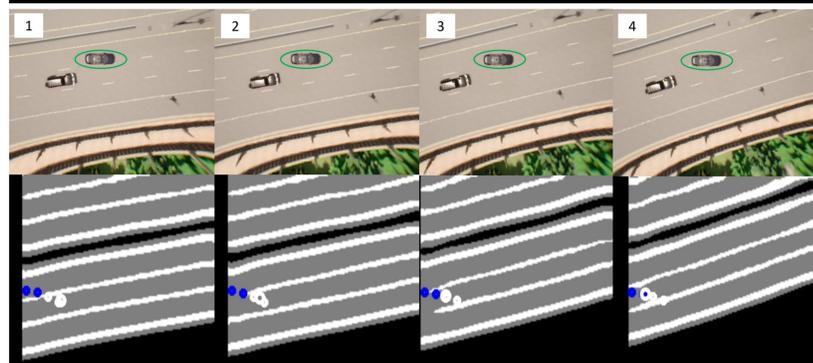


Fig.5: (GT-inspired): **competing ego-vehicle** over 4 time steps.