Synergy: Verified Control of Cooperative Autonomous Vehicles

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Problem

The potential widespread use of autonomous vehicles has raised numerous **safety concerns involving the reliability of the control algorithms** that drive these vehicles. In particular, these algorithms control vehicle maneuvers, wherein faulty control can potentially endanger human life and property.

Project Goals

Our work seeks to develop **verified maneuver regulation algorithms** to characterize the types of maneuvers that can be controlled in a safe and stable manner [1, 2, 6–9, 12–14].

Goal #1:

Construct guaranteed maneuver regulation control algorithms and characterize the space of maneuvers that are controllable given "driving conditions."

Goal #2:

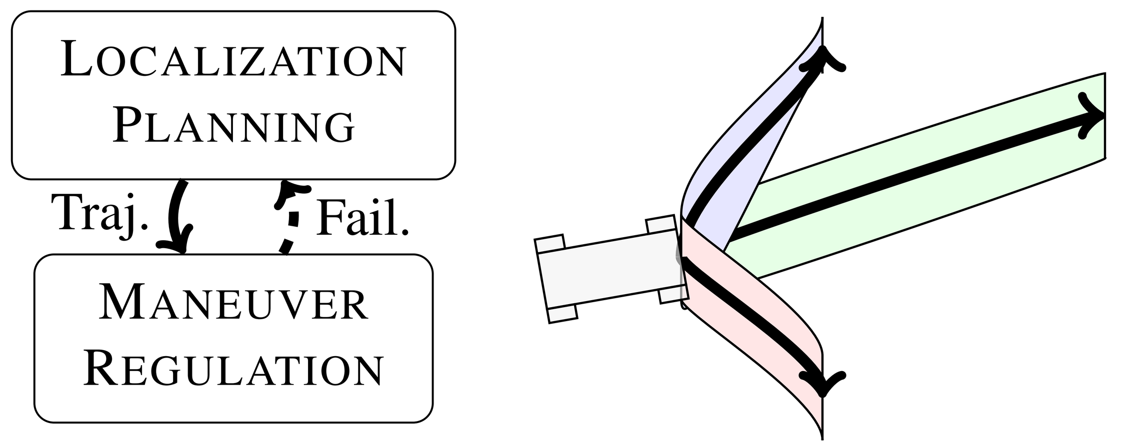
Transition from model level to augmenting the overall autonomous vehicle design.

Goal #3:

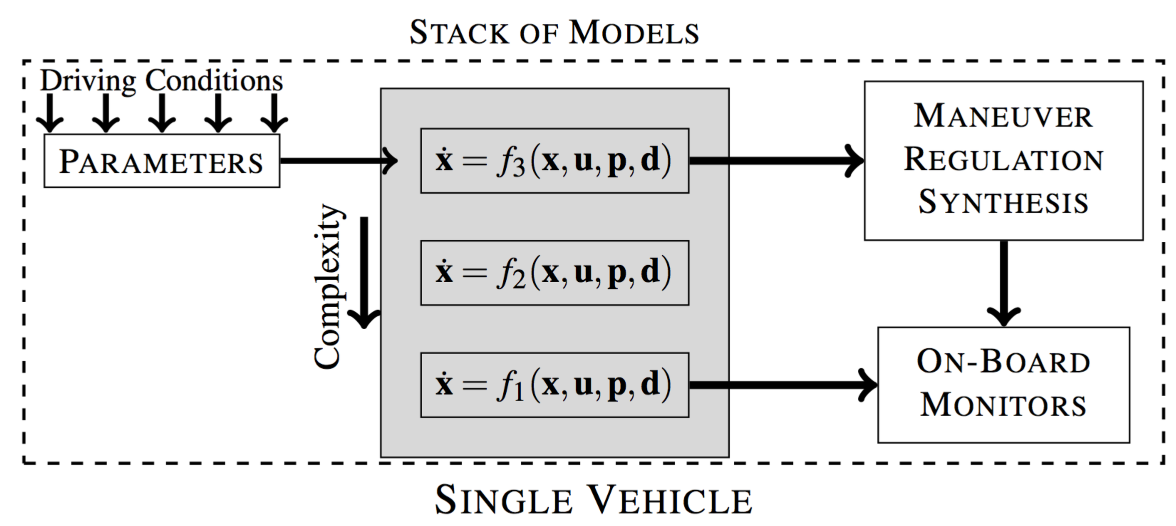
Lift ideas from a single vehicle to multiple co-operating vehicles.

Evaluation Testbed:

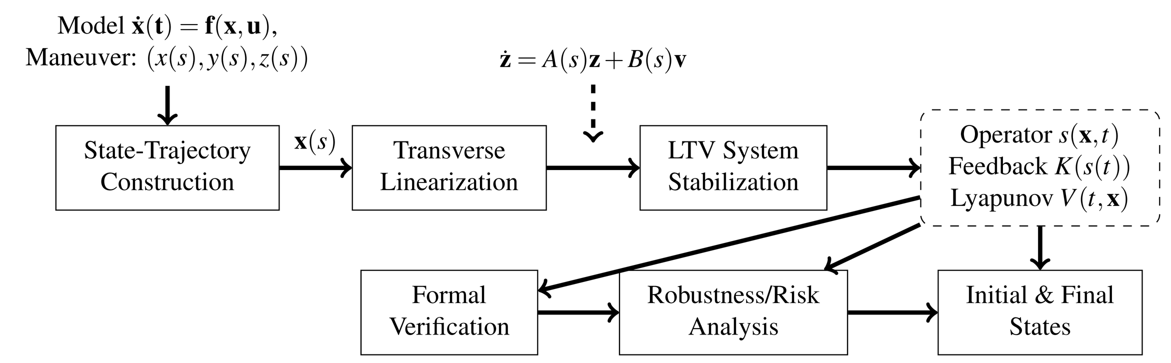
Evaluate each step of our work using the Ninja Car platform.



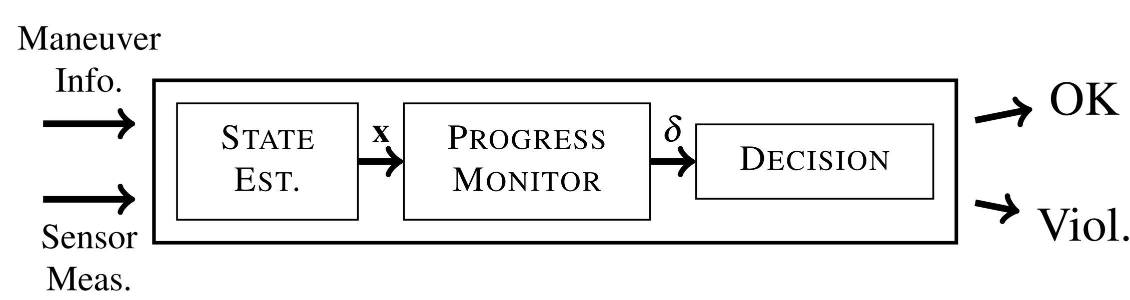
Control Model



Guaranteed Maneuver Regulation



For each trajectory, we construct associated Lyapunov and barrier functions. Sampling the trajectory space densely yields a *database of maneuvers* that incorporate trajectory information along with associated feedback law, Lyapunov and barrier functions [2, 10, 15].



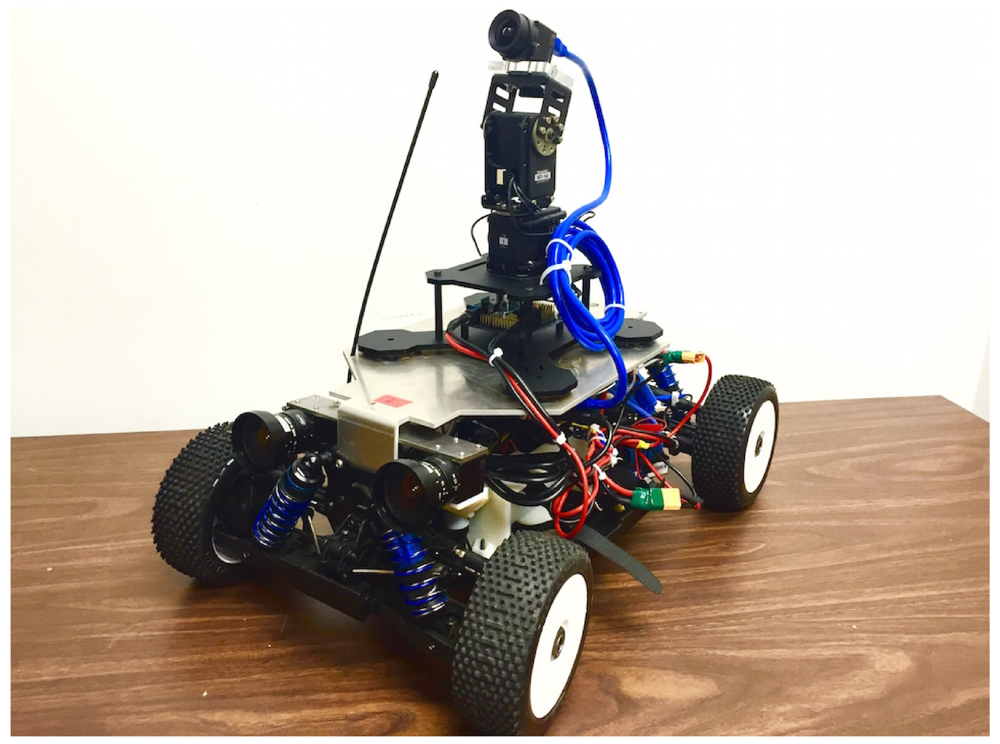
We have synthesized guaranteed control algorithms to regulate maneuvers of autonomous vehicles by bridging the gap between the capabilities of formal control design schemes and the practical details involved in translating them to realistic driving scenarios.

Outreach and Education

We have recently published two detailed surveys on model-based verification of CPS [3] and another on using CPS verification techniques for medicel devices [11].

We are integrating our research into a series of education and outreach activities that will ensure the broader impacts of this project. The Ninja Car testbed will be **disseminated as a "do-it-yourself" project** for interested students and enthusiasts under $300. The testbed is already being used in project-oriented classes offered to undergraduate students in engineering. The testbed is also being used in focused graduate classes on building autonomous vehicles from the ground up.

Experimental Testbed

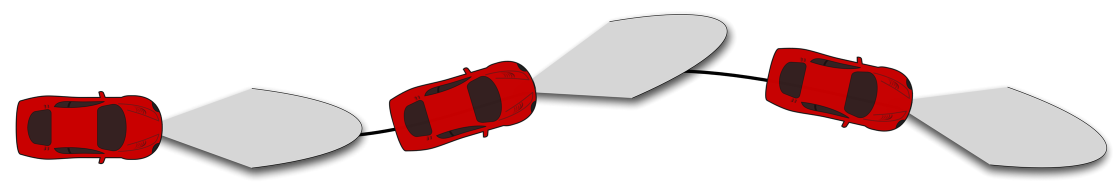


The Ninja Car is a $\frac{1}{8}$-scale model of a car that has been modified for autonomous operation using **on-board sensing and computation**. The API for the vehicle's control and sensing algorithms provide the inputs available for many levels of controller synthesis.

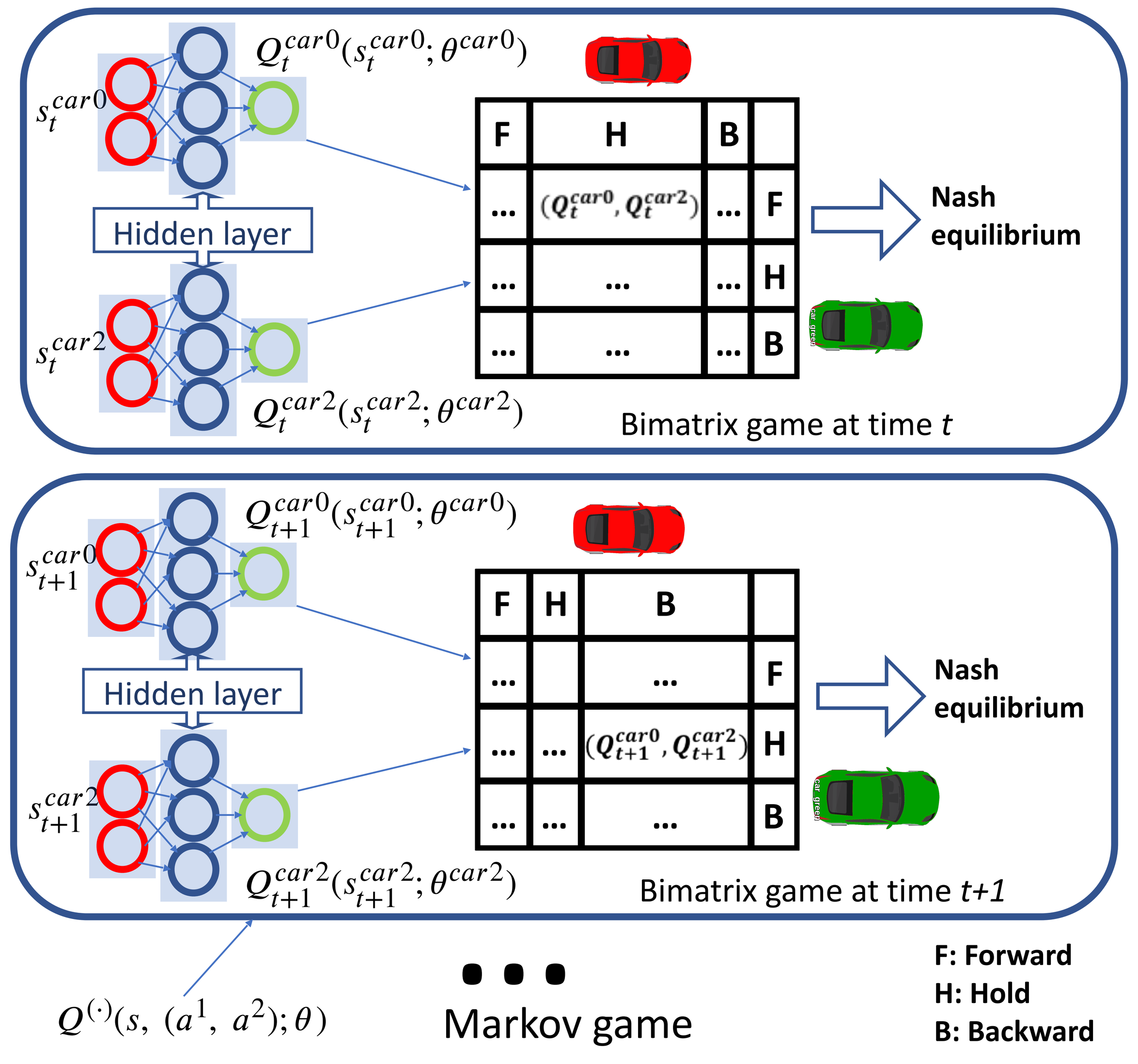
The Ninja Car platform is outfitted with advanced **state feedback sensors**, including an in-house **visual-inertial simultaneous localization and mapping** (SLAM) system, swing arm encoders, high-precision optical wheel encoders, augmented structural components, and an Intel NUC. The mast with attached pan-tilt unit as pictured is removable.

Multi-Vehicle Design

We have developed a **coarse characterization of the admissible maneuver and trajectory space** as well as the road condition for cooperative driving [4, 5].



For a sharp turn on a loose ground, a single vehicle may allow large lateral displacement for maximum stability while we may have to bound the displacement in the multi-vehicle situation. This requires ranking and pruning maneuvers based on certain computed bounds.



We have used deep reinforcement learning and solving for Nash equilibria to resolve this challenge. In the framework of game theory, we have shown it is possible to cooperatively merge vehicles in realistic physical simulations.

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