Karlsruhe Institute of Technology

METHODS FOR BIG DATA

Master thesis

Simulation-Driven Bayesian Optimization of Motion Planners for Autonomous Driving

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Possible Start
As soon as possible

Background

The behavior of autonomous driving prediction and planning modules is typically evaluated in large-scale simulation environments. Many modern planning approaches rely on Model Predictive Control (MPC), where trajectories are optimized with respect to carefully designed objective functions and constraints. However, the ultimate performance is generally measured through simulator-based metrics such as safety, comfort, progress, or rule compliance, which are often non-differentiable and do not admit a closed-form expression. As a consequence, the optimization objectives used within MPC motion planners are only indirect proxies for the actual performance targets of interest. This mismatch can lead to sub-optimal planning behavior even when the underlying optimization problem is solved perfectly.

To bridge this gap, simulation-driven global optimization methods can be employed to directly tune planner parameters against arbitrary performance targets. **Bayesian Optimization (BO)** has emerged as a sample-efficient framework for optimizing expensive black-box functions, where gradient information is unavailable and each evaluation requires running expensive simulations. Important decisions in the design of BO include the definition of the surrogate model, the choice of the acquisition function and the choice of the method to optimise it. The definition of which objectives to optimise against and the computation of outcome metrics in a way that is relevant and comprehensive for MPC is also crucial for the success of optimisation.

The goal of this thesis is to identify, implement and evaluate advanced BO methods for simulation-driven tuning of MPC-based motion planners. The work will be conducted within an **existing research software stack** that combines deep-learning motion prediction, MPC motion planning and the NuPlan simulation framework. An interface for the MPC hyperparameter configuration, simulation runtime and simulation results will be provided.

Task Details

- Conduct a literature review on BO methods for tuning MPC objective functions and constraints

- Familiarize yourself with an existing codebase for autonomous driving simulation built with **Python, PyTorch, CasADi**, and the **NuPlan benchmark**.
- Integrate selected baselines (e.g., Random Search) and BO methods into existing codebase.
- Execute systematic experiments for simulation-driven planner optimization.
- Quantitatively evaluate implemented methods w.r.t to sample-efficiency and held-out simulation performance.
- Analyze the strengths and limitations of implemented methods and derive future research directions.