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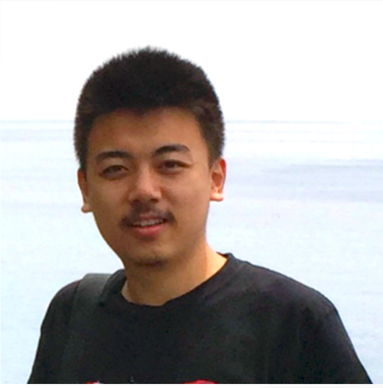
DISSERTATION PRESENTATION AND DEFENSE

Towards Solving Long-horizon Nonlinear Dynamic Programming: Scalability and Robustness

WHEN
July 14, 2021
10:00 AM, CDT

WHERE
Via ZOOM
ZOOM information will be provided in the email announcement for this seminar.



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This thesis focuses on the topic of long-horizon nonlinear dynamic programming. We address two issues: scalability and robustness. Five chapters are included. The first chapter provides an overview of the thesis, Chapters 2-4 consider different problems on nonlinear dynamic programming, and Chapter 5 provides a conclusion and discusses the future work.

In Chapter 2, we study the sensitivity analysis of the discrete-time, nonlinear dynamic programming. Sensitivity analysis is a fundamental subject before designing any scalable algorithms for solving large-scale problems. It studies how sensitive the solution is to the perturbations on the objective and constraints. Under very mild conditions, we show that the sensitivity of the solution of nonlinear dynamic programs enjoys an "exponentially decay" property: the directional derivative of the optimal state and control at stage k, with respect to the perturbation at stage i, decays exponentially in terms of the distance $|k-i|$. The difficulty of showing such a result is to analyze the Riccati recursion of a quadratic problem, whose quadratic matrices are indefinite. To address the difficulty, we apply a convexification procedure on the quadratic problem, and delve into the procedure to show some promising properties. We then focus on the convexified quadratic problem and establish the result. We validate our theoretical findings with experiments on a nonlinear, nonconvex program.

In Chapter 3, we consider solving the long-horizon nonlinear dynamic programs in an offline fashion. We design an overlapping Schwarz decomposition procedure, where we decompose the time domain into a set of overlapping subdomains, and solve subproblems defined over subdomains in parallel. The proposed procedure extends the existing temporal decomposition procedure for linear-quadratic convex problems. Based on the sensitivity result, we show that the algorithm enjoys a local linear convergence, with a rate that decays exponentially in the length of the overlap. We demonstrate the superiority of the algorithm using a highly nonlinear quadrotor motion planning problem and a PDE control problem.

In Chapter 4, we consider solving the long-horizon nonlinear dynamic programs in an online fashion. We design an online, real-time model predictive control (MPC) algorithm, where we perform only a single Newton step within each receding horizon. Based on the sensitivity result, we show that the algorithm enjoys a superconvergence: the tracking error with respect to the full horizon solution decreases with increasing shift order to a minimum value, which decays exponentially in the length of the receding horizon. This result improves the well-known stability result of real-time MPC. The key analytical step is to show that the tracking error consists of two parts: algorithmic error, which is quadratic due to the adopted Newton method; and perturbation error, which is brought by horizon truncation and decays exponentially with the lag between two successive receding horizons. The superconvergence phenomenon of the real-time iteration scheme is first discovered in this work.

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