Hybrid Dynamical Systems: From Learning Toward Estimation and Optimization

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Abstract

Hybrid dynamical systems, which combine continuous flows with discrete mode switching, provide a powerful modeling framework for real-world systems such as robotics tasks that involve contact, impacts, or constraints. In this talk, I will present our recent progress on advancing learning, estimation, and optimization in this setting. The central result is Discrete-time Hybrid Automata Learning (DHAL), which learns hybrid dynamics directly from data without requiring trajectory segmentation or event labeling, and achieves robust sim-to-real performance in challenging contact-rich tasks such as quadrupedal skateboarding. Building on this foundation, I will also discuss two recent frameworks that, while not yet applied to hybrid systems, point toward promising extensions: the Max Entropy Moment Kalman Filter (MEM-KF), which enables principled Bayesian filtering in nonlinear, non-Gaussian settings via moment-constrained maximum entropy distributions, and Riemannian Direct Trajectory Optimization, which leverages Lie group variational integrators and constrained Riemannian optimization to produce dynamically feasible, topology-preserving trajectories for rigid bodies. Together, these works illustrate a path toward a unified agenda in hybrid dynamical systems, where data-driven learning is complemented by structure-preserving estimation and optimization to enable scalable, robust, and eventually certifiable control of open hybrid dynamical systems.

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