The Thirty-Seventh AAAI Conference on Artificial Intelligence (AAAI-23)

Towards Safe and Resilient Autonomy in Multi-Robot Systems

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Abstract

In the near future, autonomous systems such as multi-robot systems are envisioned to increasingly co-exist with humans in our daily lives, from household service to large-scale warehouse logistics, agriculture environment sampling, and smart city. In these applications, robots and humans as networked heterogeneous components will frequently interact with each other in a variety of scenarios under uncertain, rapidly-changing, and possibly hostile environment. On one hand, harmonious interactions among robots, as well as between robots and humans, would require safe integration (e.g. collision-free close-proximity interactions) of heterogeneous robots, human, and human-robot autonomy. On the other hand, reliable interactions among autonomous multi-robot systems often call for resilient system integrity (e.g. communication capability with potential robot failures) to retain its capability of accomplishing complex tasks through coordinated behaviors. In the proposed talk, I will discuss our recent works towards *safe autonomy* and *resilient autonomy* that aim to facilitate correct-by-design robotic behaviors in a variety of applications.

Safe Autonomy

Safety for large-scale autonomous system is critical yet challenging under real-world factors such as uncertainty, nondeterminism and lack of complete information. While traditional approaches often assume perfect information about the robot models and well-defined environments, the precomputed guarantees could be easily violated when deploying robots in the real world that is uncertain, rapidly changing, and inherently stochastic. I will first present an explicit behavior design for computationally efficient safety assurance under uncertainty on large-scale autonomous systems, such as a team of drones. In the presence of partially known robot dynamical models and uncertain environments, I will then show a sample efficient safe reinforcement learning framework that integrates control-theoretic safe design into a learning-based approach for a robot to learn to optimally perform a task with safety guarantee. The idea is to bring together control-theoretic safety analysis and machine learning to leverage existing structure for safety assurance during exploration and the efficiency in task performance with provable regret bound. In more challenging scenarios with human presence, I will present our extended work that explicitly models the varying degrees of reactive behaviors by humans, e.g. heterogeneous human drivers with different levels of cooperation in an autonomous driving scenario, and integrates the learned human behavior models into the control design for provable safety guarantees.

Resilient Autonomy

In most cooperative robotic applications, the robotic members need to communicate or take observations from other robots for collective decision making and coordination, which is often achieved through proximity-based information-exchange networks. One common assumption is the presence of sufficiently connected networks within the coherent multi-robot systems, but it could be easily broken when the robot team spreads out over multiple widely separated task areas. In the second part of this proposed talk, I will present our novel designs that integrate graph-theoretic and control-theoretic approaches to co-optimize the coordinated multi-robot mobility tasks and the network integrity for supporting the long-term multi-robot autonomy, in addition to the safety assurance discussed in the first part of the talk. The key idea here is to formalize the network resilience in a team of mobile robots as the communication capability to endure unexpected disruptions (e.g. imperfect sensing and dynamics information of robots, loss of robots, etc), and recover swiftly from the decreasing network integrity due to the disruptions using co-optimized reconfiguration of coordinated robot motion. Then I will discuss how these results on safe and resilient autonomy lead to reliable multi-robot behavior design with guaranteed performance for practical applications such as distributed data-driven environmental sampling. Finally, I will briefly discuss future challenges and new ideas on long-term autonomy that is correct by design for robots to safely and efficiently collaborate with each other and humans.