Reinforcement Learning for Formal Language Instruction-Driven Robot Autonomy

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Abstract

The demand for automating human work involving movement in social infrastructure such as factories and plants by robots is increasing. However, in the real world, it isn't easy to formalize those task achievement criteria in changing environments, and it may depend on human expertise. Therefore, robots are required to perform tasks by incorporating decisions other than theirs while following instructed workflows. In this paper, we propose a Reinforcement Learning framework that allows robots to ensure reliable task completion by following diverse workflows while moving and appropriately querying decision makers on task progress. Our method uses Linear Temporal Logic (LTL), a formal language, to describe instructions unambiguously and addresses the following three challenges: 1) misunderstanding of tasks due to uncertainty in decisions and the increase of uncertainty due to unnecessary queries, 2) inefficiency of relearning required for each change in task completion specifications, 3) difficulty in optimizing simultaneous learning of movement and perceptual actions to achieve our robot. First, for 1), we propose a learning method that allows the robot to follow appropriate instructions depending on the level of uncertainties by modeling LTL as beliefs that can branch due to uncertainty. For 2), we propose a learning method that can immediately adapt to various task achievement specifications without relearning by learning feature extractions conditioned on those specifications. Finally, for 3), we propose a learning method that allows simultaneous learning of moving and perceptual actions through efficient exploration in a product action space by quantifying the contribution of perceptual actions to the movement actions. The effectiveness of the proposed methods is evaluated in a navigation scenario and an inspection scenario using a robotic arm in a 3D simulation environment, and the results suggest the applicability of our method to real-world applications.