Certifiable Deep Importance Sampling for Rare-Event Simulation of Black-Box Safety-Critical Systems

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Abstract

Evaluating the reliability of intelligent physical systems against rare safety-critical events poses a huge testing burden for real-world applications. Simulation provides a useful platform to evaluate the extremal risks of these systems before their deployments. Importance Sampling (IS), while proven to be powerful for rare-event simulation, faces challenges in handling these learning-based systems due to their black-box nature that fundamentally undermines its efficiency guarantee, which can lead to under-estimation without diagnostically detected. We propose a framework called Deep Probabilistic Accelerated Evaluation (Deep-PrAE) to design statistically guaranteed IS, by converting black-box samplers that are versatile but could lack guarantees, into one with what we call a relaxed efficiency certificate that allows accurate estimation of bounds on the safety-critical event probability. We present the theory of Deep-PrAE that combines the dominating point concept with rare-event set learning via deep neural network classifiers, and demonstrate its effectiveness in numerical examples including the safety-testing of an intelligent driving algorithm.

Keywords: importance sampling, neural network, black box, safety, efficiency certificate

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