SYMPAIS: Symbolic Adaptive Importance Sampling for Probabilistic Program Analysis

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Background

- Compositional probabilistic quantification by analyzing symbolic path constraints (PC).
- Individual constraints analyzed by Monte-Carlo based approaches.
- Require high-precision answers for rare events in mission-critical software; direct Monte Carlo not sample-efficient for rare events; stratified sampling (qCoral) inefficient in high dimensions.

Methods

- Combine symbolic execution with adaptive importance sampling.
- Use symbolic execution to identify path constraints and feasible initial solutions.
- Run PI-MAIS which uses MCMC to construct adaptive proposal distribution for importance sampling.

Results

- Quantify the probability that samples drawn from \( p(x) = \mathcal{N}(0, 1) \) are in the interior of a sphere, i.e., \( \|x - 1\|^2 \leq 1 \).
- SYMPAIS achieves similar performance for \( d \geq 5 \) and is orders-of-magnitude more efficient for \( d \geq 8 \).

References


Listing 1 Safety controller for a flying vehicle

```c++
// Assumptions
altitude = Normal(10000, 100);
headFlap, tailFlap = Normal([0, 0],
[[0.2, 0.1], [0.1, 0.2]]);
// Program
if (altitude <= 9000) { ...
  if (
    Math.sin(headFlap * tailFlap)
  > 0.999
  ) { callSupervisor(); } ...
} else { callSupervisor(); }
```

Figure: Graphical illustration of the SYMPAIS algorithm

Figure: Performance comparison between SYMPAIS and other algorithms on the sphere task.