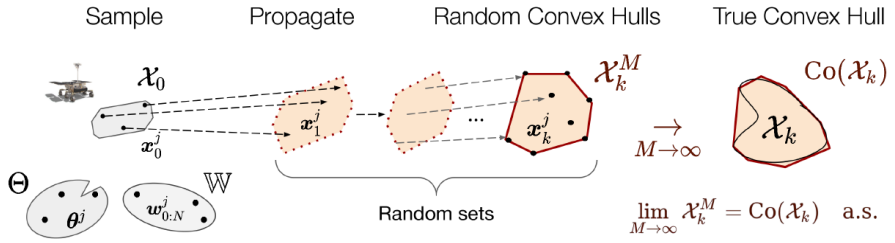
Comparison of Data-Driven and Model-Based Approaches for Reachability Analysis

Background

The deployment of cyber-physical systems in safety-critical environments requires formal verification techniques to ensure correctness with respect to the desired functionality, as failures can lead to severe economic or ecologic consequences, with examples encompassing autonomous mobility, power grids, or human-machine interaction. One of the main techniques to provide safety guarantees is reachability analysis, where all possible system behaviors are computed under uncertainty in the initial state and input. If these so-called reachable sets do not intersect any unsafe set, correctness is formally proven. In general, we can only compute over-approximations of the reachable sets to maintain soundness, but model-based approaches grow increasingly computationally expensive for more complicated systems. As a consequence, data-driven approaches have emerged, which aim to efficiently compute an approximation of the reachable sets at the cost of providing only probabilistic guarantees.



Sampling approach in [3]: Random convex hulls produced by random samples from the initial set, inputs, and parameters converge to the true convex hull as the number of samples approaches ∞.

Description

Data-driven approaches have two main advantages over model-based approaches: First, a model is not explicitly required as it suffices to consider the system as a blackbox. Second, the computation is claimed to be much faster. Despite the loss of soundness, data-driven approaches offer probabilistic guarantees, stating that a certain percentage of the true reachable set is contained within the computed one. Several approaches have been developed, e.g., [2, 3], however, the comparison to model-based techniques has not yet been thoroughly investigated. The toolbox CORA [1] offers simulations for a broad variety of system classes as well as all set operations for the processing of sampled data in the context of reachability analysis. This constitutes an ideal environment for the goal of this thesis, which is to implement data-driven approaches and compare them to the built-in model-based approaches in terms of the accuracy of the resulting reachable sets as well as computational efficiency.

Tasks

- Implementation of data-driven approaches for reachable set computation
- Evaluation of the performance on benchmark systems and comparison to model-based approaches
- Integration of the final implementation into the CORA toolbox

References

[1] M. Althoff. An introduction to CORA 2015. In *Proc. of the Workshop on Applied Verification for Continuous and Hybrid Systems*, pages 120–151, 2015.

[2] A. Devonport and M. Arcak. Estimating reachable sets with scenario optimization. In *Learning for Dynamics and Control*, pages 75–84. PMLR, 2020.

[3] T. Lew and M. Pavone. Sampling-based reachability analysis: A random set theory approach with adversarial sampling. *arXiv preprint arXiv:2008.10180*, 2020.

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