Simulate, Refine and Integrate: Strategy Synthesis for Efficient SMT Solving

Bingzhe Zhou[1] , **Hannan Wang**[1] , **Yuan Yao**[1] ,
Taolue Chen[2] , **Feng Xu**[1] and **Xiaoxing Ma**[1]

[1]State Key Laboratory of Novel Software Technology, Nanjing University, China
[2]School of Computing and Mathematical Sciences, Birkbeck, University of London, UK
{bingzhezhou, hannanwang}@smail.nju.edu.cn, {y.yao,xf,xxm}@nju.edu.cn, t.chen@bbk.ac.uk

Abstract

This note describes our Z3-SIRI framework for the automatic synthesis of efficient SMT-solving strategies. Z3-SIRI optimizes Z3 strategies via a novel, three-stage machine learning method. Our method treats strategy synthesis as a sequential decision-making process and employs reinforcement learning to navigate the vast strategy space. The key innovations that enable our method to identify effective strategies are the distinct stages of Simulation, Refinement, and Integration. This novel three-stage process allows for a deeper and more efficient exploration of the strategy space, enabling us to synthesize effective strategies.

1 Introduction

The efficiency of SMT solvers, which is heavily influenced by the heuristics they employ, often turns out to be a performance bottleneck within these applications [Palikareva and Cadar, 2013; De Moura and Bjørner, 2011]. To improve efficiency, solvers like Z3 [De Moura and Bjørner, 2008] provide a *tactic language*, which gives a high-level plan outlining a combination of tactics. However, in general, determining a suitable strategy for a given formula is challenging.

We propose Z3-SIRI a novel framework for the automatic strategy synthesis in SMT solvers. Z3-SIRI consists of three key stages. The *simulation* stage combines graph neural networks and reinforcement learning to obtain a set of tactic sequences that are efficient in solving the training SMT formulas. The *refinement* stage further enhances the tactic sequences by pruning redundant tactics and generating augmented ones. This stage also interacts with the simulation stage by feeding the refined tactic sequences back into the machine learning model. The *integration* stage integrates the refined tactic sequences into the final solving strategy by employing a specialized decision tree algorithm [Quinlan, 1993]. Specifically, we leverage various techniques to address the limitations of the existing work. We refer readers to our full IJCAI 2025 paper for more details about Z3-SIRI.

References

[De Moura and Bjørner, 2008] Leonardo De Moura and Nikolaj Bjørner. Z3: An efficient smt solver. In *Proceedings of the Theory and Practice of Software, 14th International Conference on Tools and Algorithms for the Construction and Analysis of Systems*, TACAS'08/ETAPS'08, page 337–340, Berlin, Heidelberg, 2008. Springer-Verlag.

[De Moura and Bjørner, 2011] Leonardo De Moura and Nikolaj Bjørner. Satisfiability modulo theories: Introduction and applications. *Commun. ACM*, 54(9):69–77, sep 2011.

[Palikareva and Cadar, 2013] Hristina Palikareva and Cristian Cadar. Multi-solver support in symbolic execution. In *Proceedings of the 25th International Conference on Computer Aided Verification - Volume 8044*, CAV 2013, page 53–68, Berlin, Heidelberg, 2013. Springer-Verlag.

[Quinlan, 1993] J. Ross Quinlan. *C4.5: Programs for Machine Learning*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1993.