Layered and Staged Monte Carlo Tree Search for SMT Strategy Synthesis

Zhengyang Lu[1], Stefan Siemer[2], Piyush Jha[3], Joel Day[4], Florin Manea[2] and Vijay Ganesh[4]

[1]University of Waterloo, Canada
[2]University of Goïttingen and CIDAS, Germany
[3]Georgia Institute of Technology, USA
[4]Loughborough University, UK

Abstract

Modern SMT solvers, such as Z3, offer user-controllable strategies that allow solver users the ability to tailor solving strategies for their unique set of instances, thus dramatically enhancing the solver performance for their specific use cases. However, this approach of strategy customization presents a significant challenge: handcrafting an optimized strategy for a class of SMT instances remains a complex and demanding task for both solver developers and users alike.

In this paper, we address the problem of automated SMT strategy synthesis via a novel Monte Carlo Tree Search (MCTS) based method. Our method treats strategy synthesis as a sequential decision-making process, whose search tree corresponds to the strategy space, and employs MCTS to navigate this vast search space. The key innovations that enable our method to identify effective strategies, while keeping costs low, are the ideas of layered and staged MCTS search. These novel heuristics allow for a deeper and more efficient exploration of the strategy space, enabling us to synthesize more effective strategies than the default ones in state-of-the-art (SOTA) SMT solvers. We implement our method, dubbed Z3alpha, as part of the Z3 SMT solver. Through extensive evaluations across six important SMT logics, Z3alpha demonstrates superior performance compared to the SOTA synthesis tool FastSMT, the default Z3 solver, and the CVC5 solver on most benchmarks. Remarkably, on a challenging QF_BV benchmark set, Z3alpha solves 42.7% more instances than the default strategy in Z3.

SMT 2024: 22st International Workshop on Satisfiability Modulo Theories July 22–23, 2024, Montreal Canada
john.lu2@uwaterloo.ca (Z. Lu); stefan.siemer@cs.uni-goettingen.de (S. Siemer); piyush.jha@gatech.edu (P. Jha); j.day@lboro.ac.uk (J. Day); florin.manea@informatik.uni-goettingen.de (F. Manea); vganesh@gatech.edu (V. Ganesh)