Z3++ at SMT-COMP 2023

Shaowei Cai, Bohan Li, Bohua Zhan, Xindi Zhang, and Mengyu Zhao

State Key Laboratory of Computer Science
Institute of Software, Chinese Academy of Sciences, Beijing, China
caisw@ios.ac.cn

1 Introduction

Z3++ is a derived SMT solver based on Z3-4.8.15[5]. It participates in the Single Query and Model Validation track of QF_LIA, QF_IDL, QF_NIA and QF_NRA logics.

For solving QF_LIA, QF_IDL and QF_NIA, a local search solver dedicated for integer arithmetic logic is developed, and it is deeply combined with Z3 by exchanging solving information. In the QF_NRA division, we implemented a feasible region consistency checker before the main search, and utilized sample-cell projection [4] in the NLSAT. Additionally, we optimized the QF_NRA tactic with a sophisticated flow. Furthermore, we implemented a local search solver specifically designed for QF_NRA based on interval-based information [3], which is integrated with Z3 for better performance.

2 Features

In this section, we introduce the new features of Z3++ (compared to Z3) on the divisions we mention in this document.

Integer Arithmetic: We developed a novel local search solver called LocalSMT for integer arithmetic, including QF_LIA, QF_IDL and QF_NIA. It is an extended version of LocalSMT [1, 2], which is a local search solver for QF_LIA (including QF_IDL). LS-IA directly operates on variables, breaking through the traditional framework. We propose a local search framework by considering the distinctions between Boolean and integer variables. Moreover, we design a novel operator and scoring functions, and propose a two-level operation selection heuristic. LS-IA is deeply combined with Z3 by exchanging information between each other.

QF_NRA: We have observed that the performance of solving instances in QF_NRA is greatly influenced by the order of variable assignments. To address this challenge, we have employed various heuristic arithmetic variable reordering strategies from CAD. Additionally, given DPLL(T) framework's effectiveness for multilinear instances, we have extended the time limit of DPLL(T) for these instances.

In terms of solving NRA theory, we have implemented sample-cell projection [4] in the NLSAT explain module. This new operator is similar to a CAD-like

projection operator and computes the cell (not necessarily cylindrical) containing a given sample such that each polynomial from the problem is sign-invariant on the cell. It has a singly exponential time complexity.

We have also developed a feasible region consistency checker for univariate and unit clauses before the main search. To achieve optimal performance, the checker operates in a loop and propagates as much as possible. It obtains the feasible region of variables through real root isolation and continuously takes the intersection of the regions. If the feasible region of some variable becomes empty, it indicates that the instance is unsatisfiable. Otherwise, the obtained feasible regions are added to the instance as lemmas.

Furthermore, we have created a local search algorithm for SMT(QF_NRA) [3] that takes interval-based information into account. This algorithm is combined with Z3 to improve overall performance.

3 Webpage

Further information can be found at
`https://z3-plus-plus.github.io/`

4 Contributors

This project is a result of teamwork. Shaowei Cai launches and leads the Z3++ project. Shaowei Cai (proposing the local search methodology), Bohan Li (main developer), and Xindi Zhang (code reviewer in the early stage, and proposing important ideas) are contributors to integer arithmetic theories (including QF_IDL, QF_LIA, QF_NIA), and the algorithm is a result of many discussions among them. Mengyu Zhao is the main developer for the QF_NRA division, under the supervision of Shaowei Cai and Bohua Zhan. Bohan Li is the main developer of the local search solver for SMT(QF_NRA).

References

1. Cai, S., Li, B., Zhang, X.: Local search for smt on linear integer arithmetic. In: Computer Aided Verification: 34th International Conference, CAV 2022, Haifa, Israel, August 7–10, 2022, Proceedings, Part II. pp. 227–248. Springer (2022)
2. Cai, S., Li, B., Zhang, X.: Local search for satisfiability modulo integer arithmetic theories. ACM Trans. Comput. Logic (may 2023). https://doi.org/10.1145/3597495, `https://doi.org/10.1145/3597495`, just Accepted
3. Li, B., Cai, S.: Local search for smt on linear and multilinear real arithmetic (2023)
4. Li, H., Xia, B.: Solving satisfiability of polynomial formulas by sample-cell projection. CoRR **abs/2003.00409** (2020), `https://arxiv.org/abs/2003.00409`
5. Moura, L.d., Bjørner, N.: Z3: An efficient smt solver. In: International conference on Tools and Algorithms for the Construction and Analysis of Systems. pp. 337–340. Springer (2008)