【Grant-in-Aid for Scientific Research (S)】

Broad Section J

Title of Project： Program Verification Techniques for the AI Era

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Keyword：higher-order model checking, program verification, machine learning

【Purpose and Background of the Research】

Program verification techniques have been studied for ensuring the reliability of software, but further evolution of the techniques is required due to the recent emergence and advance of AI technologies. First, because of the increasing reliance of social infrastructures on computers, a software bug may cause a serious damage; the reliability of software is thus becoming even more important. Second, program verification techniques can benefit from the recent advance of machine learning techniques. Third, the advance of AI technologies also changes the quality of software. We thus need to adapt the existing program verification techniques to the new type of software.

The aim of this research project is to advance program verification techniques such as higher-order model checking, on which our research group has been leading the world, and introduce machine learning techniques to reduce the key bottleneck of the existing program verification techniques such as invariant discovery. To cope with the change of the quality of software, we also work on new types of program verification problems, such as verification of probabilistic programs.

【Research Methods】

We set up the following three subtopics and work on them in parallel.

(A) Advance of program verification techniques such as higher-order model checking. Higher-order model checking is an extension of the system verification method called model checking, which is suitable for verification of high-level software. It has been significantly advanced during the last 10 years by our research group. Among the two kinds of higher-order model checking called HORS model checking and HFL model checking, we have so far been working mainly on HORS model checking, but our recent research showed that HFL model checking is more promising. We, therefore, shift our focus to HFL model checking, and establish automated program verification techniques based on HFL model checking. We also plan to attack important open problems on the theory of higher-order model checking.

(B) Applications of machine learning to program verification. Although the computational complexity of higher-order model checking is extremely high, thanks to the recent advance of higher-order model checking algorithms, the main bottleneck in its applications to program verification has shifted to other parts such as predicate discovery, where heuristics are required. We plan to apply and extend machine learning techniques to reduce the bottleneck.

(C) Program verification techniques for new types of software. As mentioned already, the quality of software involving machine learning components is radically different from conventional software. For instance, a machine learning component does not always provide a correct answer. We thus need to model and verify machine learning components as probabilistic programs. To this end, we extend higher-order model checking and establish "probabilistic" higher-order model checking. We also conduct experiments to verify software with machine learning components, to discover new challenges for program verification techniques.

【Expected Research Achievements and Scientific Significance】

This project will bring a significant advance in program verification based on higher-order model checking. In particular, the incorporation of machine learning techniques will enhance the practicality of the automated program verification techniques, which will increase the reliability of social infrastructures. From an academic point of view, the theory of higher-order model checking is related to vast areas of theoretical computer science, including program semantics, formal language theories, logics in computer science, computational complexity and computability, and thus its advance will impact broad areas of theoretical computer science. Also, this research will also bring an advance in the field of machine learning, through the new applications to program verification.

【Publications Relevant to the Project】

· Naoki Kobayashi, Étienne Lozes, Florian Bruse, "On the relationship between higher-order recursion schemes and higher-order fixpoint logic", Proceedings of POPL 2017, pp. 246-259, 2017

· Naoki Kobayashi, "Model Checking Higher-Order Programs", Journal of the ACM, 60(3), 20:1-20:63, 2013.

【Term of Project】FY2020-2024

【Budget Allocation】146,400 Thousand Yen

【Homepage Address and Other Contact Information】

https://www.kb.is.s.u-tokyo.ac.jp/~koba/hmcai/