BRNO UNIVERSITY OF TECHNOLOGY FACULTY OF INFORMATION TECHNOLOGY

Supervisors' Opinion on the Ph.D. Thesis of

Jiří Matyáš

Applications of Formal Methods in Approximate Computing

Approximate computing has been established as an emerging research field whose principal goal is to increase the computational performance and reduce the system resource demands. It achieves this goal by relaxing the requirement that its underlying computations are always performed correctly. Prominent applications for approximate computing include image and multimedia processing, signal processing, data mining, machine learning, neural networks, and scientific computations. Chippa et al. 2013 claim that almost 80 % of the runtime is spent in procedures that could be approximated.

Jiří Matyáš focused in his research on *functional approximation of combinational hardware circuits* that serve as basic building blocks for larger approximate systems in many application domains. The goal of the circuit approximation is to find a set of circuits that feature high-quality trade-offs between the approximation error and other design metrics such as power consumption or chip area. Since a manual approximation of complex circuits usually does not produce adequate results, various automated methods have been proposed. Existing methods, however, did not scale to complex circuits and/or failed to provide bounds on the approximation error (which is crucial in many applications). The main goal of the work of Jiří Matyáš was to improve the scalability of existing approaches by *integrating formal methods*, providing rigorous bounds on the approximation error, into *evolutionary-driven design of approximate circuits*.

The research of Jiří Matyáš was supervised by me, co-supervised by prof. Tomáš Vojnar, and conducted within the VeriFIT research group at the Faculty of Information Technology of the Brno University of Technology. The research was an important part of multiple research projects and the achieved results significantly contributed to these projects. The main results of Jiří's work are summarized below:

1. A scalable SAT-based approximate equivalence checking algorithm for arithmetic circuits that enables, for the first time, to construct complex circuits (e.g. 32-bit multipliers) with high-quality trade-offs between the power-consumption and formally guaranteed error bounds. This work was published at IEEE/ACM International Conference on Computer-Aided Design (ICCAD'17), a CORE A conference listed among the two most important conferences for Design Automation in the American CS Ranking. The impact of

this result can be also demonstrated by more than 60 citations in Google Scholar (May 2023) and Scopus Citation Percentile 95.

2. An adaptive verifiability-driven strategy for evolutionary approximation of arithmetic circuits that further shifts the scalability of state-of-art automated circuit design techniques. This work was published in Applied Soft Computing 2020 (ranked as a Q1 journal by Scopus and Q2 journal in WOS AIS).
3. A new strategy for generating approximate circuits using satisfiability solving that enables to effectively escape local optima in the search space and further improve the quality of resulting circuits. This work was published at the CORE A conference on Theory and Applications of Satisfiability Testing (SAT' 20).
4. A new mutation operator tailored to circuit approximation that uniquely combines a single active gene mutation with a sub-tree deactivation. It significantly improves the convergence of the approximation process. This work was published in Swarm and Evolutionary Computation 2022 (ranked as a Q1 journal by Scopus and Q1 journal in WOS AIS).
5. A framework for automated design of approximate circuits (ADAC) integrating state-of-the-art methods based on simulation, formal reasoning, and evolutionary circuit optimisation. It offers an outstanding performance together with formal bounds on the approximation error. This work was published at the CORE A* conference on Computer Aided Verification (CAV'18). ADAC was also awarded by a Bronze Medal in the Humies 2018 competition for results achieved by evolutionary/genetic algorithms.

Jiří's contribution spans from the formulation of the research ideas, designing methodological approaches to writing the papers. He played an essential role in the implementation including a high-performance code for computationally demanding tasks as well as in the experimental evaluation including rigorous statistical evaluation. Jiří's research work significantly contributed to an enhancement of the capabilities of automated circuit approximation techniques. The impact of his work is demonstrated by more than 75 citations according to Google Scholar (May 2023).

During our collaboration, we have witnessed not only Jiří's diligence and creativity, but also his ability to cooperate with international partners, conduct successful research in the highly competitive field of automated circuits design, and also co-supervise several successful Bachelor's theses. In our opinion, his work is of a high quality according to the international standards and his thesis satisfies all requirements associated with Ph.D. theses in computer science. Therefore, we recommend accepting his thesis.

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