

Review of a Doctoral Thesis at FIT BUT

Doctoral thesis (hereinafter referred to as "thesis"), title of the thesis: **Applications Of Formal Methods In Approximate Computing**

Name of the doctoral student (hereinafter referred to as "student"), name and surname: **Jirí Matyáš**

Name and institution of the reviewer (full name of the reviewer, full name and country of the institution):

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Please state your opinion on the following aspects of (I) the student's thesis and (II) the student's overall achievements, and (III) state your conclusion (a minimum of approx. 300 characters foreach item below is recommended):

I. Thesis

Appropriateness and relevance

Two main observations can be made about the developments in the semiconductor industry in the last decade. On the one end of the spectrum from the transistor manufacturing, with CMOS scaling and the nearing end of Dennard's scaling, the power density of chips has started increasing while providing limited energy and performance improvements. Due to the increased power density and other manufacturing challenges, an increasing number of faults are now seen in the chips. On the other end of the spectrum, while modern applications computation demands have been increasing, another trend has emerged, where the applications are increasingly more resilient to small errors in computation. Deep learning applications are especially resilient to small perturbations in the image or input data. Approximate computing leverages these two observations and relaxes the strict notion of correctness across the design stack. Instead, computations are intentionally done in an inexact manner to provide better accuracy-performance trade-off.

However, the design space for approximate computing is rather large. The thesis aims to solve this problem by using formal methods to prune the design space and identify suitable configurations quickly. It is, therefore, very timely and relevant.

A summary of the contributions of the thesis

The main goal of the thesis is to employ formal design and verification methods to identify suitable designs for combinational hardware circuits that are functionally approximate. This implies that the designs are deterministically approximate and always produce the same result, as opposed to other non-deterministic techniques like aggressive voltage scaling.

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The main contribution of the thesis is to propose techniques to improve both the generation and evaluation of the approximate designs that are generated, such that better quality i.e., PPA metrics vs accuracy trade-off can be obtained.

The first chapter describes the overall contributions of the thesis and its organization, while the second chapter covers the background knowledge in the area of approximate computing. Both manual and automated approaches are described. The third chapter introduces the techniques that are based on SAT-solvers, and aim to improve the existing error evaluation approaches. This is by far the most interesting contribution of the thesis and has been published in ICCAD and Eurocast.

The fourth chapter improves the earlier approach and introduces the adaptive verifiability driven search strategy. This provides good performance in circuit approximation.

In addition to research contributions, the candidate has also made contributions to tooling and compiled the engineering work into a nice tool to explore the design space and design approximate circuits automatically. The tool work was also published in a top conference. This contribution is described in the fifth chapter.

The sixth chapter combines evolutionary algorithms with the satisfiability algorithms to explore the design space quickly and ensure that the flow doesn't get stuck in a local minimum. This helps improve the overall quality of the final solution. The last contribution chapter improves the synthesizer component which generates the approximate solutions by improving the genetic mutations that are generated. The last chapter provides the conclusions and some directions for future work.

Novelty and significance:

The domain of the work done cuts across two topics – formal analysis and circuit design. It is not very easy to find candidates who have expertise in both these topics. Addressing this intersection naturally lends novelty to the approach.

I must admit that the length of some of the chapters was rather short. Some of the topics could have been explored more in depth, especially in terms of evaluation. For example, in Chapter 5, just a single table is shown for the result, and the overall chapter is just over 4 pages long. One would expect the main contribution chapters to be much longer. It is also surprising that the original publication, on which the chapter is based on, already contains more figures/text than what's included in the thesis.

Evaluation of the formal aspects of the thesis:

The language could be improved. Already in the very first paragraph in the abstract, the last sentence isn't grammatically correct.

- Techniques for approximate computing developed → techniques for approximate computing are developed.
- Instead of listing just the papers as contribution in the introduction, it would have been better to phrase the distinct contributions in his own words and then refer to the publication.
- CGP is only expanded in Czech language and never in English. Given that it is a rather important concept in the thesis, it would be prudent to expand and explain it.

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Quality of publications

The student has published his work in decent conferences. While some of the works are in the top venues in the field, like ICCAD and Elsevier Swarm and evolutionary computation, the others are not so great, like DSD. However, given the overall count and quality of publications, it is acceptable.

II. Student's overall achievements

The writing quality is surely good, indicating thoroughness in his work. Some of the early publications of the candidate already have over 50 citations, which is very good. The candidate has also won several awards in Brno university, including during his PhD studies. The journal papers are also in very high-impact venues, including those with impact factor of over 10 (Swarm and evolutionary computation).

III. Conclusion

The thesis in my view is of sufficient quality and the articles based on the work done by the students have been accepted in good conferences in the area highlighting the acceptance of the work in the community. In my opinion, the author of the thesis demonstrated her ability to perform independent research and achieved original scientific results. The submitted work clearly meets all the requirements to be accepted as a doctoral dissertation. **I would, therefore, recommend the candidate to be awarded the PhD degree.**

Dresden, 09.11.2023

Signature of the reviewer: