Formal Methods Supported by Symbolic Computation for Engineering Applications in Cloud Computing and Artificial Intelligence
Abstract

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This habilitation thesis presents the most significant scientific and academic achievements of its author, beginning in December 2012 when she defended her PhD thesis titled *Computational Logic and Quantifier Elimination Techniques for (Semi-)automatic Static Analysis and Synthesis of Algorithms* at the Research Institute for Symbolic Computation, Johannes Kepler University, Linz, Austria. During this period, the author *collaborated* with established scientists as well as junior researchers to produce papers submitted to conferences and journals. These contributions are highly relevant in the fields of *formal methods, automated deduction, and symbolic computation*, with applications in *Cloud Computing* and *Artificial Intelligence.*

The author also served as the director of two national competitive research grants: *MANeUveR: Management Agency for Cloud Resources* and *SAGE: A Symbiosis of Satisfiability Checking, Graph Neural Networks, and Symbolic Computation.*

Additionally, she was awarded the prestigious *Fulbright-RAF Scholar Award in Entrepreneurship,* which emphasizes her interests in entrepreneurship education for Computer Science students and exploring the market potential of research results.

The author initiated her *scientific career* during her MSc studies at the Research Institute for Symbolic Computation. She began *teaching activities* in February 2014 at the Department of Computer Science, West University of Timisoara, initially as an Associate Assistant and later as a Lecturer. In October 2021, she was promoted to Associate Professor. At West University of Timisoara, *she introduced courses on formal methods and satisfiability checking* at both the Master's and Bachelor's levels. Notably, *she integrated research topics into her teaching activities*, exposing Computer Science students to research early in their studies. Most of the Bachelor's and Master's theses she supervised were research-oriented. All these achievements are detailed in Chapter 2 of the thesis.

Chapter 3 of the thesis provides a comprehensive overview of the candidate's research contributions, with a *focus on formal methods in various domains,*

including symbolic computation, Cloud computing, and data-intensive applications. It also highlights *contributions to machine learning and computer science education*, which serve as preliminary work for applying formal methods in these exciting domains or developing effective methods for teaching formal methods.

Section 3.1 centers on *formal methods combined with symbolic computation*, showcasing the candidate's significant work on real quantifier elimination for synthesizing optimal numerical algorithms, particularly in the case study of square root computation. The section further highlights efficient simplification techniques for special real quantifier elimination, with applications to the synthesis of optimal numerical algorithms.

Section 3.2 discusses the *utilization of formal methods in Cloud Computing*, with a particular focus on Security SLA enforcement and component-based application deployment optimization. Topics covered include automated security SLA enforcement in the Cloud, a methodology for setting up security capabilities on Cloud services, and benchmarking optimization solvers for efficient deployment. The section provides insights into experimental analysis, showcasing results and discussions on solver performance.

Section 3.3 presents the work on *formal verification and quality assessment of distributed systems in the context of Storm technology.* It introduces an automated formal verification approach utilizing Storm topologies' formal models constructed through CLTLoc metric temporal logic, reinforced by counters. Formal models are generated from high-level topological descriptions, while the Zot verification tool assesses queue-related properties. Complementary to the CLTLoc metric temporal logic approach, it formalizes data-intensive applications on Storm through an array-based systems formalism, utilizing quantified first-order logic and the Cubicle model checker to verify safety properties.

Section 3.4 delves into various applications and methodologies. It begins by presenting a *tool for fake news detection*, addressing the problem statement and the approach taken. The implementation details, including parsing, machine learning, and cosine similarity techniques, are outlined. The experimental results showcase the tool's effectiveness in content and title detection. Additionally, this section covers the *architectural development of Binarized Neural Networks (BNNs) for traffic sign recognition.* It explains BNNs, datasets, and the experimental setup. The proposed methodology, including XNOR and Binarized Neural Architectures, is discussed in detail, as well as the experimental results.

Section 3.5 centers on *Computer Science Education*, delving into the research conducted on transferring learning into the workplace and evaluating a student-centered learning approach through the lens of computer science students.

The thesis concludes with Chapter 4, which outlines the scientific and academic roadmap of the author.